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Virtual Reality for Cultural Heritage Applications

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ABSTRACT

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Virtual Reality (VR) technology opens up many new possibilities. Advances in VR technology especially in the field of 3D computer graphics modeling and animation techniques and faster computing power has enabled us to create increasingly realistic Virtual Environments (VE) and 3D virtual humans, animals and objects to inhabit these Virtual Environments. VR technology is being used in a variety of real-time application domains including architectural visualization, vehicle design & prototyping, entertainment, simulation & training, teleoperations, scientific visualization, engineering, education, medicine / non-invasive surgery, and cultural heritage. Innovative and intuitive interaction techniques and methods need to be developed and employed in these VR applications to further enhance the interactive experience of the user. This thesis presents a cultural heritage application utilizing VR technology to recreate a fully immersive 3D environment of a complex heritage structure specific to Singapore. Many heritage and cultural sites all over the world are being destroyed or lost to urbanization, pollution, neglect, and even tourism and the recognition of the issues of preservation, restoration, and interpretation of cultural heritage sites has increased tremendously over recent years. VR technology provides for an important educational tool by offering immersive and interactive qualities where the user can virtually enter and explore the digital reconstructions in real-time while providing a “learning-by-doing” scenario through innovative interaction techniques within the 3D Virtual Environment. The goal of this research work is to virtually recreate realistic high-quality 3D representations of the selected culture of the Peranakans and provide transparent and context-specific user-friendly interaction methods to this immersive virtual environment. To achieve this goal, two interaction methods specific to the Virtual Heritage scenario has been identified. The first interaction with the user is achieved through a Virtual Tour Guide capable of real-

ABSTRACT

time speech and animation. The second interaction technique is to use a Chinese Calligraphy brush to execute commands and to navigate the VE. The Virtual Tour Guide educates and informs the visitors on the history and culture while also guiding the visitors around the VE. He also provides information on how to use the Chinese calligraphy brush as an interaction device. The research challenge here lies in developing a framework for generating real-time Virtual Heritage applications incorporating different interaction methodologies.

This thesis first briefly looks at the background technology on Virtual Reality technology and the state-of-the-art on Virtual Heritage applications and hand-writing recognition. It then presents the overall Virtual Heritage framework and proceeds to the details of the development and implementation of this framework focusing on the Chinese calligraphy brush. A prototype that has been implemented as proof of concept and usability tests are presented before future directions of this research work is discussed.

Keywords

Virtual Reality, Cultural Heritage, Virtual Heritage, Interaction, 3D Modeling, Virtual Tour Guide, Chinese Calligraphy Brush, Recognition

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CHAPTER 1

INTRODUCTION

Virtual Reality is a medium. Therefore, we can begin to understand the potential of VR in the communication and exploration of ideas by examining how it is related to other media of human communication [1].

Advances in Virtual Reality (VR) technology especially in the field of 3D computer graphics modeling and animation techniques and faster computer power have enabled us to create increasingly realistic Virtual Environments (VE) and virtual humans, animals, and objects to inhabit these Virtual Environments. These Virtual Environments are used for a variety of different interactive real-time application fields including engineering, scientific visualization, design/prototyping, medical visualization, education, entertainment, and cultural heritage. The main strength of VR lies in the 2 key elements it provides to the users that are crucial to man-machine interface – immersion and interaction. Illusion of participation is created by immersing the user into the VE where the users are able to directly interact with the objects within the VE. Contrast to pre-rendered computer graphics animations such as 3D movies, VEs provides users with dynamic real-time feedback where the users are given the option to play an active role within these Virtual scenarios.

In this thesis VR technology will be utilized to digitally create a high-quality 3D scenario of a Singapore specific heritage model. A framework for developing a Virtual Heritage

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application incorporating new and innovative interaction techniques capable of optimal real-time rendering will be presented.

1.1 Motivation and Objectives

Many heritage and cultural sites all over the world are being destroyed or lost to urbanization, pollution, neglect, and even tourism and the recognition of the issues of preservation, restoration, and interpretation of cultural heritage sites has increased tremendously over recent years. By using VR technology, fully immersive environments of historical heritage objects and environments can be digitally recreated, entered and viewed in real-time. Providing innovative interaction techniques where the users can directly interact within these environments enhances the understanding of historical and cultural content by providing the user with a ‘learning-by-doing’ scenario. ‘Learning-by-doing’ scenarios are proven to be much more effective than passive learning techniques. Developing a Virtual Heritage (VH) project requires skills and knowledge from both the artistic and the technical backgrounds since the VR environment that is created need to be aesthetically pleasing to the visitors.

Singapore is a diverse city-country with many different ethnic groups living together. It has a very rich culture that is a mixture of different ethnicities creating its own unique identity. To better understand the Singaporean history, the impact of the Peranakans (which in Malay means ‘*born here*’), also known as the Straits-Chinese, cannot be dismissed. A Peranakan man is called a *Baba* while the ladies are known as *Nyonya*. The Peranakans are descendants of an early Chinese community that settled in the Malay Archipelago at least since the 17th century [2]. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the indigenous Malay since the Chinese women were not allowed to leave the country until the 19th century. This unique community developed distinct customs, cuisine and even their own language, as they

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blended Chinese and Malay ways of life to form a new and rich culture adding another dimension to the Singaporean society. They played a key role in bringing Malaysia and Singapore to independence [3][4][5][6][7][8][9][10].

The Peranakans and their culture have been selected for the cultural heritage project because, as mentioned above, the Peranakans are an important part of understanding Singapore's history and little work has been carried out in the virtual heritage realm to recreate their identities as of yet.

The main goal in this research is to create a real-time user-centered Virtual Heritage application where the interface engages the user to experience the VE first hand. The aim is to create an edutainment application by combining educational aspects of the historic and cultural content that is at the same time entertaining. Therefore, the VH application that will be presented in this thesis aims to be a flexible and dynamic one where the content of the VH application can be generated and updated quickly according to the user's requests. It also presents new and innovative ways of interacting within the VR environment.

There are two objectives behind this work.

- i. To develop a framework for generating real-time Virtual Heritage applications.
- ii. To develop and use transparent and intuitive, context-specific interaction techniques.

The first objective is to develop a framework for generating real-time Virtual Heritage applications. This framework can be adapted to different heritage scenarios to create a system that can be updated quickly and the content can be dynamically generated. All the content is created as a reusable library of objects whether they are the cultural artifacts, their descriptions, or virtual avatar behavior motions. These objects libraries are dynamically assembled according to the user's requests. The users should be able to

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customize and compose the library elements in order to reuse them for different tasks. At the same time there need to be tight constraints in the use of library objects. Without these constraints, the configuration task becomes overly complex and prone to misconfiguration. Keeping a balance between flexibility and constraints is a major challenge.

The second objective is to develop transparent and intuitive, context-specific interaction techniques. The aim is to provide for an engaging pedagogical environment where the visitors can learn history by virtually experiencing the historic content thus combining education and entertainment. The two interaction methods that have been developed for this project are the Virtual Tour Guide and the Chinese Calligraphy brush. The Virtual Tour Guide guides the visitors while the visitors also have the option of executing simple commands as well as freely navigating through the scenario using a Chinese Calligraphy Brush. A Virtual Tour Guide was selected because by virtually representing a human from a specific time period that is capable of interacting with the users and providing specific information, the users will be able to experience the culture first-hand in a familiar and non-obtrusive way. With the recent trend to move interaction closer to the task domain by using instrumented “props” specific to the task [11], a Chinese Calligraphy Brush has been selected as an interaction tool to diversify the user experience in the VR environment. By utilizing a physical object as an interface, the object’s properties such as shape, weight, texture, centre of gravity, and solidity provide some haptic information to the user thus enhancing the user’s ability to perform simple physical operations [1]. For continuous interaction within the VH scenario and to eliminate the need to change interaction devices, navigational functionalities have been added to the brush.

The proposed interaction techniques are integrated into the real-time framework as flexible and modular components. This modularity allows for substitution of components

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where the heritage scenario and the interaction device can be replaced with other heritage scenarios and/or interaction devices such as a 3D spacemouse or tablet. The framework's flexible components contribute to the overall aim of creating a dynamic VH application.

1.2 Concept

Developing a Virtual Heritage project involves many different facets and modules that are later integrated into a final application. It is a truly an interdisciplinary project involving expertise in various fields ranging from historians to technicians and engineers.

The conceptualization stage is very important since it determines the direction of implementation developments and the content of the future research areas to be explored.

The diagram presented in Figure 1 shows the general overview of the Virtual Heritage application and its major components. This system serves as the base foundation for developing the Virtual Tour Guide and integrating the Calligraphy brush interaction.

Figure 1. Overall System [7]

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The overall system can be divided into 4 main parts.

- **3D Modeling**

Modeling of the Virtual Tour Guide, its associated facial expressions and visemes, and the Peranakan object library of cultural artifacts and architecture

- **Calligraphy Brush Interaction**

Development of Calligraphy brush interaction techniques including stroke recognition for Chinese character commands and navigation

- **Behavior Modeling**

Modeling of the basic human behaviors for the Virtual Tour Guide such as walking, turning, and climbing the stairs

- **Application-specific Configuration**

Configuration of all the objects in the VE. This configuration is very general and generic to support easy and flexible scene layouts and updates

- **Virtual Heritage Application**

The top components are tied into the overall Virtual Heritage application. The content presented is user-dependant where the user chooses when and what content to view. All content is visualized onto a VR output device such as an immersive table or a wall projector. It can further be extended in the future to be shown onto other forms of output such as the WWW or museum installations.

With this overall system as a basis, it is further developed and refined as the framework which is presented in detail in Chapter 3.

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1.3 Contribution

The contribution of this thesis is presented below.

- This thesis presents a generic and modular framework for developing and implementing real-time Virtual Heritage applications that can be easily configured. Research carried out in Chapter 2 shows that little work has been done in the area of presenting a framework for generating real-time VH applications.
- An interactive Virtual Tour Guide (VTG) is integrated into the VH scenario capable of real-time animation in the VR application. Facial and behavior animation sets are built as library components enabling the flexibility of reusing the library components individually or in combination to create new animations on the fly. The VTG responds to user's commands adding familiarity to the VR environment.
- The Chinese Calligraphy brush has been introduced as an interaction and navigation tool. Props allow for more *flexible* and more *intuitive* interactions with virtual worlds [1].

As proof of concept of the framework, a Singapore-specific heritage scenario has been realized in a fully immersive VR environment. User tests have been conducted to test the feasibility of utilizing a Chinese Calligraphy Brush as an interaction tool and to find out the public's opinion on using VR technology for VH applications.

The most important contribution is the modularity of the framework. Through interchangeable components, new heritage scenarios, interaction devices as well as presentation environments can be configured to view the desired VH scenario.

1.4 Overview of Thesis

This thesis is organized as follows. Chapter 2 will give an overview of Virtual Reality technology and related work in the field of Virtual Heritage and interaction. Chapter 3

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presents the Virtual Heritage framework and describes the overall system in detail. Chapter 4 presents the related work on brush recognition and the development of the Chinese calligraphy brush as a writing and navigation tool. In Chapter 5, the prototype of the Virtual Heritage application and its implementation details are presented together with usability test results. Finally in Chapter 6, conclusions and future direction for this research work will be presented. The appendices present the entire 3D model object library and the list of papers that have been accepted to various conferences and journals.

CHAPTER 2

VIRTUAL REALITY TECHNOLOGY- BACKGROUND AND APPLICATION DOMAINS

This Chapter will briefly look into the background of Virtual Reality (VR) technology and its application domains – concentrating on the field of edutainment applications in the area of cultural heritage.

2.1 Virtual Reality

What is Virtual Reality and where does Virtual Reality fit in the spectrum of “realities” we are presented with? Milgram et al. [12] introduces the Virtuality Continuum shown in Figure 2 that describes how Virtual Environment, Real Environment, and Mixed Reality work are related.

Figure 2. Milgram's Reality-Virtuality Continuum [12]

CHAPTER 2 VIRTUAL REALITY TECHNOLOGY - BACKGROUND AND APPLICATION DOMAINS

As Figure 2 shows, “Virtual Reality” on one end of the continuum while the “Real Environment” is on the opposite side and everything in between is “Mixed Reality”. VR being on the other end of the continuum indicates that the presented environment is totally synthetic.

In this section we take a brief look at the definition of Virtual Reality, the minimum requirements for a presentable VR environment, the device technology for interacting and displaying the environment and the classic VR system.

2.1.1 Definition

The term Virtual Reality (VR) was coined by Jaron Lanier [13] in the early 1980s although origins of Virtual Reality technology can be dated back to the 1920s [14][15].

Many definitions of Virtual Reality exist since Virtual Reality is still regarded as a relatively new technology and researchers and users alike all have different points of view.

According to Gigante’s [16] definition,

Virtual Reality is the illusion of participation in a synthetic environment rather than external observation of such an environment

There are two key elements to Virtual Reality – immersion into the synthetic environment or virtual world and interaction with the virtual world where the virtual world responds to the user’s input and the user receives some sort of sensory feedback. Here the virtual world refers to the computer generating visual, auditory, or sensual outputs of a synthetic three-dimensional world and objects within the computer that the users can directly interact and manipulate with in real-time. Illusion of participation is created by immersing the user into this synthetic environment by using special technologies to stimulate the user’s senses and display the synthetic world. Immersion is a sensation of being in an environment and can be purely mental or can be accomplished through physical means.

CHAPTER 2 VIRTUAL REALITY TECHNOLOGY - BACKGROUND AND APPLICATION DOMAINS

Physical immersion is the defining characteristic of Virtual Reality [17]. Since the users are able to directly interact with the synthetic world, a tracking system must be used to track the user's position and orientation within the synthetic environment.

Brooks [18] neatly summarized the four technologies crucial for VR as the following:

- The visual (aural and haptic) displays that immerse the user in the virtual world and that block out contradictory sensory impressions from the real world.
- The graphics rendering system that generates (at least 20 to 30 frames per second) the ever changing images.
- The tracking system that continually reports the position and orientation of the user's head and limbs.
- The database construction and maintenance system for building and maintaining detailed and realistic models of the virtual world.

2.1.2 Device Technology

There are two main categories for the devices used for correctly displaying and interacting with Virtual Worlds – input devices and output devices. The input devices interface to the world and track the user's positions as well as the user's motions and interaction. The output devices replace the user's sensory input from the physical world with a computer-generated one.

2.1.2.1 Input Devices

Input devices give the user the freedom to navigate the virtual environment as well as manipulate and interact with the objects within the virtual environment. The input devices allow the users to input commands into the computer and provide feedback from the simulation back to the user through special technologies. VR interfaces are varied in functionality and they address several human sensorial channels.

CHAPTER 2 VIRTUAL REALITY TECHNOLOGY - BACKGROUND AND APPLICATION DOMAINS

There are two types of monitoring – position tracking which tracks the user’s location and /or orientation to the computer and body tracking which senses the user’s position and actions.

There are several types of position tracking sensors. They are categorized with how the movements are captured. Many exist and below are some of the main examples.

Mechanical	
<ul style="list-style-type: none">• Usually a mechanical arm attached to the tracked object• Very accurate, short lag time but restricts movement• Well suited for controlling puppets and animatronics	<div> </div> <div>Hand Puppet Waldo® and Arm Waldo®</div>
Electromagnetic	
<ul style="list-style-type: none">• Measures strength of magnetic fields in coils attached to objects or wireless• Fast, short lag time but often prone to interference• Limited range	<div> </div> <div>Ascension Technology™ Flock of Birds</div>
Optical	
<ul style="list-style-type: none">• Either reflective markers or pulsating LEDs monitored by a camera at a fixed position• Fast, reasonably short lag, but often prone to interference caused by ambient lighting conditions• Line of sight problems	<div> </div> <div>Ascension Technology™ Laser Bird</div>
Acoustic	
<ul style="list-style-type: none">• Utilizes a hybrid of inertial and ultrasonic sensing technologies to measure 6 degrees of freedom position and orientation• Longer range than magnetic tracking• Line of sight problems• Ambient noise interference	<div> </div> <div>InterSense™ IS-600 Mark 2 Plus</div>

Table 1. Position Tracking Systems

Body tracking can also be further categorized into head tracking, hand/finger tracking, eye tracking, feet tracking, and others. Below are some of the body tracking devices and their descriptions.

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3D Mice	
<ul style="list-style-type: none">• Offers 6 degrees of freedom (X, Y, Z, pitch, roll, and yaw movement)• Easy to use• Usually comes with programmable buttons to customize user's preferences for motion control	Logitech™ Magellan Space Mouse
Spaceballs	
<ul style="list-style-type: none">• Offers 6 degrees of freedom (X, Y, Z, pitch, roll, and yaw movement)• When gripped by the user, forces and torques are measured and input to the computer to push, pull, twist 3D objects• Programmable function keys	IBM™ 6094 Model 051 Spaceball
Eye tracking	
<ul style="list-style-type: none">• Visually tracks some feature of the eye and a computer then determines where the user is looking• Most common : head-mounted & remote• Frees up hands so good for potential multimodal and non-command based interfaces	SensoMotoric Instruments™ Head-Mounted and Remote Eye Tracking Systems
DataGloves	
<ul style="list-style-type: none">• Measures each finger and the orientation (pitch and roll) of the hand• Provides freedom of navigation through hand gestures and orientation of the hand• Can emulate a mouse and also be used as a baseless joystick	5DT™ DataGlove

Table 2. Body Tracking Devices

2.1.2.2 Output Devices

Output devices interface to the world. The user’s physical perception of the virtual world is based entirely on what the computer displays through the output devices. In a VR system, the output is rendered to reflect the changing position of the user. The most well-known are the head-mounted displays. The display technologies are getting smaller and more versatile with alternative displays such as shutter glasses and virtual retinal displays. Many of the output displays use stereoscopic displays. In stereoscopic displays, two images that differ slightly are presented in front of each eye using head mounted displays, 3D goggles, or other display technology [19]. When these images are processed quickly enough the brain is fooled into thinking that it is looking at one single image and this

CHAPTER 2 VIRTUAL REALITY TECHNOLOGY - BACKGROUND AND APPLICATION DOMAINS

causes the perception of depth. Below are the descriptions for some of the display technologies.

Head Mounted Displays	
<ul style="list-style-type: none">• Can display either stereo or mono images depending on the type• Fully inclusive or see-through display modes• May include a built-in head-tracker• May have built-in stereo headphones	5DT™ Head Mounted Display
Shutter Glasses	
<ul style="list-style-type: none">• Display shows left and right images alternately, switching at high speed between images• Stereoscopic image is seen when the display is viewed with special glasses• Typical 'Fish tank VR'• Particularly good for large audiences in a theatre	CrystalEyes® Shutter Glasses
BOOM - Binocular Omni-Oriented Monitor	
<ul style="list-style-type: none">• Uses a CRT to provide high-resolution display• It is comfortable to use, since it does not have to be worn• Has fast, accurate, built-in tracking	FakeSpace™ Systems
Virtual Retinal Display	
<ul style="list-style-type: none">• Image is projected directly onto the retina• High resolution with full color displays• Brightness sufficient for outdoor use• True stereo display with depth modulation• Fully inclusive or see-through display modes	Microvision™ Nomad Augmented Display
Large Scale Displays	
<ul style="list-style-type: none">• Ultra-thin, high resolution LCD monitor for big, bright images• High resolution WXGA with support for most computer and video sources• Wide viewing angle makes it easy for everyone to get the message• The latest direct view LCD technology eliminates the heat and burn-in challenges often seen with plasma technology• Theatre-like multiple projection cylindrical screens	Christie™ Flat Screen Display

Table 3. Graphic Display Technologies

2.1.3 Classic Virtual Reality System

A classic Virtual Reality system presented by and Coiffet et al. [20] consists of the very basic components of *User, Task, I/O Devices, VR Engine, and Software & Databases*.

Figure 3. Five Classic Component of a VR System [20]

These five components are essential in creating a VR application.

The *Users* are given some kind of *task* (i.e. walk around, execute a command) to perform in the VR world they are immersed in through the *input and output devices*. The data of the Virtual World that is presented to the user is stored in the *software and databases* component that is rented and presented to the user through the *VR engine*.

2.2 Virtual Reality Application Domains

Virtual Reality offers enormous benefits to many different application domains. It provides a “learning-by-doing” scenario which is particularly useful for creating immersive educational environments. This section looks at the early pioneers of Virtual Reality applications and some of the main application domains VR technology is currently being used for today.

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2.2.1 Early Pioneers for Virtual Reality Applications

The very first applications addressing the requirements of virtual reality were in realistic vehicle simulations [14][15] which dates back as far as the 1920s to the work of Edwin Link who formed Link Aeronautical Corp., in Binghamton, New York in 1929. While trying to obtain his pilot's license, Link tried to develop a training device so that pilots could start learning to fly safely and inexpensively without leaving the ground. It was in the mid 1930s when the Army Air Corps ordered six of Link's instrument trainers to enhance its pilot training program, he began to gain recognition ultimately leading to the development of the whole field of flight simulation [21]. These vehicle simulations were primarily for aircraft but there were simulations for automobiles [22] and for ships [23] [24]. Simulation systems synthesized the content, geometry, and dynamics of the control environment for training and for testing of new technology and procedures. The flight simulators used dome-projection displays which were later replaced by one of the first head-mounted displays - the CAE fiber-optic helmet-mounted display [25]. The second major technological influence in VR applications were in teleoperations and telerobotics systems dating back to the 1940s. Teleoperations and telerobotics systems were usually panel-mounted displays but in the 1960s, Raymond Goertz at Argonne National Laboratory [26] and Charles Comeau and James Bryan of Philco [27] worked on teleoperation displays using head-mounted, closed-circuit television systems.

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Figure 4. Head Mounted Display developed by Philco [27]

It was Ivan Sutherland [28] who in the 1960s pioneered the personalized graphics simulation and produced the first system to replace the video signal with a totally synthetic image produced through computer graphics through his Head Mounted Three-Dimensional Display using mechanical position sensors. In his doctoral thesis ‘SKETCHPAD: A man-machine graphical communication system’, Sutherland revealed how computers could be used for interactive graphics.

Figure 5. Ivan Sutherland's Head Mounted Three Dimensional Display worn by Quint Foster, 1967 [28]

Since then, the application domains using and benefiting from this VR technology has grown exponentially into a variety of fields from medicine to humanities to entertainment

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to automobile design. Listed below are some of the application fields using VR technology along with short descriptions.

- **Architectural Visualization**

By fully visualizing the architectural building in 3D and providing real-time virtual walk-throughs, the architects and clients alike can explore and evaluate first-hand their design decisions on the virtual building before it is actually built during the conceptual design phase. They have the option to experiment with the layout of the house, furnishings, lighting, and get a 'feel' for the space through immersive displays. It can also be used to demonstrate how a planned construction fits into the environment [29].

- **Vehicle Design & Prototyping**

VR technology is used to create rapid prototypes on automobiles to test in a fully immersive environment the aesthetics, ergonomics, styling, and engineering before the actual vehicle is built. This reduces the time, effort, and cost involved in actually building full mock-ups [30].

- **Entertainment**

More and more VR theme parks and computer arcades are developing and installing single/multi-user virtual sets and virtual rides fully equipped with the VR hardware where the users wear a HMD and interact with the virtual world through many devices such as joysticks and pirate ship guns [31].

- **Simulation & Training / Teleoperations**

As seen above, the most common example here is the vehicle simulator. Vehicle simulators have lower operation costs and are safer to use than the actual vehicle whether it is an aircraft or a ship. Teleoperations are also very beneficial for people working in hazardous or dangerous environments. For example, workers in

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radioactive, space, or toxic environments can use VR environments and operate remotely reducing their risks of dangerous exposure [32].

- **Scientific Visualization**

In Scientific Visualization, computer graphics is used to create visual images that aid in the understanding of complex (often massive) numerical representations of scientific concepts or results [33]. By combining Scientific Visualization and VR, real-time intuitive interfaces are provided for exploring the data while still facilitating the use of Scientific Visualization in the research process.

- **Engineering**

Engineering processes and simulation data that were represented only as numbers and 2D graphics are now fully visualized and represented in an immersive 3D environment for different kinds of logistics and simulation where objects can be manufactured, inspected, assembled, and tested in a virtual factory saving time, effort, and cost [34].

- **Education**

Virtual Reality proves to be an effective educational tool since any place, time period, humans, creatures, or objects that are not accessible can be virtually reconstructed where the students can visit and experience interactively with immediate feedback as they explore and understand the presented material. For example, they can learn about gorillas and interact with them in first person [35].

- **Medicine / Non-invasive surgery**

By using Virtual Reality technology, medical training simulators where surgeons can develop and train surgical skills on virtual patients without harming animals or human beings have already been developed. VR is used in many fields in medicine including training & teaching, surgery planning, computer assisted surgery, telemedicine, and rehabilitation [36].

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- **Cultural Heritage**

Emerging as one of the main areas of VR application domains [37], many cultural heritage sites are being digitally reconstructed and showcased through VR technology. There is a diverse range in the field of heritage preservation is using this technique for heritage applications - ranging from digital archiving, surface model generation, laser scanning, museum installations, color restoration, and reconstructing cultural heritage environments. The next section presents an in-depth survey on recent work carried out Virtual Heritage applications and interaction techniques.

2.3. Virtual Reality for Cultural Heritage

Combining cultural heritage content with Virtual Reality (VR) technology has created a new domain - Virtual Heritage. Rapid advances in VR technology offer immersive and interactive qualities to the cultural heritage content thus accurately representing digital reconstructions of heritage sites that are no longer in existence or are inaccessible. Many Virtual Heritage projects are being developed world-wide over the recent years because numerous heritage sites are on the verge of extinction. VR technology enables us to not only recreate Virtual Heritage sites but also to recreate the historical content that no longer exist or even recreate the different times in history with the same content Another major advantage using VR technology is being able to explore the heritage objects in a nondestructive manner without manipulating or harming the original piece and/or setting. Cultural Heritage has been identified as one of the key application domains for driving the development of new human-computer interfaces by the first EC/NSF joint Advanced Research Workshop in 1999 [37].

VR technology is being actively used in the various cultural heritage fields including archaeology, digital archiving, surface model generation, laser scanning, integration of

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VR and AR (Augmented Reality), museum installations, color restoration, reconstructing and recovery of cultural heritage environments, virtual art galleries/museums, and even in the artistic realm such as painting.

The following sections present a current survey on Virtual Heritage applications, interaction technologies, and Virtual Humans. It examines the positive aspects as well as the limitations of the current systems and presents the challenges that have been identified.

2.3.1 Virtual Heritage Applications

One of the earlier projects of recreating and restoring a massive cultural site can be seen in the Xian Project [38]. This project recreated the process of the excavation of the grave complex of the Ch'in emperor Shi Huang Ti in Xian in the 1970s by reconstructing the life-size terra-cotta soldiers in 3D. In this project, the 3D terra-cotta soldiers that were inside the earth gradually come to life and start walking and displaying emotions through facial expressions, body movements, and through their armor.

A recent example of an archaeological site reconstruction using high-resolution recording techniques for reconstruction and restoration can be seen in Beraldin et al. [39]. They selected a Byzantine Crypt of Santa Cristina located in Carpignano, Apulia in Italy which was excavated around the 9th century. A framework was proposed and implemented for heritage recording using photogrammetry and 3D laser scanner to capture the accurate heritage site data for virtual visits and restoration.

Notre-Dame de Paris is one of the best-known cathedrals in the world. This 900 year old cathedral initially took over 200 years to build and is always in a state of reconstruction or preservation since it attracts over 50,000 visitors every day. Victor et al. [40] digitally recreated the Notre-Dame Cathedral of Paris using high-quality 3D modeling. They based their research entirely on 3-Dimensional architectural and photographic data, accurately reconstructing a 3-Dimensional representation of the cathedral. The merit of their work is

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that it is multi-user and accessible to the public in real-time from anywhere in the world. They incorporated the idea of a Virtual Tour Guide and presented their work on CD-ROMs and the internet allowing for the global access of this beautiful cathedral.

An example of using VR as an interface for interpreting historic archives in a fun and exciting manner was undertaken by Cremer et al [41]. They reconstructed a 3D model of a 49 square block region of the turn-of-the-20th century Cedar Rapids, Iowa and installed it into an immersive interactive museum exhibit. They incorporated a “time machine” where the visitors actually sit and operate the “time machine” to go back in time and access the multimedia content associated with buildings and other historically significant sites. This also indirectly provided for an exciting channel for teaching science and technology to the museum visitors. Currently they have expanded their research embarked on a multiphase research project with Smithsonian Institution’s National Museum of American History [42] to evaluate the usability and potential applications for virtual environments in a museum setting.

Behr et al. [43] introduced innovative techniques in presenting a digital model of one of the most picturesque cathedrals in Europe – the Dome of Siena during the EXPO 2000 in Hanover, Germany. The Siena Cathedral was chosen for 2 main reasons: for its rich historic background and the technical challenge related to reconstructing this complex building along with its ornaments, sculptures, paintings, and much more - in real-time. They provided for innovative interaction techniques for the general public involving the user through a Virtual Tour Guide and an ancient book as touch screen navigation. They put special focus on the real-time frame rate and the visual quality by applying a variety of techniques such as different levels of detail mechanisms, texture-paging techniques, and innovative lighting simulation based on radiosity. Figure 6 shows the interior of the Dome of Siena with Luigi, the Virtual Tour Guide.

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Figure 6. Luigi in the Dome of Sienna [43]

Another good example of heritage restoration can be seen in Lutz et al. [44][45]’s work in recreating the Dunhuang cave. The Dunhuang caves in China were painted by Buddhist monks from the fourth century to the fourteenth century. There are 570 caves with around 3,000 statues with extensive murals. Unfortunately, these caves are suffering badly from weather conditions and tourism. In Lutz et al.’s work, they reconstructed the Dunhuang cave No. 428. They focused on the high-end 3D VR presentation with innovative interaction techniques using a virtual flashlight. Figure 7 showcases the Dunhuang cave with the real-time flashlight.

Figure 7. Virtual Dunhuang Cave [44][45]

Sanders et al. [46] developed a digital reconstruction of the ancient archaeological site from the Northwest Palace of Ashur-nasir-pal II. In their work, they created a 3D virtual avatar of the King Ashur himself to present the historical information on the Palace in real-time. They took the advantage of the VR technology and applied it to their archaeological, art, and technological research by implementing an integrated virtual environment at the UB Virtual Site Museum. A Virtual Site Tour is given by the King to provide the historic and artistic information of the Palace.

The above applications cited here are good examples of cultural heritage reconstruction. They preserve an aspect of a selected cultural heritage by reconstructing the sites in realistic 3D environments and incorporating intuitive interactions that are appropriate to the scenario. An overview of interaction devices used in Virtual Heritage applications is summarized in the next section.

2.3.2 Interaction within Virtual Heritage Applications

Interaction is a crucial part in the development of VR technology since the user's role is an active one - participating and interacting with the virtual environment and its objects.

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Some examples of interaction in VR include hand gestures [47], virtual-walk-through-specialized slippers, natural speech, virtual humans, fragrance, touch screen kiosks and using props as an interface tool.

In the work of the Virtual Dunhuang Art Cave in the previous section, Lutz et al. [44][45] presented an intuitive interaction technique appropriate to the cave context by using a “virtual flashlight” which could be connected to a real flashlight to navigate within the cave. The positions and orientations of the real flashlight held by the user are tracked and this data is used to render the photorealistic representation in real-time.

An example using the brush as an interaction device in the virtual heritage and museum domain can be seen in the project undertaken by the Seattle Art Museum [48] together with the HIT Lab of the University of Washington. Together they opened an exhibit titled *Treasures from a Lost Civilization: Ancient Chinese Art from Sichuan* virtually displaying more than 150 priceless bronze, clay and gold pieces of art from the Sichuan region in China. Wanting a more interactive exhibition, they combined VR and AR techniques where the visitors to the museum play the role of an archeologist and can virtually brush away the earth with a real brush or a shovel.

Refsland et al. [49] constructed a model of the Golden Temple (Kinka Kuji) in Kyoto, Japan and designed artificial life “fireflies” to inhabit the neighboring temple gardens. They connected the fireflies in real-time to the actions of the NASDAQ stock market to simulate night-time. Not only did this provide a means to ‘light-up’ the virtual scene in real-time, it also added to the magical quality when visiting the temple. As with the ‘virtual flashlight’ project, this project shows innovative ways of presenting transparent context-specific interface. Hirayu et al [50] are developing a system where not only are they reconstructing the historic villages of shirakawa-go, they are also teaching the rope-tying techniques from the ancient craftsmen by letting the users interact with sensor-

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inserted ropes that detect and track the user's actions. They are also planning to simulate weather conditions.

On the art front, a CavePainting system that uses the entire CAVE as an artist's canvas was developed by Keefe et al [51]. They used physical props such as a paintbrush, bucket, and cups and the artist uses these familiar interaction tools to paint freely in the CAVE environment. The artwork and entire processes are digitized and the artist has the option to playback and watch the techniques and processes he/she used for the painting. Another interesting VR art application was developed by Eschler et al. [52] called Virtual Graffiti which was presented at Cybernarium Days 2002 and CeBit2003. Since graffiti is in most cases illegal, Virtual Graffiti solves this problem by using a dummy spray can without the paint which is tracked and the virtual color is painted onto a rear-projected screen. Different colors can be selected and the pressure of the button is also taken into consideration.

It can be seen that many VH applications use "props" as an interaction tool. All the props are objects that can be found in everyday life and are context-specific. Using context-specific props help in creating a seamless interface between the VE and the user. The next section looks at Virtual Humans.

2.3.3 Virtual Humans

Since us human beings are such complex entities, digitally recreating ourselves is not an easy task. Numerous studies in recreating realistic virtual human beings/avatars are currently in progress. The virtual humans can be autonomous, programmed, or guided depending on their purpose. Real-time virtual humans are also increasingly showing complex features along the dimensions of appearance, function, time, autonomy, and individuality. Full surveys for the fields of natural language generation and speech

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recognition for Virtual Humans have not been carried out here although these fields are relevant to the research in conversational Virtual Humans.

Cassell [53] developed an embodied conversational agent named Rea (Rea Estate Agent). Rea is a real-time 3D avatar capable carrying out conversations and interacting with real human beings.

Badler et al. [54] developed a software system called *Jack* for creating, sizing, manipulating, and animating virtual humans. This virtual human architecture provides a level of abstraction by including low-level motor skills, a mid-level parallel automata controller, and a high-level conceptual representation for driving virtual humans through complex tasks with natural-language instruction representation to animation control.

The Thalmanns [55] developed sensory perception in human modeling by equipping virtual humans with visual, tactile, and auditory sensors to make them aware of their environments. At their MIRALab in the University of Geneva [56], intensive research on the real-time recognition of emotions and interactive reactions of virtual humans through emotional models, simulation of physics-based deformable models such as clothing and hair alongside with many other researches on Virtual Human simulation and Virtual Worlds/Augmented Reality is also being actively carried out.

Some other architectures on Virtual Humans include Perlin et al. [57]'s Improv System and Chi et al. [58]'s EMOTE system. The Improv System combined scripted actions with stochastically generated motions to achieve controllability and believability of the Virtual Humans while the EMOTE team introduced a new approach to procedural human animation that tried to close the gap between manually animated characters and procedurally animated characters.

H-ANIM [59] working group developed standard way of representing Virtual Humans (:humanoids) in VRML97 [60] in real-time. H-ANIM humanoids can be animated using

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keyframing, inverse kinematics, performance animation systems, and other techniques.

Figure 8 shows the H-ANIM 1.1 specification and the hierarchy for a given humanoid.

Figure 8. H-ANIM 1.1 Specifications and Hierarchy for a Humanoid [59]

Virtual Humans are representing diverse roles from Real Estate Agents [53] to Virtual Tour Guides [43][46]. As we can see, they are becoming more complex as they engage in conversations, see, touch, and feel emotions. Courses are being conducted for the simulation of real-time Virtual characters for Mixed Reality Cultural Heritage applications [61]. Still more research needs to be carried out for generating real-time

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behaviors and emotions for the dynamic interaction between the real and the Virtual human beings.

2.3.4 Limitations and Challenges

Although it has been proven that VR is a highly suitable medium for presenting cultural heritage, the main limitation that has been identified through the survey on VH applications is the lack of a generic workflow for the development and implementation process. None of the VH applications present a concept for streamlining the development process that is easily configurable and interchangeable. Thus, conceptualizing a generic and modular workflow where the underlying components can be configured to specific needs, scenarios, interaction devices as well as available resources of the development environment is a major challenge.

Another major challenge lies in providing intuitive interfaces between the VE and the user. Incorporating props as an interaction device is a recent trend [11] and many VR applications are currently utilizing context-specific everyday objects as an interface tool [44][48][51][52].

To overcome the limitations and to meet the challenges presented above, a framework for generating real-time VH applications is derived and presented in Chapter 3. For the proof of concept, a Singapore-specific heritage scenario is realized in a fully immersive VR environment. To enhance the intuitive interaction between the VE and the user and to further immerse the user into the presented culture, a real-time Virtual Tour Guide and a cultural heritage object has been integrated into the heritage scenario.

2.4 Summary

In this Chapter, we first looked at the definition of Virtual Reality, where Virtual Reality fits into the spectrum of realities, the input/output device technologies and the classic VR

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system. This was reviewed to serve as a background for what VR is and to get a glimpse of what VR has to offer, its technology requirements, and the components essential for creating VR applications. We then present an overview of the VR application domains, starting from the pioneers of VR. There are a variety of application fields VR is being used for - especially in the field of training and education. Another key domain is the field of cultural heritage. As one of the key domains, we carry out a survey on Virtual Heritage applications, interaction techniques employed by these applications and Virtual Humans. Through this intensive survey, it is shown that VR is a good medium for representing cultural heritage sites and it is fast becoming a trend to use physical objects as an interaction device. It is crucial to provide intuitive interaction between the VE and the user. We also found that there was no proposed generic workflow for the development and implementation of VH applications. To overcome this limitation, we present a framework for generating real-time Virtual Heritage applications in Chapter 3. The feasibility of the framework is proven through the proof of concept on a Singapore-specific heritage model. For the interface between the user and the VE, we introduce a Virtual Tour Guide and a cultural-specific heritage object, the Chinese Calligraphy brush.

CHAPTER 3

FRAMEWORK

Based on the limitations and challenges identified in Chapter 2, this Chapter reviews content presentation workflow from other VH applications, the classic VR system and behavioral animation framework. With this as a basis, a framework for real-time Virtual Heritage applications is presented and the implementation of the different components is described in the following sections. The implementation component for the Chinese Calligraphy brush is presented in Chapter 4.

3.1 Framework

Although the Virtual Heritage applications in Chapter 2 fail to present a concrete framework, the following workflow components have been identified.

The first phase is the *information collection phase* for the selected heritage structure. This research stage can include heritage site visits, interviews with historians/museums, and consulting specialized books. The information gathered at this stage is filtered and later presented to the users through the generated 3D environment. All the VH applications incorporated a specific *interaction device or interface* to communicate with the user. Thus identifying how the users will interact with the 3D environment should also be researched and selected at this stage. After the necessary information has been gathered, the 3D

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objects are identified and generated. A variety of methods can be used for this process such as modeling through commercial 3D software, using and customizing stock 3D models, and laser scanning. These *3D objects are then showcased* to the visitors in a real-time VE. The visitors *interact* with the VE to obtain information on the presented heritage structure. This basic workflow is also roughly based on the classic VR system [20] introduced in Chapter 2. We revisit the classic VR system diagram in Figure 9.

Figure 9. Five Classic Component of a VR System [20]

As the classic VR system is quite simplistic, we present a Behavioral Animation Framework from Millar et al. [62]. Miller et al. presented the generic model for behavioral animation seen in Figure 10. In this model, there are 4 communicating models – the environment model which consists of all the 3D models in the virtual world (objects, virtual characters), the perception model where the virtual characters perceive their environment through senses, the behavioral model which incorporates a behavioral technique to determine how the virtual characters will react to their environment, and

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finally the motor model where movements are generated based on the motor techniques of the virtual characters and the requests from the behavioral model.

Figure 10. Behavioral (Stimulus-Response) Animation Framework [62]

There are several limitations to the proposed the classic VR system and the Behavioral Animation Framework.

- The frameworks are very general and they give no instruction on how to implement the different modules. While this gives the frameworks the flexibility to deal with many different kinds of tasks, they do not help the developer in the internal design and implementation of the modules.
- There are no definitions for communication interfaces between the modules thus making it difficult to combine newly developed modules with existing ones or to exchange them with other alternatives.
- The frameworks do not address the need for reuse of components in the visualization. Standards have to be defined to make the import/reuse/adaptation of content possible.

With the classic VR system as the foundation, a new framework is derived from a combination of identified workflow components from other VH applications and the Behavioral Animation Framework. The limitations outlined above have been taken into consideration and the proposed framework addresses the need for component reusability and communication between the modules.

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The framework is designed to support different types of heritage content and interaction devices. To prove the applicability of the framework, the Peranakans, a Singapore-specific heritage model, has been selected for the heritage content. A brief background on the Peranakans and the motivation behind this selection is presented in Chapter 1. While researching for interface possibilities, a Peranakan Virtual Tour Guide from the early 1900s and the Chinese Calligraphy brush were identified as suitable candidates. These ideas were initially tested on the Peranakan public and there was positive feedback, especially in using a cultural object as an interaction tool to immerse into the Virtual Peranakan Heritage Environment. Chapter 4 is dedicated to the implementation of the Chinese Calligraphy brush.

The framework presented in Figure 11 shows the customized framework specific to the Peranakan heritage model, which it is being applied to. It can be seen from the framework that it addresses the five classic components of a VR system and also addresses the behavioral stimulus-response animation framework for developing Virtual Heritage applications. This framework can be further extended to accommodate sub frameworks as presented in Chapter 6.

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Figure 11. Detailed Framework for Virtual Heritage Applications [9][10]

The five components of the classic VR system correspond to the following in the framework.

- Input / Output Devices → Interaction Devices / Visualization
- User / Task → User Tracking / User Observation
- Software and Databases → 3D Models / Behavior Model
- VR Engine → Visualization

The four communicating models of the behavioral animation framework correspond as follows.

- Environment Model → Content Creation Framework : Environment Model
- Perception Model → User Tracking / User Observation
- Behavioral Model → Behavior Model

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- Motor Model → Motor Model

The next section will look into the detailed components of the above framework.

3.2 Hardware

Since the final VH application will be presented on a large-scale projection display capable of stereoscopic output, the Chinese Calligraphy brush needs to be accurately tracked for this environment. There are a couple of tracking sensors commercially available and they are summarized in Table 1. At the Centre for Advanced Media Technology's VR/AR lab, Flock of Birds from Ascension Technology™ [93] is used for tracking objects in the VR environment. It is an electromagnetic tracking system that measures the strength of the magnetic fields in coils attached to the objects. It is fast and has a short lag time but is often prone to interferences and has a limited range. The electromagnetic and the optical tracking systems are ideal for connecting and tracking physical objects since it provides 6 degrees of freedom.

In order to bring the VH application closer to the public and make it more portable, the interaction device can be changed to a PDA or a writing tablet. This alternative navigation will limit the degrees of freedom but opens up new possibilities. The same VH application can be configured for different viewing environments – large projection VR lab, desktop VR, and out on the streets of Singapore combining reality with virtuality.

3.3 Work Packages

The main goal in this research is to create a real-time user-centered Virtual Heritage application where the interface engages the user to experience the Virtual Environment first hand. The aim is to create an edutainment application by combining educational aspects of the historic and cultural content that is at the same time entertaining. Therefore, the application that is developed aims to be flexible and dynamic through the

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implementation of reusable libraries and customization. To achieve these goals, the following work packages have been identified through the framework presented in the previous section. These work packages are outlined below.

- Content Creation Framework: Environment Model [10]
 - Generation of 3D Models – Static
 - Virtual Tour Guide
 - Culture Material
 - Architecture
 - Generation of 3D Models - Dynamic
 - Facial Animation - Speech
 - Soft Body Motion Sets for Basic Behavior
- Run-Time Framework [10]
 - Interaction Devices
 - Calligraphy brush interaction
- Visualization

The *Content Creation Framework* and *Visualization* components are described in more detail in the following sections. The Calligraphy brush interaction component is described separately in the next Chapter.

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Figure 12. Overall Framework : Static/Dynamic/Animation

3.4 Generation of 3D Models and Animation

The 3D modeling processes for this project can be broadly categorized into virtual human modeling, culture material modeling, and architectural modeling. Applications developed for Virtual Reality (VR) environments *must* ensure realistic high-quality 3D models since, on the surface-level, these 3D models visually represent the core of the application to the users who are presented only with these models during their interaction and experience with the system. These models are used in a real-time system so polygon count is extremely important. Special attention paid to the 3D modeling techniques and high-quality textures were used for optimal 3D modeling.

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3.4.1 Virtual Avatar

A virtual avatar is a computer model of a person that is controlled by humans with behaviors inspired by human beings. There are several classifications but generally they are classified as being guided, autonomous, or programmed according to the different degrees of behavioral autonomy [63]. Guided avatars are avatars that are driven by the user and their behaviors are provided externally. Autonomous avatars on the other hand should have the capability of acting independently and demonstrate behavior. They should have mechanisms to perceive their environments and possess memory, reasoning, and learning. In programmed avatars, all possible behaviors are pre-programmed.

The Virtual Tour Guide presented in this thesis is a guided avatar.

Good examples of using virtual humans capable of natural speech and animation as an interaction medium for the users can be seen in the above mentioned work Behr et al. [43]'s virtual tour guide Luigi and Sanders et al. [46]'s virtual King Ashur.

3.4.1.1 Virtual Tour Guide

The Virtual Tour Guide has been modeled using the commercial software Autodesk's Maya™ [64]. For the Virtual Human, the main objective was to create an 'Asian' looking avatar to fit into the overall project since many readily available models are of Caucasians. To accomplish this, the head was modeled from scratch using photographs of Asian actors as the base to extract specific 'Asian' facial features. Since this model has to be used in real-time for speech and animation, the model was created as a template human that is easily extendible. The head was created using NURBS modeling and the body was created using sub-division modeling techniques. The body was then mapped with a biped skeleton.

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3.4.1.2 Face Modeling

To create a stylized 3D human head capable of speech and animation, it is crucial to understand the basic anatomy and muscle structure of the human head. Figure 13 shows the basic muscle structure of the human head.

Figure 13. Basic Muscle Structure of the Human Head [65]

The following definitions have been referenced from the General Practice Notebook - a UK Medical Encyclopedia on the World Wide Web [65].

- **Orbicularis Oculi** : One of the muscles of the eyelid. It surrounds the orbit and extends out onto the temporal region and cheek. It aids in the closing of the eyelids.
- **Orbicularis Oris** : one of the muscles of the mouth. It arises from structures around the mouth. It aids in closing the mouth and pursing/everting the lips.
- **Zygomaticus** : Zygomaticus major is one of the muscles affecting the shape of the mouth. It raises the angle of the mouth superiorly and laterally.
- **Frontalis** : The full name Occipitofrontalis is one of the muscles of scalp. The actions of occipitofrontalis include weakly moving the scalp skin anteriorly, wrinkling the forehead, and elevating the eyebrows.

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- **Depressor Angoli Oris** : The depressor anguli oris muscle is one of the muscles of the mouth. Its action is to depress and laterally displace the angle of the mouth.
- **Masseter** : Masseter is a jaw muscle that acts to close the jaw.
- **Sternocleidomastoid** : This muscle divides the neck into anterior and posterior triangles. It connects the skull from behind the ear to the sternum allowing for the head turning motion.

The Orbicularis Oculi, Orbicularis Oris and the Zygomaticus are used to elevate various portions of the upper lip that generate expressions of either joy or sadness. Depressor Angoli Oris lowers the corner of the mouth to generate expressions of sadness or frustration.

The head is modeled using a technique called NURBS modeling. This technique makes use of NURBS which stands for Non-Uniform Rational B-Spline. NURBS is an industry standard tool for the representation and design of 3D geometry. Since the foundation of a NURBS surface is a curve and the surfaces are webs of interconnected curves, it is suitable for creating organic, flowing surfaces such as animals and humans. The Virtual Tour Guide's face has been modeled with the major muscle lines described above to accurately derive the viseme heads and expression faces.

Figure 14. Virtual Tour Guide Major Muscle Lines

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Once the base head was created, variations of the head for the 16 base phonemes that become the base morph targets for speech animation are built through deformers in Maya™ [4][5][6][7][8][9][10][66]. A phoneme is the smallest part of a grammatical system that distinguishes one utterance from another in a language or a dialect [67]. It represents the actual sound rather than the letters of the word to create the words in a speech. Visemes are the visual phonemes are the actual mouth positions that represent the sounds we hear in a given speech. There are 16 very basic visemes. Table 4 depicts the 16 basic phoneme templates created for the Virtual Tour Guide.

1. Bump	2. Cage	3. Church	4. Earth

5. Eat	6. Fave	7. If	8. New

9. Oat	10. Ox	11. Roar	12. Silent

13. Size	14. Though	15. Told	16. Wet

Table 4. Phoneme templates [10]

In addition to the 16 phoneme heads, a set of expression faces was also created. These include blink, smile and frown, frontalis and corrugator.

Blink	Smile	Frown

Frontalis	Corrugator	

Table 5. Expression Faces [10]

3.4.1.3 Body Modeling

The body is built on subdivision surfaces. Subdivision surface modeling essentially uses polygon surfaces to model by subdividing the surfaces for finer detail. This technique is easier for building models that are less organic. This technique was used since the underlying body does not need to be modeled and only the clothes need to be modeled. Once the body was built, the biped skeleton was mapped to the body [4][5][6][7][8][9][10][66]. Joints on the biped skeleton are hinged to follow human anatomy. By default, the biped resembles a human skeleton and has a very stable Inverse Kinematics hierarchy. The structure of the biped is very similar to the structure defined by H-ANIM shown in Figure 8. For the enveloping of the skin, there are two types – flexible and rigid. Rigid skin envelopes are mainly used for computer games and avatars. It requires less calculation time since the vertices influenced by a rigid envelope follow the link itself (i.e. upper arm link) rather than the deformation spline. Deformable envelopes, on the other hand, follow the physical deformation spline that runs through the joints in the hierarchy of the body, which in turn requires more calculation time. Rigid skin envelopes are used for animating the Virtual Tour Guide in the real-time engine. Figure 15 shows the body and the biped skeleton of the body.

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Figure 15. Virtual Human Body and Skeletons [7][8]

A library of motions has been created for the basic behaviors of the Virtual Tour Guide. These motions include walk, ascend stairs, descend stairs, and turns.

Ascend Stairs	Turn Right	Walk	Descend Stairs

Table 6. Library of Motions [10]

3.4.2 Material Culture

Objects specific to the Peranakan material culture were obtained through numerous photographs from museum visits, actual heritage site visits, and through specialized books on the Straits-Chinese [68][69][70][71][72]. Objects from furniture, ceramics, silverware, and embroidery and beadwork were selected to build a scalable 3D object library to showcase the lifestyles of the Peranakans. All these objects have distinct styles that are very specific to the Peranakans. Extensive texturing has been applied to represent the beauty of these objects. The extensive library of cultural material objects are listed in Appendix A.

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3.4.3 Architecture: The Peranakan House

When the Peranakans first settled in Singapore in the early nineteenth century, they first settled in shophouses and terraced houses [73]. A shophouse has two or more levels and was used for both commercial and private purposes. The first floor was used for commercial purposes and while the tenants resided in the upper floors. These shophouses were connected to several other shophouses to form a shophouse block. A terrace house is a shophouse where the tenants used both the ground and the upper floors for residential purposes [74]. Many shophouses are still in existence today in Singapore. The Peranakan House is an integral part of the Peranakan culture since it symbolizes the setting in which Peranakan art, rituals, and traditions are expressed. The lifestyles of the Peranakans including all religious ceremonies and were celebrated in the house. The richness and wide range of architectural vocabulary derived from the hybrid of western and eastern styles and traditions can also be found in the Peranakan House.

The shophouses in Singapore are still preserved in many areas. After consulting with the Peranakan Association experts, a sample shophouse based on photographs from actual existing shophouses and books have been modeled. Figure16 shows the wireframe and the textured model of the shophouse.

Figure 16. Wireframe and Textured Shophouses

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3.4.4 Texturing

To create realistic 3D models and to reduce polygon count for real-time rendering, realistic high-quality texturing is crucial in the modeling process. All the 3D objects' textures have to be scanned or photographed into the computer as high-resolution images. Each image then needs to be reformatted and adjusted before it is applied as a texture. Figure17 shows an example of texturing the shirt and the skirt of the virtual human.

Figure 17. Example of Texturing

3.5 Visualization

The visualisation is the central component of the proposed system that incorporates the Peranakan object library, content, the Virtual Tour Guide, and the Calligraphy brush interaction. All these components have an influence on the final scene that has to be shown.

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Figure 18. Visualization

The Peranakan objects and the Virtual Tour Guide are based on X3D [75] and the Humanoid Animation component (H-ANIM). The core of the visualization is a system that supports X3D. It is a real-time engine that runs on low cost platforms and has an interface to the rendering component, which is done with OpenSG.

3.6 Summary

In this Chapter, we first identify the workflow components for VH applications from the literature reviewed in Chapter 2. We then analyze the components of the classic VR system and the Behavioral Animation Framework and with these systems as the foundation, we derive a new framework for generating real-time VH applications. The proposed framework has been designed to be modular and generic supporting different types of heritage content and interaction devices. To prove the applicability of the proposed framework, the Peranakans, a Singapore-specific heritage model, was selected for the heritage content and a Peranakan Virtual Tour Guide and a Chinese Calligraphy brush have both been identified for the interaction interface. By utilizing an actual cultural object as the interaction device, the users are able to “experience” the culture first-hand. The Peranakan Virtual Tour Guide is dressed in the Peranakan costume from the early 1900s and will guide the users around the VE as well as present the users with

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cultural information on the heritage model. Detailed developments and implementations for the different workpackages of the Virtual Tour Guide, cultural artifacts, architecture, and visualization were presented. The next Chapter presents the development and implementation of the Chinese Calligraphy brush.

CHAPTER 4

CHINESE CALLIGRAPHY BRUSH

This Chapter first presents the motivation behind selecting the Chinese Calligraphy brush as an interaction tool. It then reviews the recognition process for “pen & paper” focusing on online vectorized recognition. Then the implementation of the brush as an input device of the framework is presented in detail.

4.1. Chinese Calligraphy Brush

Calligraphy is an art dating back to the earliest day of history, and widely practiced throughout China and other parts of the world to this day. It is a very familiar tool to the Asians since they are exposed to it an early age whether it is at school or other environments. This cultural object has been chosen as an interaction device for this project because it is very specific to the Chinese and Asian culture thus fitting well into the overall interface and the Peranakan-specific content [4][6][10][66]. Many people in Singapore are of Chinese descent (around 70%) and are somewhat familiar with Chinese calligraphy. This is an advantage because it provides intuitive interaction by presenting the user a familiar device they can immediately bond with and they do not have to spend much time learning how to use this interaction device. Although Chinese calligraphy is a dying art in Singapore due to many unforeseen factors, the Chinese Calligraphy Society

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of Singapore (CCSS) offers 4 term courses per year. Each course has roughly 400-500 students. They also offer electional courses in the 2 universities. The CCSS has had roughly 20,000 students to date. Another driving factor behind selecting the Chinese Calligraphy brush also lies in bringing calligraphy back into Singaporean society and beyond through the use of new technologies.

The two driving requirements for the design process for VR according to Bryson [11] are :

- The virtual environment and its interface should be tailored to the task
- Stringent performance constraints must be met for the benefit of virtual reality to be realized

Bryson also mentions the idea of *metaphors*. The idea is to allow the user to think in terms of interacting with objects which are directly related to the task at hand, rather than thinking in terms of interacting with a computer. Taking these into consideration, we have tailored the functionality of the brush to write very simple Chinese characters using an actual calligraphy brush onto a physical board to execute commands and to navigate around the VE. This idea extends the concept of using *metaphors*. Writing Chinese characters provides the users with a task that is not computer related but related to the Chinese culture. To eliminate the need to change interaction devices during the immersive cultural visit, navigational functionalities have been added to the brush. Changing interaction devices disrupts the continuity of the VR experience as the user has to physically step away from the VE. For the first phase of the implementation, limited functionalities have been added to the Chinese Calligraphy brush. By limiting the number of Chinese characters that can be recognized and simplifying the navigation around the VE, it takes less time for the users to orient themselves in the VE. We also look at and compare Bryson's four design principles in designing 3D VR interfaces to the Chinese Calligraphy brush.

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Bryson's Design Principles	Chinese Calligraphy Brush & Board
Each objects should have its own virtual controllers associated with it	<ul style="list-style-type: none">Chinese Calligraphy brush<ul style="list-style-type: none">Users use the actual brush while a virtual representation is presented to the user when the brush is in useThe virtual controller for the brush is the brush itself. The users can write with it on the board or point at the screen for navigationBoard<ul style="list-style-type: none">Provides tactile and haptic feedback for the brush and the user. The mock-up interface gives the users a sense of actually writing on a piece of rice paper with the brush.
Meaning of hand gestures depends on which object the hand is touching	<ul style="list-style-type: none">The writing hand holds the brush and the opposite hand holds the board, thus this interface is tailored for both right-handed users and left-handed usersThe writing hand is the dominant hand that writes the Chinese characters or uses the brush to navigate
Avoid global environment control directly through the hardware interface, that is avoid gestures that have meaning all the time. It is too easy to make such commands unintentionally.	<ul style="list-style-type: none">Commands are executed only when the brush is touching the board or it is detected that the user is pointing at the screen
Hide virtual control as much as possible, but make them easy to get at.	<ul style="list-style-type: none">Writing<ul style="list-style-type: none">The user is presented with the board only when the user lifts the board up to the brush to start writingNavigating<ul style="list-style-type: none">Virtual controllers on the screen appear only when the brush is pointing at the screen

Table 7. Bryson's Design Principles

The next section looks at the background of recognition. For the purposes and the relevance of this thesis, we focus on *online vectorized recognition*. We then present a detailed implementation of the Chinese Calligraphy brush. To prove the feasibility of using the Chinese Calligraphy brush as a navigational tool, usability tests have been carried out against a conventional 3D spacemouse. The evaluation results are presented in Chapter 5.

4.2 Recognition

Before presenting an in-depth survey on recognition, it is important to outline current literature on PDA and handwriting input devices for VR applications.

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Poupyrev et al. [76] presented a Virtual Notepad where the users can take notes, annotate documents and input text using a pen in a fully immersive VR environment. This Virtual Notepad was then evaluated in a VRER (Virtual Reality Emergency Room) to take notes and to annotate medical images. Nam [77] presented a VR framework for using the PDA to aid in the design process of coloring buildings and its environments. Kukimoto et al. [78] also used the PDA for visualizing scientific data in the VE. The PDA is used both as a direct writing utensil as well as a touch screen for pre-drawing. Hartling et al. [79] proposed “Tweek”, a Java-based GUI, that enables controlling the VR application through a PDA.

Recognition is broadly categorized into either *on-line* or *off-line* and *bitmapped* or *vectorized* [80]. In this thesis we look into *online vectorized* recognition. In on-line recognition, the computer recognizes the writing while the user writes so the data is captured in real-time. The advantage of on-line recognition is that can capture dynamic data such as pen-tip movement, speed, pressure, number of strokes, stroke order, and the direction of the writing for each stroke. There is a close interaction with the user and it is easily adaptable since recognition is presented immediately and thus, any errors can also be corrected immediately. Generally for on-line recognition, vectorized recognition is used. In vectorized recognition, the characters and symbols are usually interpolated from the coordinate points that the input provides since it is possible to obtain the x, y coordinate positions of the pen movement as well as the dynamic information such as the pen speed, pressure, and sampling rates. This method can easily adapt to the user's different writing styles that is not possible with bitmap recognition.

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4.3 On-line Recognition

Although different classifications exist, generally, on-line recognition can be classified into the following 2 stages. [5]

Figure 19. General On-Line Recognition Stages

Stage 1: Preprocessing

In the preprocessing stage, raw data is captured from the pen tip movement on the digitizing tablet in a sequence of strokes. One stroke is defined as one sequence of the writing of the user from pen down to pen up. The data is preprocessed and 'cleaned up' in preparation for the next stage. Some of the preprocessing methods include:

- Dynamic data extraction
- Feature extraction
- Segmentation
- Smoothing
- Filtering
- Normalization
- Deskewing
- Dehooking

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Stage 2: Classification and Recognition

In this stage, the raw data that has been preprocessed in Stage 1 is classified and used for the various recognition methods for pattern recognition. Features that were extracted are matched to find the desired result. It is extremely difficult to categorize the matching methods and algorithms since so many different approaches and opinions exist, but many of the ones being widely implemented can be broadly categorized into statistical methods and structural analysis methods [80][81][82][83][84]. In statistical methods, various features including the starting positions and ending positions of the strokes are extracted and the features are tested against templates using statistical methods. These methods are designed to be trainable, hence being able to learn by example the new patterns while the user uses the system. In structural analysis methods, each character is classified by its stroke structures. Some major examples of the algorithms statistical matching methods use and the basic categories of structural matching are outlined below. In addition, some other examples are listed.

- Statistical Methods
 - Neural Networks
 - Fuzzy Logic
 - Hidden Markov Models
- Structural Analysis Methods
 - Contour Matching
 - Stroke Matching
 - Hierarchical Matching
- Other Methods
 - Curve Matching Methods
 - Syntactic Methods

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Many more methods not mentioned here exist and these categorizations can vary drastically according to the individual matching methods and preferences. Also, many methods use different combinations of the different algorithms and approaches for better and more efficient results. For example, Singh et al. [84] proposed a system for recognizing Chinese characters using fuzzy recognition. In their work, they first obtain the raw data through chain-coding and then extract the features through dominant point algorithm and obtain the primitive features. They then use a fuzzy membership function to calculate the degree of membership for each test pattern. It can be seen here that a variation of structural matching is performed before the statistical matching.

It is beyond the scope of this thesis to delve into the different categories of the specific recognition algorithms and methods outlined above. However, a more detailed look into specific examples of several preprocessing and structural matching methods that are more relevant to this thesis and research topic will be examined over the next 2 sections.

4.3.1 Preprocessing

In this stage, the x, y locations, writing speed, direction, and pressure of the user's pen movements are captured for processing. One approach is to capture and represent the raw data in a form of 'chain-codes'. Xue et al. [85] proposed an off-line character recognition method that uses dynamic programming to find the best match between 2 contour sequences of pseudo-stroke positions and directions. They used a method called 'chain-coding' to represent the binary image. Generally, a chain-code string is formally defined as a sequence of components $C = c_1, c_2, \dots, c_n$ where each component c_i is a tuple (x_i, y_i, d_i) . The x_i and y_i are the positional coordinates and d_i is the slope direction. By using the 'chains' of the components, the edges of an image can be encoded successfully. In Singh et al.'s [84] work, they also used 'chain-coding' to obtain the raw handwritten data before

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applying a dominant point algorithm and matching the results to 6 primitive features they defined. In their approach, they used a leave-one-out method for the cross validation in recognizing the Chinese characters. In the BoE (Back of Envelope) system developed by Gross et al. [86], stroke data from the tablet was captured as a stream of (x,y,p) data where x,y is the location coordinates and p is the pressure. They also used time-out duration as a factor to determine if the user has finished writing.

To implement segmentation of on-line freehand sketches, Qin et al. [87] used the drawing position, direction, speed, and acceleration information to establish fuzzy knowledge and infer the user's intentions. They observed that the drawing speed for each curve will increase, remain steady, and then decreases when a segmentation point is approached. Using this knowledge together with the fuzzy knowledge adaptive thresholds, corner points were detected. Similar works using the user's speed data have been undertaken by Calhoun et al. [88], in their trainable recognizer for multi-stroke symbols, and by Sezgin et al. [89] in their work for defining sketch-based interfaces. Calhoun et al. used the pen speed and curvature data to segment a stroke into its constituent lines or arcs. They examined the motion of the pen tip as the strokes were created and observed that it is natural for the user to slow down at the corners while drawing. Below is an example of drawing a typical square and its speed profile from their work.

Figure 20. Speed profile from drawing a typical square [88]

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Although chain-coding is often used as compact representations for off-line binary images, this approach is very flexible for representing the raw handwritten data whether it is off-line or in the case of this report, on-line. This data can then be successfully used for segmentation and feature extraction as seen in the examples above. In Section 4.3.2, a variation of this chain-code method is proposed.

4.3.1.1 Classification and Recognition Stage

Since so many different recognition methods exist, building a system that is able to process multiple recognition methods is very practical. Julia et al. [90] proposed algorithms for recognition and beautification used for graphic design applications. In their work, they used two kinds of methods for the recognition of on-line pen entries: delayed and early recognitions. Some simple strokes such as one stroke geometrical figures and a set of gestures were recognized in early recognition and more complex strokes were recognized in the delayed recognition. This modular method is very efficient since they complement each other's recognition methods. Similar work can be also seen in Alpaydin et al. [91]'s work. They proposed a multistage method called *cascading*. In their method, a sequence of classifiers are ordered in terms of complexity where more complicated recognition methods are carried out only when the simpler ones fail using a reject option. This type of recognition is advantageous in the sense that multiple recognition methods can be implemented where each classifier uses different learning algorithms or different representations of the same input data.

For the actual recognition methods, a more detailed look into Chinese recognition methods have been carried out due to the fact that the work presented here involves interacting with Chinese characters. Chinese characters comprise of strokes. They have a base set of characters called *radicals* in which the words are built on. There are around

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50,000 Chinese characters and the stroke count varies from 1 to more than 30 in one character. The average stroke count is 8~10. In Dang's [92] Appendix A of his dissertation work, he presents 10 fundamental strokes of the Chinese characters. He uses the different combinations and positioning of these 10 fundamental strokes to determine the different characters. Singh et al. [84] used 6 primitive features for matching the strokes after the features have been extracted. Example of fundamental strokes for the Chinese character is shown in Figure 21.

Figure 21. Example of Fundamental Strokes for Chinese Characters

4.3.2 Brush Interaction and Recognition

For the implementation, a board and a calligraphy brush are connected to an electromagnetic tracking system from Flock of Birds™ [93] by Ascension Technology. Figure 22 shows the basic setup of the board and the brush. [10] The top view of the physical setup shows the user (1) holding the brush (3) and the board (2) as well as the tracking system and emitter (4) and the screen (5). Two sensors are used for the brush and the board. Their movement is detected relative to the position of the emitter. In order to calculate the position of the board and the brush and to detect whether the user points at the screen or draws on the board, the position of the emitter, the position and dimension of the screen, the length of the brush and the dimension of the board must be known beforehand and cannot be changed while the application is running. This setup works well with any kind of screen. However, it is easier to use the brush to point at objects if the screen has a diameter of at least 70cm. We use back projection which allows for a sufficient big screen size and minimizes disturbances of the tracking system.

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The calligraphy brush and the board have virtual models as their counterparts which are displayed at all times while the user interacts with the brush and the board in the VR environment. The brush and the board also provide for physical haptic feedback. The virtual brush was modeled in Maya™ and then exported to the VRML97 format so that it can be imported with the appropriate OpenSG or VSC Loader. OpenSG is a Scenegraph-based rendering API for the representation of computer-generated scenes especially designed for Virtual Reality real-time applications. OpenSG and VSC are described in more detail in Chapter 5.

Figure 22. Calligraphy Brush Interaction Setup [5][8][10]

The following section describes in detail the system components for the brush recognition and interaction system.

4.3.2.1 System Components

The system component for the brush interaction which is presented next is the subcomponent *Interaction Devices* and *User Tracking/User Observation* in the run-time framework.

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Figure 23. Overall Framework : Interaction Devices/User Tracking/User Observation

The system component for the recognition system can be categorized into 3 parts: Online data, OpenSG/VSC, and Recognition. Figure 24 shows the framework for the system components and their relationships.

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Figure 24. Recognition System Framework and Components [10]

4.3.2.2 Online Data

Online data refers to all the data that the user inputs before the recognition is started or while it is running. For the input, the board and the calligraphy brush that are connected to the electromagnetic tracking system are used. Through this tracking system, the position and orientation of the brush is tracked. The tracked data are returned as a matrix using VSC (Scientific Visualization, Simulation, and Computation Library) as an

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interface to the tracking system. Other input options such as the mouse and keyboard can also be used. The mouse changes the position of the brush and commands on the menus and the keyboard input changes the settings that influence the behavior and appearance of the system.

4.3.2.3 OpenSG/VSC

In the component OpenSG/VSC, optical feedback for the user is realized through real-time rendering using OpenSG [94] and VSC. The virtual counterparts of the brush, the board, and paper textures are read in and are constantly shown on one part of the screen while the user writes. Since the user writes on a physical board with a brush but with no physical ink, the user has to refer to the screen to visually see what he/she is writing. To visually represent what is being captured from the users' inputs in real-time, an interaction test is performed. The interaction test is executed within an endlessly running loop. Since the tracking system is set up with the length of the brush and the board size, it is able to determine when an intersection occurs between the virtual model of the brush and the board. When an intersection occurs, the texture and deformation are updated. Changing the texture of the board is what visually simulates virtual ink being written on the virtual board. The texture of the board can be changed using different methods. It can either be changed by drawing stencils wherever an intersection occurs or by drawing lines from the previous intersection point to the current one. The line and stencil can either have a fixed width or variable widths depending on the deformation of the brush tip. To enhance the realistic effects of the brush, a deformable model based on a damped particle-spring system is applied to the brush tip. Deformation is updated whenever intersection occurs.

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4.3.2.4 Recognition

Recognition is where the characters or symbols that the user draws on the board are recognized into something more meaningful for interaction. The recognition system is broadly categorized into 3 steps [6][10]:

- i) Capturing of the raw data
- ii) Cascading recognition method
- iii) Interface to the VR system.

Step 1: Capturing of the Raw Data

In this first step, the basic class of the recognition component gets the data from the user's brush movements on the board. The data is captured at each intersection and this 'raw data' is saved as a 'chain-code' [7]. Chain-code is a chain of codes containing specific data. In the proposed system, each code element contains the (x, y) positions of the intersection, the time intervals of the intersections, and the pressure or the intersection depth of the brush [66]. Each recognition method inherits this raw data from this basic class for further processing in the next step.

Step 2: Cascading Recognition Method

In this step, a cascading recognition method is implemented where more than one recognition method can be used sequentially - one after the other, or in parallel - at the same time. The cascading recognition method contains all possible recognition methods that will be implemented. If more than one recognition method exists, the simplest one is started first. Only if the simplest ones fail due to various reasons, more complicated recognition methods will be started [10]. Alternatively, more than one recognition methods can be simultaneously started and run in parallel. Each recognition method is encapsulated in a class that inherits from the basic class from Step 1. This enables access

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to the chain code from each method. Since recognition methods can be run sequentially, it is also possible for recognition methods to inherit from other recognition methods. The characters and symbols to be detected by the system are stored in databases. Each recognition method has its own database and the databases can be classified according to the different characters and symbols and recognition approach [5].

The recognition system has been designed to be flexible and easily extendible. Different recognition methods can use different approaches to recognizing the character or the symbol. A Decision Maker is implemented so that it intelligently chooses the best recognition method(s) to use. The Decision Maker is part of the interfacing to the VR system.

Step 3: Interface to the VR System

In this step, a Decision Maker chooses the ideal recognition method only if there are more than one recognition method running and if the results from the different recognition methods are different. This decision is based on the *priorities* and *error weighting* each recognition method is assigned to. If one recognition method is more accurate than another, it gets assigned a higher priority. For error weighting, each recognition method returns a number that indicates the recognition rate in percentage. Even if a character or symbol is matched to database, depending on how identical the source and the target characteristics are, the recognition rates can differ. The Decision Maker selects the final results from the recognition methods and passes the recognized characters and/or symbols to the VR system.

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4.3.2.5 Basic Character and Symbol Set

So far 5 basic pictorial Chinese characters have been identified for recognition. These 5 characters were chosen for its meaning as well as its form. They are relatively easy to learn, even for users not familiar with the Chinese language since the strokes are minimal and their forms nicely represent the meaning of the words. Table 8 shows the 5 characters and their stroke composites.

人 [Ren : Person] : Toggle calling the Virtual Tour Guide					
人	=	丿	㇏		
日 [Ri : Sun] : To go outside the building					
日	=	丨	冂	—	—
中 [Zhong : Middle] : To go back into the building. Main					
中	=	丨	冂	—	丨
一 [Yi : One] : Storey 1					
一	=	一			
二 [Er : Two] : Storey 2					
二	=	一	一		

Table 8. Characters Identified for Recognition System

4.3.2.6 Navigating with the Chinese Calligraphy brush

The functionality of the brush has also been extended to be used as a navigational tool within the virtual environment to avoid the user having to change to another interaction device during the interaction experience [6][10]. This is carried out by pointing the brush

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onto predefined areas on the screen. A navigational cursor appears at the position where the visitor points to. Due to this simple navigation instrument, navigation is restricted to walking on the ground [7][10]. The left-right directions rotate the visitor either to the left or right inside the VE. Forward and backward movements are accomplished by pointing the brush to the top or bottom of the screen. The shape of the cursor is dependant on where the visitor points to. For example, if he/she points at the left side, the cursor turns into a left arrow. The cursor changes its shape to indicate if the visitor points at the intended side. The cursor can also be used to get additional information about an exhibit. Whenever the visitor points at an exhibit, the cursor changes its shape into a hand to indicate that the exhibit can be selected. Keeping the cursor above the exhibit for a predefined period of time triggers selection. After a selection, if the visitor is positioned in front of an exhibit and the Virtual Tour Guide appears and offers more information about the exhibit. Figure 25 shows examples of navigation of the brush and its corresponding cursors on the screen.

Figure 25. Navigation with the Brush [7]

For tracking the brush movements, a plane is defined that has the same size as the screen [66]. It is placed right in front of the screen. The setting is shown in Figure 26. The Figure also shows a ray that originates at the tip of the brush. It has the same direction as the roll axis of the brush. Whenever the visitor moves the brush, this ray is computed and intersected with the defined plane. The resulting intersection point is the new position of the cursor. Figure 26 also shows that the plane is divided into five partial areas, four at

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each edge of the plane and one in its center. After an intersection occurs the system determines in which partial area the intersection point is situated. If it is in one of the partial areas at one edge of the plane the shape of the cursor becomes an arrow that indicates the direction in which the visitor will move. If the intersection point is situated in the partial area in the center of the screen, the system checks if the visitor is pointing at a certain exhibit in the VE. For that purpose the bounding box of each exhibit that lies in the current field of view of the visitor is intersected with the ray. If an intersection occurs, the cursor changes into a hand to indicate that an exhibit can be selected. Since the Chinese Calligraphy brush has no button that the visitor can press to execute the action, navigational actions do not occur instantly. Fixing a button to the brush would degenerate the brush qualities so instead, the user has to keep the cursor within the defined area for a certain time period [6]. The area makes the system more tolerant so that the visitor does not have to hold the brush absolutely still. The correct time period is crucial since a large period will make the interaction with the system slow and a too short time period can trigger the system to move into the wrong direction while the visitor is still selecting an object [66].

Figure 26. Navigation with the Chinese Calligraphy brush

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4.4 Summary

This Chapter first presents the motivation behind selecting the Chinese Calligraphy brush as an interaction tool. As an attempt to bring culture closer to the users, a cultural object – the Chinese Calligraphy brush – has been selected as an interaction device. According to Bryson [11], the two driving requirements for the design process for VR are first, the virtual environment and its interface should be tailored to the task and second, stringent performance constraints must be met for the benefit of virtual reality to be realized. These 2 factors have been taken into consideration while further exploiting the idea of using the Chinese Calligraphy brush as an interaction tool. The tasks presented with the brush include writing very simple Chinese characters on an actual board. The users are faced with the challenge of writing Chinese characters and rewarded with the command execution. For a more seamless interaction and to eliminate the need for changing the interaction device during the VR visit, navigational functionalities have been added to the brush. Currently the brush's navigation is restricted to left/right/forward/backward. Tight performance constraints have been applied so the user does not have to spend much time getting used to the brush or get lost.

We then present an in-depth survey on recognition. As Chinese characters are stroke-based, our system is set up to recognize the basic strokes of the character that the users input. The recognition is carried out in 3 stages. First the raw data is captured through “chain-codes”. We then implement a cascading recognition method for identifying the inputted characters. Lastly, the characters are displayed on the screen for user feedback and the associated command is executed.

Navigation is triggered when the user points the brush at the screen. Initial internal tests showed that the recognition methods are robust and users do not need to be very accurate when writing on the board. The board and brush provide tangible

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cultural interface to the intangible VH environment. In Chapter 5, we present the prototype and the usability tests.

CHAPTER 5

PROTOTYPE

Figure 27. Prototype Screenshot

In this Chapter, the prototype of the Virtual Heritage application that has been developed as proof of concept is presented. The prototype is a fully running Virtual Reality application that incorporates the realistic 3D environment, the avatar, and the user interaction with the Chinese Calligraphy brush. The prototype is general and can be used for a variety of Virtual Heritage scenarios. The complete scenario such as the street, shophouses and exhibits are defined in a configuration file and can be changed or replaced without programming.

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The system configuration and software used for the prototype implementation is as follows:

- Dell Workstation PWS530
- CPU : 2.00 GHz
- 1 GIG RAM
- Microsoft Windows 2000 Platform
- Visual Studio 6.0

5.1 Introduction to VSC and OpenSG

5.1.1 VSC – Visualization Simulation Computation

VSC, which stands for Visualization Simulation & Computation, is a library that has been developed at and is currently being used by the Centre for Advanced Media Technology (CAMTech). It allows for fast development of Virtual Reality applications. It provides all the functionalities typically needed in VR applications. Although VSC is an X3D based VR system, it does not utilize the X3D specification to its maximum since X3D does not support many new concepts. As such, VSC's core extensions access OpenGL's parameters for advanced functionalities such as prelighting.

The functionalities utilized for the development of the prototype can be divided in the four groups - base, loader, input, and visual rendering. The first group contains basic functionality and types such as vectors and matrices and mathematical operations. The second group combines functions used to load 3D objects created in commercially available 3D modeling software and saved in various formats. The format of choice for this prototype was VRML97/X3D. The input-group combines functions that allow for the communication with input devices that are specific for VR. The prototype can be used with a conventional mouse and keyboard, a 3D spacemouse, or an electromagnetic tracking system. The latter was utilized to obtain the orientation and position of the

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Calligraphy brush and board. The fourth group combines all functions needed for the visual rendering of the complete 3D environment and the virtual avatar. Once the models that make up the 3D environment are loaded, VSC uses OpenSG [94] to render the complete scene.

In order to carry out development with VSC, each C++ class has to be derived from a VSC DataContainer. A DataContainer is a specialized class that incorporates methods for memory management, loading of settings from configuration files, and fields and routes. Fields and routes enable new classes to communicate with each other and with the existing VSC DataContainers that provide all the described functionality. Fields and routes is a concept known from VRML. Each VSC DataContainer can have a set of *fields*. Fields that belongs to different DataContainers can be connected with each other if they are of the same type. This connection is called a *route*. Once the connection is established, the value of the second field is automatically set to the value of the first field whenever the first field is changed.

```
#VRML V2.0 utf8
# VRML2.0 output created from Alias|Wavefront Maya

#|hallSideChair
Transform
{
  translation -227.300000 5.800000 75.900000
  rotation 0.000000 -1.000000 0.000000 1.570796
  scale 1.000000 1.000000 1.000000

  children
  [
    #|hallSideChair|chairBottomLeft
    Transform
    {
      translation 0.000000 0.000000 0.000000
      rotation 0.000000 0.000000 1.000000 0.000000
      scale 1.000000 1.000000 1.000000

      children
      [
        DEF _hallSideChair_chairBottomLeft_chairBottomLeftShape Shape
        {
          appearance DEF hallSideChair_final_Material__7SG1 Appearance
          {
            material Material
            {
              diffuseColor 1.00000 1.00000 1.00000
              transparency 0.00000
            }
            texture MultiTexture
            {
              mode
              [
                "DOTPRODUCT3"
```

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```

    "MODULATE_DIFFUSE"
    ""
  ]
  source
  [
    "FACTOR"
    ""
    ""
  ]

```

Figure 28. Sample VRML File of Object's Position/Transformation/Color/Material

The VSC DataContainers created for this prototype and their routing with each other and other components of the VSC library are described in section 5.3.

5.1.2 OpenSG

OpenSG [94] is a scene graph rendering system that can be used to create real-time graphics programs. It is comparable with other scene graphs such as Java3D[95] and offers typical graph nodes such as Groups, Transformations, Lights, Materials, and Geometries. The major difference is that it supports parallel processing and multi-threading enabling rendering that can be distributed across a cluster of machines and multiple displays that can be driven at the same time. OpenSG is Open Source and based on OpenGL.

5.1.3 VR System Comparison

One of the main factors for choosing CAMTech's VR system over other VR engines such as game engines and classic VRML and X3D engines lies in CAMTech's VR system's support for single and multi-screen setups running on single pipe (PC, Windows, Linux), multi-pipe (SGI Prism, Linux IA64) and cluster (PD, Linux) set ups. The prototype also needed specific extensions such as the Maya™ exporter for skin and bone system for the Virtual Tour Guide and the light maps for the VE which were only available at CAMTech. As scene graphs are used only for rendering, they need a complete VR system to allow for flexible configuration of I/O devices and the dynamics model. Other scene graphs

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such as OpenSceneGraph, Java3D and Performer do not have this support whereas OpenSG works hand in hand with VSC to provide rendering for interactive real-time applications. It was not feasible to use other VR systems since other VR systems such as Eon and OpenVRML require the developers to reinvent the wheel by recoding what is already inside their VSC for any customized functionalities such as multi-piping, multi-staging, particle systems, volume rendering, and H-ANIM support.

Porting the VR application to a VRML97 specification for other platforms as well as the web will definitely compensate many features such as the degree of realism including multi-texturing and lighting, stereoscopic output, and immersion. The 3D interface needs to also change to a web-based or portable 2D interface.

In the next sections, the *Scene Layout/Configuration* for the *Environment* will be presented.

Figure 29. Overall Framework : Configuration/Environment/Visualization

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5.2 Data Structure

The data structure where all static objects are stored that make up the 3D scene is called the “*world*”. The *world* consists of everything the user can see such as the street, shophouses, and the exhibits inside the shophouses.

One of the main goals of the prototype development was to make it as general and generic as possible. To achieve this goal, the scenario is set up so that it is not hard coded but can be specified in a configuration file following the VRML notation. The scenario is subdivided into elementary elements that can be configured and combined. The defined elements are street tile, house, room, level, stairs, and exhibit. Each element has a VRML-file assigned to it containing the appropriate 3D model and other data such as the position, orientation, dimension, and texture information.

The scene is made up of one or more street tiles. A street tile contains a set of houses and streets specified by paths that the Virtual Tour Guide can follow to move from one shophouse to another. A shophouse contains one or more levels and the information needed by the Virtual Tour Guide such as its location and the location of the doors inside the house. Each level has a set of one or more rooms and has stairs that connect two levels.

The following Figure 30 shows a simple configuration file that creates one street tile with one house that has one room, one level and two exhibits.

```
PROTO Silverplate
{
    VSCDHExhibit
    {
        id                "silverplate"
        geometryFilename  "Data/silverplate.wrl"
        location          70.3 10.5 30.4
        dimension         20.5 20.5 7.0
        orientation       90.0
    }
}

PROTO SilverwareRoom
{
    VSCDHRoom
    {
        geometryFilename  "Data/silverwareRoom.wrl"
        location          0.0 100.0 0.0
        dimension         500.0 500.0 300.0
    }
}
```

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```

        doors
        [
            VSCDHDoor
            {
                location 0.0 100.0 0.0
                status 1
            }
        ]

        exhibits
        [
            Silverplate
            {
            }
        ]
    ]
}

PROTO Stairs01
{
    VSCDHStairs
    {
        geometryFilename "Data/stairs01.wrl"
        location 200.0 400.0 0.0

        levels
        [
            0,
            1
        ]
    }
}

PROTO PeranakanBasement
{
    VSCDHLevel
    {
        geometryFilename "Data/peranakanBasement.wrl"
        level 0

        rooms
        [
            SilverwareRoom
            {
            }
        ]

        stairs
        [
            Stairs01
            {
            }
        ]
    }
}

PROTO PeranakanHouse
{
    VSCDHHouse
    {
        geometryFilename "Data/peranakanHouse.wrl"
        locationX 0.0 0.0 0.0
        door 0.0 100.0 0.0

        levels
        [
            PeranakanBasement
            {
            }
        ]
    }
}

PROTO STile01
{
    VSCDHStreetTile
    {
        geometryFilename "Data/stile01.wrl"
    }
}

```

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```

    row      0
    column   0
    dimension 1000.0 1000.0
    streetWidth 150.0

    paths
    [
        0,
        0,
        100.0,
        0.0
    ]

    houses
    [
        PeranakanHouse
        {
        }
    ]
}

world VSCDHWorld
{
    streetTiles
    [
        STile01
        {
        }
    ]
}
```

Figure 30. Configuration File

For each elementary element a VSC DataContainer was implemented. The configuration file shows that the appropriate VSC DataContainer for the House “*PeranakanHouse*” is called VSCDHHouse.

The prototype loads this configuration file and creates a data structure. The resulting data structure is always a tree with the *world* as the root node. The root node has Street tiles as children and each street tile in turn can have houses as children. The upper configuration file would cause the prototype to create the following data structure.

After creating the data structure, the prototype traverses it, loads each VRML model, and adds it under a new transformation node to the scene graph. The transformation node is used to adjust the position and orientation of the model according to the values in the configuration file.

By changing the configuration files and replacing the appropriate VRML models, a complete new scenario can be created without the need of programming a single line of code. Whole street sections and houses can be added or changed and exhibits can be

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added to rooms or completely rearranged. Configuration files can also be used to create scenes with different levels of detail by leaving out some of the objects or loading simpler VRML models. Once the models are created, only the file names have to be changed.

5.3 User Interaction

Another goal of the prototype is the evaluation of the user interface. It comprises of the Chinese Calligraphy brush and the Chinese character recognition, the navigation with the brush, the menus, and the Virtual Tour Guide. Similar to the data structure, all needed components were implemented as VSC DataContainer and interconnected by *fields* and *routes*. All components can access the *world* data structure. The following diagram gives an overview of the implemented DataContainers and their routing. The DataContainers are in boxes, and arrows visualize the routing. The labels at each arrow describe the data that is sent with the appropriate route.

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Figure 31. Overview of Data Containers

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5.3.1 DataContainer DHBrushInteraction / DataContainer DHCursorController

The VSC DataContainer “*DHBrushInteraction*” receives data of all the interaction devices. The VSC library provides the DataContainer that interface with different devices and can be routed to the newly created DataContainers. The VSC library sends the two routes “brushSensor” and “boardSensor” when the tracking system detects a movement of the Chinese calligraphy brush or board. “mouseData” is sent whenever the mouse is moved or one of its buttons is pressed. In a similar way, data from other input devices can be routed in order to extend *DHBrushInteraction*.

Based on the information from the brush and the board sensor, *DHBrushInteraction* decides whether the user writes on the board or points at the screen. If the user writes on the board, it calculates the current position of the tip of the brush on the board and passes it to the recognition. If the user points at the screen, it calculates the position on the screen and passes it to the cursor controller “*DHCursorController*” which shows the requested type of cursor at the position passed to it. If the cursor is above the navigation area, “*DHBrushInteraction*” passes the direction to move to the visitor.

5.3.2 DataContainer DHVisitor

“*DHVisitor*” stores the position and orientation of the user in the 3D scene. Whenever new direction data comes in, it updates the position of the user and passes it to the navigator.

5.3.3 DataContainer DHNavigator

“*DHNavigator*” controls the camera that is always at the position of the user. The camera determines which part of the 3D scene is rendered and simulates what the user sees in the virtual world. The result of *DHNavigator* is a matrix that is routed directly into the transformation node of the camera in the scene graph.

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5.3.4 DataContainer DHMenuController

When the cursor is above certain areas that function like buttons, the menu controller “*DHMenuController*” gets activated. It shows the requested menu and gets control over the cursor. Transfer of controller over the cursor is accomplished with two routes that pass cursor information to “*DHBrushInteraction*” and “*DHCursorController*”. Each menu that gets activated shows the requested data and can have other buttons that open up the sub menus. In some menus the user can make selections or activate commands. Information about these selections is passed to the knowledge controller “*DHKnowledgeController*”.

5.3.5 DataContainer DHRecognition

Another way of entering commands is by writing the appropriate Chinese characters with the brush. This is monitored by “*DHRecognition*”. It receives the position of each imprint the user makes and combines these imprints to strokes that make up all Chinese characters. The detected strokes are then compared and if a character is recognized, it is passed to the knowledge controller.

5.3.6 DataContainer DHKnowledgeController

All information on exhibits that can be shown in menus or that the Virtual Tour Guide tells the visitor is stored in “*DHKnowledgeController*”. The visitor can request information in menus or by writing a command. Therefore routes come in from “*DHMenuController*” and “*DHRecognition*”. It analyses the incoming commands and either passes them to the Virtual Tour Guide or shows the requested information by referring it to the media controller.

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5.3.7 DataContainer DHMediaController

“*DHMediaController*” is able to show different kinds of media such as text, images, music, and videos. It simply gets the data about the media and shows it.

5.3.8 DataContainer DHAvatarController

“*DHAvatarController*” controls the movement, facial expressions, and speech generation of the Virtual Tour Guide. Using the “avatarData” route, the “*DHKnowledgeController*” tells the Virtual Tour Guide on a high level what to do. An example might be “go to exhibit “silverplate” and tell information 3” in a coded form. Using path planning and the positions in the *world* data structure, the Virtual Tour Guide finds his way to the exhibit and activates its speech generation component to tell the requested information.

5.4 Menus

The Virtual Heritage application can run in full stereoscopic 3D. Windows and pop-up boxes provided by libraries of the operating system cannot be used because they are not suitable for stereoscopic display and can only be seen by one eye. Furthermore, the unique interaction device implemented here requires special selection methods. These restrictions have prompted us to develop our own menu hierarchy and elements [10].

Menus have been implemented to help the users navigate around the scene, make selections, and display requested information. Figure 32 shows a screenshot with the navigation menu at the bottom and an information menu on the upper righthand side of the screen. The navigation menu shows floor plans of the current room and the position of the user. It also shows the five Chinese characters that the user can write together with their command title and function. When the user moves the cursor above any of the characters, a sequence animation of how each character is written is displayed.

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Information menus display background information on the selected exhibits. Currently these menus contain images and text.

Figure 32. Information and Navigation Menu [10]

Each menu has a set of activation areas. Activation areas are basic menu elements from which more complex ones are derived. They pass a signal to the menu whenever the cursor is above them. They have been specially adapted for being used in conjunction with the brush. The signal is only sent to the system when the cursor is above the area for a specified time delay. Activation areas change their shape as soon as the cursor is above the area to send feedback to the user. They can also change their shape at different intervals to show either a sequence or indicate time delay [10].

One way of making menus suitable for stereoscopic output is to let them become a part of the 3D scene. Therefore, the menus and menu elements that have been implemented are textured planes placed in front of the camera. When the camera moves, the same transformation is applied to the menu planes so that they always stay in front of the camera. Since they are a part of the 3D scene, correct stereoscopic rendering of the menus is guaranteed [10].

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5.5 Example of a Virtual Heritage Scenario Visit

A sample scenario will be presented in this section. When the visitor first arrives at the screen, he/she will see Figure 33. Basically the visitor can use the Calligraphy brush to navigate around the scene in the North/South/East/West zones on the screen or call up the main menu by placing the brush on the red arrow.

Figure 33. Initial Screen with Brush Navigation

When the visitor calls up the main navigation menu, he/she will see the following.

Figure 34. Main Menu

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On the left, the floor plans for the 1st and 2nd storey are displayed. A red dot will indicate where the visitor is situated in the virtual scene at the current time. This is to help the visitors orient themselves in the virtual scene.

On the right, the 5 Chinese characters are displayed. When the visitor places the brush on top of one character, he/she will see the sequence of how the character is written in an animation. When the cursor changes on the selected character, the command will be executed. The user can also pick up the board and start writing the commands with the brush to execute the specific command.

Figure 35. Sequence for YI = ONE

The user can select any of the exhibits that are displayed in the shophouse. When the user places the brush on top of an exhibit for a couple of seconds, the description of the selected exhibit will appear on the screen. The user has the option to close this description by placing the brush on the arrow of the description window.

Figure 36. Different Combinations of Menu and Object Description Displays

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Through this navigational menu and the integration of the brush as a writing tool and as a navigational tool, the interaction is made simple with very few steps to achieve the desired results. The Virtual Tour Guide shows up every time an exhibit is selected or the user can manually select the Virtual Tour Guide through the main menu.

5.6 User Evaluation

To test the feasibility of the brush as a navigational tool, a testbed was set up to evaluate the Chinese Calligraphy Brush against the 3D spacemouse. The users were given 3 tasks to perform both with the Chinese Calligraphy Brush and the 3D spacemouse. After a set of tasks were complete, the users were given a questionnaire which they had to fill out for both the Chinese Calligraphy Brush and the 3D spacemouse.

5.6.1. Test Environment and Tasks

The test environment was set up with one shophouse, the surrounding environment and the static Virtual Tour Guide in front of the shophouse. Each user was given 3 tasks to complete in 2 sets - one set for the 3D spacemouse and one set for the Chinese Calligraphy brush.

Aim : To warm up the user and to test navigation to default position

Task 1: Stand in front of the Virtual Tour Guide

Aim : To test orientation control

Task 2: Walk around the shophouse and come back to the Virtual Tour Guide and stop

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Aim : To test higher degree of navigational control

Task 3: Walk into the shophouse then walk out of the shophouse using the five-feet walkway

With this 3 tasks completed with both the Chinese Calligraphy brush and the 3D spacemouse, the users were given the questionnaire they were asked to fill out. The results are presented next.

Figure 37. User Evaluation

5.6.2. Survey Demographics and Questionnaire Results

A total of 26 samples were taken. They were a mix of Nanyang Technological University student and staff. 80% of the samples were male and 50% in the age group 25-30. It is important to note that 54.2% of the users have had previous experience in navigating Virtual Environments. An overview of the survey sample results are presented below.

Chinese Calligraphy Brush		
1. What is your age group?		
20-25	<div></div> 33.3%	(8)
25-30	<div></div> 50.0%	(12)

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30-35	<div><div></div></div> 12.5%	(3)				
35-40	<div><div></div></div> 4.2%	(1)				
40-45		(0)				
45-50		(0)				
TOTAL	<div><div></div></div> 100.0%	24				
2. What is your gender?						
Female	<div><div></div></div> 20.8%	(5)				
Male	<div><div></div></div> 79.2%	(19)				
TOTAL	<div><div></div></div> 100.0%	24				
3. Do you have experience in navigating in Virtual Environments?						
Yes	<div><div></div></div> 54.2%	(13)				
No	<div><div></div></div> 45.8%	(11)				
TOTAL	<div><div></div></div> 100.0%	24				
4. Do you have experience with a Chinese Calligraphy brush in general?						
Yes	<div><div></div></div> 41.7%	(10)				
No	<div><div></div></div> 50.0%	(12)				
TOTAL	<div><div></div></div> 91.7%	24				
5. What do you think of using a Chinese Calligraphy brush as a writing and navigational tool?						
Quite innovative	<div><div></div></div> 79.2%	(19)				
Not a good idea	<div><div></div></div> 16.7%	(4)				
TOTAL	<div><div></div></div> 95.8%	24				
6. Do you think the Chinese Calligraphy brush enhances the Virtual Heritage experience compared to a conventional spacemouse?						
Yes it enhances the experience	<div><div></div></div> 50.0%	(12)				
No it doesn't enhance the experience	<div><div></div></div> 41.7%	(10)				
TOTAL	<div><div></div></div> 91.7%	24				
7. On a scale from 1 to 5, is it easy or difficult to navigate with a Chinese Calligraphy Brush?						
	Average Rank					
	1	2	3	4	5	
1 – Quite easy 2 – Easy 3-Normal 4-Difficult 5-Very Difficult	<div><div></div></div>					(2.3)
8. How long did it take you to get familiar to using the Chinese Calligraphy Brush?						
Less than 3 minutes	<div><div></div></div> 79.2%					(19)
Less than 5 minutes	<div><div></div></div> 16.7%					(4)
More than 5 minutes	<div><div></div></div> 4.2%					(1)
TOTAL	<div><div></div></div> 100.0%					24
9. Was it easier to navigate with the 3D spacemouse or with the Chinese Calligraphy brush?						
3D spacemouse was easier	<div><div></div></div> 25.0%					(6)
Chinese Calligraphy Brush was easier	<div><div></div></div> 75.0%					(18)
TOTAL	<div><div></div></div> 100.0%					24
10. Do you think props such as flashlights or Chinese Calligraphy Brush should be used according to the specific Virtual Environment?						
Yes, props should be used	<div><div></div></div> 75.0%					(18)
No, conventional mouse is OK	<div><div></div></div> 20.8%					(5)
TOTAL	<div><div></div></div> 95.8%					24
11. What are the limitations you encountered using the Chinese Calligraphy brush as a navigational tool?						
#	Response					
1	A bit slow, no acceleration, low accuracy					
1	Angle limited					

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1	Currently only two dimensional movements are allowed
1	Does not have as many degrees of freedom as the 3D spacemouse
1	I cannot control the navigation speed
1	Intuitively I don't understand how Chinese Calligraphy brush can help the navigation
1	Limited with one direction at on point of time
1	Look up and down
1	More directions may be better
1	Movement of acceleration should be present
1	Moving it to the bars, thus time consumption
1	No button
1	No height variation
1	Not so natural
1	Only be able to move in 1 direction at a time
1	Only have 4 direction navigation, lack of increasing speed after some time
1	The navigation freedom is limited. Speed can not be controlled. Response is delayed a bit.
1	The way I hold the brush is not how calligraphers hold it. The brush can be changed to just a pointer.
1	Too limited orientation and uncontrollable speed
1	Too slow
1	You have to do big movement with your arm, limited degrees of freedom
1	Zoom in and out
12. Lastly, what are your thoughts on showcasing heritage in a Virtual Reality environment?	
#	Response
1	A more natural way of control
1	Good
3	Good idea
1	Good idea, accessible for everybody, protection of the real heritage site/object
1	Great
1	Great! Very impressive
1	Helpful for preservation and learning
1	Innovative interactive tools can combine more the real world with the virtual world.
1	Innovative. Unable to visit such a place in real world anymore.
1	Interesting
1	It might be easier if the brush can "touch" the screen. And the pressure can be used delicately as information to control the "forward" and "backward" direction
1	It's a good idea
1	It's good. Mix and match.
1	It's interesting. However the use of a Chinese Calligraphy Brush is not fully justified. Anything else like a "magic wand" can replace this idea.
1	It's ok
1	New innovative way. More interaction with the environment. A VR env can also provide more informative stuff.
1	No thoughts
1	On the heritage point of view, yes
1	Quite good avoiding damage of visitors and it is convenient for people all over the world.
1	Spacemouse is harder for layman to pick up
1	VR is ideal for showcasing heritage

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3D SPACEMOUSE						
13. Have you used a 3D spacemouse before?						
Yes	29.2%					(7)
No	66.7%					(16)
TOTAL	95.8%					24
14. On a scale from 1 to 5, is it easy or difficult to navigate with a 3D spacemouse?						
	Average Rank					
	1	2	3	4	5	
1 – Quite easy 2 – Easy 3-Normal 4-Difficult 5-Very Difficult	(3.3)					
15. How long did it take you to get familiar to using the spacemouse?						
Less than 3 minutes	41.7%					(10)
Less than 5 minutes	41.7%					(10)
More than 5 minutes	12.5%					(3)
TOTAL	95.8%					24
16. What are the limitations you encountered using the 3D spacemouse as a navigational tool?						
#	Response					
1	Due to the degree of freedom, you tend to navigate too fast					
1	Hard to use					
1	It's not easy to control. Training is required to use it as well.					
1	Left – right orientation while moving parallel					
1	Natural but easy to get lost					
1	Need to practice to get the action work together					
1	Need to set to a lower max value for speed, so it would be easier to control					
1	No limitations; you just need to get the feeling for the tool					
1	None					
1	Nothing except it's too sensitive					
1	Sensitivity of the mouse					
1	Sensitivity will sometimes cause user to go in undesired direction (unexpected tilting)					
1	Spacemouse navigation is too sensitive. Hard for non-professional to pick up					
3	Too sensitive					
1	Too sensitive – takes a little longer to get used to					
1	Too sensitive to control					
1	Too sensitive and you cannot that you only move in one direction.					
1	Too sensitive, often causes tilting which I don't want					
1	Very sensitive					

Table 9. 3D Spacemouse vs. Chinese Calligraphy Brush Questionnaire Results

5.6.3. Evaluation

From the results of the questionnaire, it can be derived that close to 80% of the users thought it was quite innovative to use the Chinese Calligraphy brush as a writing and navigational tool even though only 40% had experience in using a Chinese Calligraphy brush. 50% of the users thought using the Chinese Calligraphy brush actually enhances the Virtual Heritage experience and it took most users less than 3 minutes to become

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familiar with the interface. The difficulty level was average compared to the 3D spacemouse which the users ranked 'difficult'. Many users took on average 3 to 5 minutes to get used to the 3D spacemouse. Naturally, 75% of the users thought it was easier to navigate with the Chinese Calligraphy brush compared to the 3D spacemouse.

Users were very positive to the question on whether props should be used for interaction within VEs as well as using VR for showcasing cultural heritage.

The biggest limitation users faced using the Chinese Calligraphy brush was the limited degrees of freedom and the speed. On the other hand, the users found the 3D spacemouse too sensitive and many users lost their orientation in the VE.

These limitations will be taken into consideration to help improve the interaction interface and functionality of the Chinese Calligraphy brush.

5.7 Summary

This Chapter introduces VSC and OpenSG, CAMTech's internal VR system that is used to develop and run the prototype on stereoscopic display. It then presents the detailed implementation of the prototype as proof of concept for the applicability of the proposed framework. The prototype is a fully running VH application that incorporates the high-quality 3D environment, Virtual Tour Guide, and the user interaction with the Chinese Calligraphy brush. The data structure shows that the VH application is indeed generic and can be applied to a variety of VH scenarios by simply updating the configuration file. An actual screen by screen Virtual Heritage scenario visit is simulated focusing on the interaction through the GUI. Lastly, user evaluation on the feasibility of using a Chinese Calligraphy brush as a navigational tool is conducted. The evaluation is tested against a conventional 3D spacemouse. Overall, users thought using the Chinese Calligraphy brush as an interaction tool was quite innovative and took less time learning to use the brush than the 3D spacemouse. The majority of the users liked the idea of using props for VR

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environments and thought VR was a very good medium for presenting heritage. The next Chapter will conclude and present future work.

CHAPTER 6

SUMMARY, CONTRIBUTIONS AND FUTURE WORK

6.1 Summary

With the ever rising need to preserve and restore culture world-wide, Virtual Reality is fast becoming an alternative to reconstructing and presenting cultural heritage to the world through immersive and interactive VR site visits. Limitless possibilities in VR call for innovative interaction techniques and many VR applications are taking advantage of using everyday life objects and converting them into interaction devices. VR proves to be an ideal environment for providing hands-on learning environments and have been used for training and education for decades.

In this thesis, we survey the current status of using VR for reconstructing cultural heritage including interaction methods employed by other research groups. It is shown that no concrete workflow for generating real-time VH applications is presented. Realizing a need for a generic and modular workflow, we propose a framework for generating real-time VH applications. To prove the applicability of the framework, we have reconstructed a fully immersive 3D Virtual Heritage application on the Peranakans and their culture using Virtual Reality technologies. A Virtual Tour Guide and a Chinese Calligraphy

CHAPTER 6 SUMMARY, CONTRIBUTIONS AND FUTURE WORK

brush were selected for the interface between the user and the VH scenario. In Chapter 5, a prototype of the Virtual Heritage application on the Peranakans is presented. Through the implementation of the prototype, it is shown that the framework is easily configurable and the content associated with the Heritage application can be dynamically loaded. The entire content was created from a reusable library of objects as shown in Chapter 4. The implementation of a Calligraphy brush presented in Chapter 5 also proves to blend well into the heritage scenario and by extending the capabilities of the brush to not just a writing tool but also as a navigation tool, and the need to change interaction devices is eliminated for a seamless VR experience.

6.1.1 Demonstrated Results

In Chapter 5, we present the usability test on the Chinese Calligraphy brush. The survey's goal was to found out users' opinions on using VR for cultural heritage, using props for interaction, and the feasibility of using a Chinese Calligraphy brush as a navigational tool. The brush was tested against a conventional 3D spacemouse.

The demographic of the users who partook survey were 80% male and the majority in the age group 20 – 30. 54% of the users had previous experience with VEs.

Overall many users thought using VR for cultural heritage was innovative and a great idea for showcasing and preserving heritage. On the question of using props for VR applications, 75% of the respondents thought that props should be used over a conventional 3D spacemouse. 80% of the users also thought using the Chinese Calligraphy as writing and navigational tool was quite innovative even though only 40% actually had any previous experience using a Chinese Calligraphy brush. 75% thought using the Chinese Calligraphy brush was easier than the 3D spacemouse although many complained of the slow speed and the lack of freedom. On the flip side, almost everyone thought the 3D spacemouse was too sensitive and was very easy to get lost in the VE.

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The survey showed that using the Chinese Calligraphy brush as an interaction tool generated positive response and users are open to accepting new and innovative ways of interacting with the VE.

6.2 Contributions

6.2.1 Preservation of Cultural Heritage

One of the main contributions of this thesis is the preservation of cultural heritage.

As this was one of the main motivations, we selected a Singapore-specific heritage model – the Peranakans. Singapore is a diverse country with many different ethnicities cohabiting in a small area. It has a very rich culture that is unlike any other as the mixture of different cultures and ethnicities have created its own identity. The Peranakans are a prime example of this unique Singaporean identity. The Peranakans, also known as the Straits-Chinese, are descendants of an early Chinese community that settled in the Malay Archipelago since the 17th century. To preserve a piece of the Peranakan culture, we have reconstructed a setting from the early 1900s – including the shophouse, Peranakan avatar, and cultural artifacts – through VR technology. A prototype of a Virtual museum has been implemented and can be explored on a large-scale projection screen capable of stereoscopic output. We have succeeded in bringing culture one step closer to the public through the use of VR technology. In future, we hope to showcase this application in museums for tourists and locals alike.

6.2.2 Streamline Workflow

The workflow for generating VH applications has been streamlined.

A framework for generating real-time VH applications was proposed and its applicability was proven through the implementation of the prototype. The framework enabled us to identify the different workpackages and the modular components of a generic VH

CHAPTER 6 SUMMARY, CONTRIBUTIONS AND FUTURE WORK

application. Thus, the proposed framework supports different types of heritage content and interaction devices. This is shown through the usability test where the interaction device can be easily changed from the Chinese Calligraphy brush to the 3D spacemouse.

6.2.3 Intuitive Interaction

A new interaction device using a cultural heritage object is introduced. By incorporating a Chinese Calligraphy brush as an interaction tool, the interaction dynamic between the user and the VH scenario changes from being purely navigational to actually experiencing culture through the object in hand. By giving the users specific tasks to perform using the Chinese Calligraphy brush, (i.e. write simple Chinese characters, navigate and select artifacts) the users become active participants of the VE creating a truly “learning-by-doing” scenario. The feasibility of using a Chinese Calligraphy brush was proven to be innovative through the usability test presented in Chapter 5.

Although the Virtual Tour Guide has been implemented for maximum flexibility for dynamic content creation, the Virtual Tour Guide presented in this thesis has limited behaviors and responses. The behaviors are more goal-driven where the actions are tied into the user’s requests. To enhance the believability of the Virtual Tour Guide, it is important to display not just goal-driven behaviors but also more subliminal behaviors that aren’t always goal-driven. In the next section, future direction of this work is discussed.

6.3 Future Work

To successfully build *believable* autonomous avatars that are more life-like, they need to also display personalities, emotions, moods, attitudes, and individuality through their behavior. These behaviors should go one step deeper and be able to display the subtle

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dynamics and even subliminal behavior through gestures and body language that is not always goal-driven. An avatar is believable if one can infer the emotional or mental state of the avatar just by observing its behavior [96]. Personality is generally considered a crucial feature to increase an agent or avatar more life-like since personality has a strong influence on emotion expression, social behavior, and decision-making [97][98]. Personality is a pattern of behavioral, temperamental, emotional, and mental traits that distinguish people from one another and the way one perceives, acts, and reacts is influenced by one's personality [96]. On the other hand, the presence of emotion does not create individuality in people since everyone reacts with different emotions even to the same situation and this emotional reaction is dependant on their personalities. These personalities, emotions and autonomous behaviors, intelligence, interactions, and reasoning can be employed through behavioral animation [62]. In behavioral animation, a set of rules are specified for a character and the character is able to animate based on its own response to environmental stimuli and its own set of internal motivations. One of the pioneering work on behavioral animation is from Reynolds [99] and his model for animating flock behavior in birds. In his system, each bird was given a set of rules that would enable it to engage in animation mimicking the way real birds flock together. Behavior animation can be categorized into 2 levels – lower level tools which quickly react to the environment and higher level tools that plan complex tasks or execute scripts. In the next phase of the research work, a sub-system framework for the automatic generation of subtle behavior for virtual avatars will be developed and implemented. The framework should be easily customizable for different types of avatars for the various VR applications. The suggested sub-system framework is a further implementation of the subcomponent *Behavior Model*. The sub-system framework is shown in Figure 39.

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Figure 38. Overall Framework : Behavior Model

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Figure 39. Subtle Behavior Generation Framework

In order to develop this framework, the first steps are to take a deeper look into the different psychological theories for personality and emotions and also look into movement analysis theories and physically based animation for the generation of the gestural movements in the virtual avatar. Further research has to be carried out in developing the rule bases for generating the personalities and emotions and correctly mapping the rule base to the gestural movements of the virtual avatar. The major challenge and goal is to be able to successfully generate subtle behaviors of the avatar that not only portrays emotions such as happiness or frustration, but also give individuality to the virtual avatar through different personalities. The existing avatar state

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has to be factored to generate unique subtle behaviors where each scenario can generate a different behavior.

Furthermore, other factors that affect the human behaviors such as culture and physical location have to be identified. Culture is an important factor since different cultures display different types of behaviors. This can be extended to the Peranakan culture and Peranakan-specific gestures and behaviors. The subtle actions that are generated should be easily blendable into higher levels of behavioral actions. These factors will serve as the foundation to build a framework for the generation of subtle behavior. The Virtual Tour Guide also needs to develop senses to perceive the environment around him and the animation library will be extended by developing and adding more natural facial expressions and locomotion.

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APPENDIX A: MATERIAL CULTURE OBJECT LIBRARY

Category	Item	Image	Description	
Furniture	Armchair		Type	Chair
			Year	1870-1910
			Usage	An English-style teakwood chair. Such chairs were never intended to be dining chairs, but rather, side chairs.
	Cabinet		Type	Cabinet
			Year	Between 1928 and 1939
			Usage	A cabinet incorporating an architectural façade of European inspiration and traditional Chinese art motifs.
	Chair		Type	Chair
			Year	1870-1910
			Usage	An English-style teakwood chair.
	Dining Table		Type	Dining Table
			Year	1870-1910
			Usage	The long dining table (or tok panjang) is a reproduction based on an original invention of the Victorian era.
	Dressing Table		Type	Dressing Table
			Year	1915 – 1920
			Usage	A type of bridal furniture.
	Hall Chair		Type	Hall Stool
			Year	19 th Century
			Usage	A stool that is placed alongside the tea table in the hall area.
	Hallside Chair		Type	Hall Side Chair
			Year	19 th Century
			Usage	Blackwood armchair of the type, which dispenses with the use of figured marble slabs and mother-of-pearl inlays.
	Hallside Table		Type	Hall Side Table
			Year	19 th Century
			Usage	A small table that is normally placed in between 2 armchairs at the side of the hall.

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	Hall Table		Type	Hall Table
			Year	19 th Century
			Usage	The centre floor space of the reception hall is normally taken up by this circular tea table.
	Reclining Chair		Type	Chair
			Year	-
			Usage	A reclining chair
	Wardrobe		Type	Wardrobe
			Year	1920-1940
			Usage	A wardrobe for hanging garments and apparel of various types.
	Washstand		Type	Washstand
			Year	Late 19 th Century/ early 20 th Century
			Usage	Used as a bridal washstand
Ceramics	Blue White Spoon		Type	Spoon
			Year	19 th Century/ 20 th Century
			Usage	Used for dining purposes
	Dark Green Teapot		Type	Dark green ground ware
			Year	Late 19 th Century
			Usage	Used to hold tea
	Globular Body Vase		Type	Vase
			Year	Late 19 th Century
			Usage	Placed on the ancestral altar-table
	Indigo Wine Warmers		Type	Indigo blue ware
			Year	unknown
			Usage	To keep wine warm
	Jade Baluster-shaped Spittoon		Type	Spittoon
			Year	Late 19 th /Early 20 th Century
			Usage	To hold spitted, chewed sireh leaves
	Joss Stick Holder		Type	Altar ware
			Year	1875-1908
			Usage	To contain unused joss sticks used for praying to ancestors or Gods
	Large Offering Dish		Type	Dish
			Year	
			Usage	Only for making religious offerings
	Lime Green Vase		Type	Lime green ground ware
			Year	1875-1908
			Usage	unknown
	Phoenix Kat-Mau		Type	Kat-mau
			Year	Huang-hsu period
			Usage	Used for storing steam bird's nest soup or boiled herbs
	Phoenix Peony Tea Tray		Type	Tea tray
			Year	Late 19 th century or 20 th century

APPENDIX A: MATERIAL CULTURE OBJECT LIBRARY

	Pink Brown Coffee Cup		Usage	Used to hold ceremonial cups of tea in Chinese wedding ceremonies
			Type	Pink and Brown Ground Ware
			Year	1912-1949 Republican mark and period
			Usage	Serving coffee
	Pink Green Kamcheng		Type	Kamcheng Pot (Covered pot with two side handles)
			Year	Early 20 th Century
			Usage	"Ginger jars". For storing boiled water or serves as soup-tureens
	Pink Green Steamer		Type	Pink green ware
			Year	Early 20 th Century
			Usage	Commonly to steam food with medical herbs.
	Pink Stem Dish		Type	Ritual ware
			Year	1875-1908
			Usage	Used for holding offerings
	Powder Blue Cricket Box		Type	Nyonya ware (cricket box)
			Year	1875-1908
			Usage	Traditionally used to keep crickets that were captured. Most collectors regard these so-called cricket boxes as soap boxes
	Quatrefoil Phoenix Peony Tea Tray		Type	Tea-tray
			Year	late 19 th century/ 20 th century
			Usage	Used to hold ceremonial cups of tea in Chinese wedding ceremonies
	Rose Pink Teng-kat		Type	Teng-kat or tiered food-container
			Year	Tung Chih period
			Usage	Used to contain food for each level
	Rose Yellow Ground Offering Dish		Type	Offering Dish
			Year	Late 19 th /Early 20 th Century
			Usage	Used during Chinese New Year
	Small Kuan-shaped Spittoon		Type	Spittoon
			Year	Late 19 th /Early 20 th Century
			Usage	To hold chewed sireh leaves with sliver-thin slices of areca nuts, gambier and lime
	Wedding Basin		Type	Ceremonial Bridal Basin
			Year	1875-1908
			Usage	Used during weddings or placed on the wash basin
	White Teacup		Type	Teacup
			Year	Tun Chih period

APPENDIX A: MATERIAL CULTURE OBJECT LIBRARY

		Usage	Used to hold tea
	Yinxing Teapot		Type	Stoneware teapot
			Year	Early 20 th Century
			Usage	Used to contain tea
Shophouse	Shophouse
Silverware	Bridal Buntai Pelok		Type	Bridal accessory
			Year	unsure
			Usage	Used to decorate the bridal bolster ends
	Candle Stand		Type	Candle Stand
			Year	Late 19th century to early 1900s
			Usage	Used to hold candles upright
	Oval Soup Dish		Type	Soup dish
			Year	Malacca, late 1800s
			Usage	Used to contain soup
	Pillow Plates Johore		Type	Pillow Plates from Johore
			Year	unsure
			Usage	Silver plates for the opposite ends of pillows and bolsters
	Pillow Plates Malacca		Type	Pillow plates from Malacca.
			Year	Late 1800s~Early 1930s
			Usage	Silver plates for the opposite ends of pillows and bolsters
	Silver Kamcheng Pot		Type	Pot
			Year	Late 19th Century
			Usage	Such kamcheng pots maybe used to hold soup on the dinner table
	Sireh box or Tempat Sireh		Type	Box
			Year	unknown
			Usage	Used to hold the shears used to slice the betel nuts, lime, and cup
	Sireh Globular Casket		Type	Globular Casket
			Year	Late 1800s~Early 1900s
			Usage	Keep shredded tobacco leaves, sliced betel nut or gambier and cloves
	Sireh Cup		Type	Cup
			Year	Late 1800s~Early 1900s
			Usage	Used to hold the gambier and cloves
	Betel-nut Cutter		Type	Cutter
			Year	Late 1800s~ Early 1900s

APPENDIX A: MATERIAL CULTURE OBJECT LIBRARY

		Usage	Nut Cutter, part of Sireh Set
	Cylindrical Container with Mixing Spoon		Type	Container,
			Year	Late 1800s~ early 1900s
			Usage	Used to hold lime, part of Sireh Set
	Wedding Tea Tray		Type	Tray
			Year	Unknown
			Usage	Part of Wedding Tea Set
	Wedding Teacup		Type	Teacup
			Year	unknown
			Usage	Part of the Wedding Tea Set
	Wedding Teapot		Type	Teapot
			Year	unknown
			Usage	Used for weddings
	Wine Ewer		Type	Wine Ewer
			Year	Late 19th century
			Usage	Used to hold wine
Embroidery	Alter Cloth		Type	Alter Cloth
			Year	Late 19th century
			Usage	This rich and gorgeously embroidered altar hanging cloth, was obviously intended for Strait Chinese wedding ceremonies
	Beaded Handbag		Type	Handbag
			Year	Late 19 th to Early 20 th Century
			Usage	Beaded handbag executed by threading
	Beaded Vase		Type	Vase
			Year	Unknown
			Usage	One of the many fineries of the traditional Straits Chinese that were to be included in the bridal chamber
	Black Slippers		Type	Slipper
			Year	Unknown
			Usage	A type of footwear
	Rectangular Silk Panel		Type	Silk Panel
			Year	Unknown
			Usage	Unknown
	Red Slippers		Type	Slipper
			Year	Unknown
			Usage	A type of footwear
	Round Table Cover		Type	Table Cover
			Year	Late 19 th / Early 20 th Century

APPENDIX A: MATERIAL CULTURE OBJECT LIBRARY

		Usage	Acts as a round table cover
	Table Mat		Type	Table Mat
			Year	Late 19 th / Early 20 th Century
			Usage	Serves as a mat for dishes on a dining table

APPENDIX B: LIST OF PUBLICATIONS

AUTHOR LISTING

- Meehae Song : Main author for all publications. She is responsible from the conceptualization to the implementation of the presented Virtual Heritage application including 3D modelling, Virtual Tour Guide generation and Calligraphy Brush implementation.
- Thomas Elias : Co-author for 6 publications. He was brought onto the project to assist in the backend implementation for connecting the Virtual Heritage application to the real-time system (OpenGL & VSC). This was part of an internal CAMTech project he was assigned to and has not published or carried out graduate work on this topic.
- Ivan Martinovic : Co-author for 2 publications. He worked on the non-linear storytelling component of the Virtual Heritage application. This is a separate component and is not included in the scope of the presented thesis.

Dr. Wolfgang Mueller-Wittig : Director of CAMTech and Thesis Supervisor.

Dr. Tony K.Y. Chan : Supervisor (retired)

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Reconstructing Peranakan Identities through Digital Heritage

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Abstract

With the advent of technological developments in Virtual Reality (VR) and the abundant content and need for the preservation and conservation for cultural heritage, there has been an explosion of Digital Heritage projects world-wide. Virtual Reality technology provides an important educational tool to recreate historical content in an immersive high-quality 3D environment where the user can enter and explore the virtual representation in real-time. It also provides intuitive interaction techniques for the user adding to the enhanced educational value and experience they were never exposed to before. We have chosen to utilize this VR technology to present the historical content of the Peranakans specific to the Singapore region. We will first generate a virtual scenario and then explore and realize innovative and intuitive interaction and navigation techniques specific to our content. Finally, we will present early results from the developments and implementations carried out thus far.

Keywords : Digital Heritage, Virtual Reality, Interaction, Peranakan, Calligraphy Brush

1. Introduction

Singapore is a diverse city-country with many different ethnic groups living together. It has a very rich culture that is a mixture of different ethnicities with its own unique identity. To better understand the Singaporean history, we cannot dismiss the impact of the Peranakans (which in Malay means 'born here'), also known as the Straits-Chinese. A Peranakan man is called a *Baba* while the ladies are known as *Nyonya*. The Peranakans are descendants of an early Chinese community that settled in the Malay archipelago at least since the 17th century [1]. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the indigenous Malay since the Chinese women were not allowed to leave the country until the 19th century. This unique community developed distinct customs, cuisine and even their own language, as they blended Chinese and Malay ways of life to form a new and rich culture adding another dimension to the Singaporean society. They played a key role in bringing Malaysia and Singapore to independence [2].

We have selected the Peranakans as our topic for cultural heritage project because, as mentioned above, the Peranakans are an important part of Singapore's history and little work has been carried out in the digital heritage realm to recreate their identities as of yet.

1.1 Virtual Reality for Cultural Heritage

Using Virtual Reality technology for recreating cultural heritage has become increasingly popular over the last few years due to the following reasons. We can digitally recreate fully immersive environments of historical heritage objects and environments covering all aspects of cultural heritage ranging from archaeology, architecture, to ceramics where history is presented to the public who now have the possibility to experience cultural heritage in new forms. Many historical content that has been lost or destroyed over time can be recreated for the conservation, preservation, and interpretation of our cultural and natural history [7] world-wide. The beauty of Virtual Reality lies in the fact that not only can we create fully immersive 3D environments that can be entered and viewed in real-time, we can also provide innovative interaction techniques where the users are able to directly interact within these environments. This is an

important aspect to interactivity since it increases the curiosity of the user and at the same time aides the understanding of the historical and cultural content by presenting the user the ‘learning-by-doing’ scenario.

In our project, we will be presenting the Peranakan digital heritage environment by focusing on the following aspects. We have put our main focus on the audience and the visitors that will be visiting our cultural site. Therefore, intuitive user interaction is key. To achieve this goal, we have put special attention on creating attractive high-quality 3D models capable of optimal real-time rendering and innovative user interaction techniques where the visitor will be given the option to explore and navigate through their specific needs.

A Peranakan Virtual Tour Guide will guide the visitor and provide more information about the Peranakan culture while the visitor will also be able to directly interact with the environment by using an actual Chinese calligraphy brush to paint directly in the virtual scene.

1.2 The Peranakans and their Culture

Due to the mixture of the cultures, the Peranakans have a diverse assortment of a rich material culture. Their rich material culture include silver, porcelain, beadwork and embroidery, jewelry, furniture, and architecture. While a lot of the furniture were ordered from cabinet-makers in China or locally domiciled carpenters and the Straits Chinese porcelain, also known as ‘Nyonya ware’ were imported from China and even Japan, the beadwork and embroidery were made by the Nyonyas themselves[3]. Through this it can be seen that the Peranakans have a distinct aesthetic to their material culture.

To reconstruct the Peranakan culture, we have selected to focus on digitally recreating the different types of furniture, ceramics and porcelain, and silverware. We will also present some of the artwork from the Peranakans.

This paper is organized as follows. In Section 2, we will give a brief overview of the current state-of-the art on virtual humans, interaction techniques, and digital heritage. In Section 3, we will introduce the development and early implementation of our concept followed by Section 4 which describes and evaluates the early results of our project. Finally in Section 5, we will conclude our work and present future work.

2. State-of-the-Art

2.1 Virtual Humans

Since we human beings are such complex entities, digitally recreating ourselves is not an easy task. Numerous studies in recreating realistic virtual humans beings/avatars is currently in progress. The virtual humans can be autonomous, programmed, or guided depending on their purpose. Cassell [8] developed an embodied conversational agent named Rea (Real Estate Agent). Rea is a real-time 3D avatar capable carrying out conversations and interacting with a real human beings. Badler et al [9] developed a software system called Jack for creating, sizing, manipulating, and animating virtual humans. The Thalmanns[11] developed sensory perception in human modeling by equipping the virtual humans with visual, tactile, and auditory sensors to make them aware of their environments. Some other architectures on virtual humans include Perlin et al [12]’s Improv System and Chi et al [10]’s EMOTE system. The Improv System combined scripted actions with stochastically generated motions to achieve controllability and believability of the virtual humans while the EMOTE team introduced a new approach to procedural human animation that tried to close the gap between manually animated characters and procedurally animated characters. H-ANIM [5] working group developed standard way of representing virtual humans (: humanoids) in VRML97 real-time. H-ANIM humanoids can be animated using keyframing, inverse kinematics, performance animation systems and other techniques.

2.2 Virtual Reality Interface and Interaction Techniques

Many studies have been carried out in the field of Virtual Reality interaction techniques. Some examples of interaction in VR include hand gestures, virtual walking through specialized slippers, natural speech,

virtual humans, fragrance, and touch screen kiosks among others. Here we present a few examples of interface and interaction techniques employed by other heritage and art-related environments.

Lutz et al [15] presented an intuitive interaction technique appropriate to the cave context by using a virtual flashlight connected to real flashlight to navigate through the Virtual Dunhuang Art Cave. Behr et al [14] integrated a Virtual Tour Guide and a touch screen book interface to guide the visitors through the Dome of Siena during the EXPO 2000 in Hannover, Germany. This is a good example of using a virtual humans capable of natural speech interaction as an interaction tool for users in real-time. Refsland et al [13] constructed a model of the Golden Temple (Kinka Kuji) in Kyoto, Japan and designed artificial life “fireflies” to inhabit the neighboring temple gardens. They connected the fireflies in real-time to the actions of the Nasdaq stock market to simulate night. Not only did this provide a means to ‘light-up’ the virtual scene in real-time, it also added to the magical quality when visiting a temple. As with the ‘virtual flashlight’, this project shows innovative ways of transparent context-specific interface. Hirayu et al [16] are developing a system where not only are they reconstructing the historic villages of shirakawa-go, they are also teaching the techniques from the craftsmen by letting the users interact with sensor-inserted ropes and are planning to simulate weather conditions. On the art front, a CavePainting system which uses the entire CAVE as an artist’s canvas was developed by Keefe et al [17]. They used physical props such as a paint brush, bucket, and cups.

2.3 Digital Heritage

Over 100 Virtual Heritage Projects have been developed over the past 4 years. Virtual Reality technology is actively being used in the virtual heritage fields of digital archiving, surface model generation, laser scanning, integration of VR and AR (Augmented Reality), museum installations, color restoration, and reconstructing cultural heritage environments. In Singapore, a Singapore National Project that emphasizes socially responsible entertainment based on communication, collaboration, and construction rather than violence, competition, and destruction called HistoryCity [4] was developed. HistoryCity was modeled on 1870 Singapore and is a collaborative distributed environment for children that aims to teach children about the Singapore history. Some examples of high-quality 3D cultural heritage reconstructions using Virtual Reality technology projects are listed below. Victor et al[19] digitally recreated Notre Dame Cathedral of Paris using high-quality 3D modeling also incorporating the idea of a Virtual Tour Guide and presenting their work on CD-ROMs and the internet allowing for the global access of this beautiful cathedral. Cremer et al[20] reconstructed a 3D model of turn-of-the 20th century Cedar Rapids, Iowa and installed the exhibit in the museum. They incorporated a “time machine” where the visitors sit and operate it to go back in time. Behr et al [14] presented a digital model of one of the most picturesque cathedrals in Europe – the Dome of Siena during the EXPO 2000 in Hannover, Germany incorporating a Virtual Tour Guide and an ancient book as a touch screen navigation for the general public. Sanders et al [18] developed a digital reconstruction of the ancient archaeological site from the Northwest Palace of Ashur-nasir-pal II. They used a 3D avatar of the King Ashur himself to present the historical information on the Palace.

As we can see from some of the examples of related work, the selection of an interesting cultural heritage topic as well as using transparent context-specific user interaction techniques friendly to the user is very important. We can see that little work has been carried out on the Peranakans in the digital heritage context incorporating a Chinese calligraphy brush as an interaction device with an Asian Virtual Tour Guide. From the technology point of view, using a Calligraphy brush also provides a natural way of interacting within a Virtual Environment. Therefore, we have selected this combination of presenting the Peranakans heritage using an Asian Virtual Tour Guide and a Chinese calligraphy brush as our main interaction method. The Virtual Tour Guide will be implemented using an extension of the H-ANIM.

3. Development and Implementation

The development and implementation of the project can be divided into several stages although currently we are in the preliminary stages. First we have to use novel modeling techniques to model attractive 3D representations of the Peranakan culture. Part of this process will include the modeling of the Virtual Tour Guide. The Virtual Tour Guide is an Asian-origin avatar created specifically for this project. He will give the visitors real-time feedback with audio output and guide the visitors through out the environment and at the same time provide historical information. Second, we have to export the 3D models into a real-time

engine that is able to animate and display the 3D models in real-time. Lastly, we have to develop intuitive ways of interacting with the Chinese brush within the environment. For the VR projection, we will use a VR system called Virtual Design II™ [6] developed by vrcom GmbH and Fraunhofer-IGD. Virtual Design II™ features many different control and output devices as well as different lightning simulations. Please see Figure 1. for the overall workflow of the project. The sections below describe the stages in detail.

Figure 1. Overall diagram of workflow and different work packages

3.1 3D Modeling of Material Culture

To create high-quality models capable of fast real-time rendering, we have to pay special attention to the polygon count while maintaining the high-quality. We are using extensive textures to present the 3D models using a commercial 3D software package - 3D Studio Max™. For data acquisition, we have gathered information on the Peranakan material culture by visiting the Peranakans museums, through specialized books on the Straits-Chinese, and through actual heritage sites. Figure 2. shows some examples of the heritage objects.

Furniture
	Armchair	Dining Table
Ceramics
	Offering Dish	Kat Mau (Soup Bowl)

Figure 2. Examples of Peranakan material culture

3.2 Virtual Tour Guide

The Virtual Tour Guide we have created for our project is of Chinese ethnicity to fit the Peranakan profile. To further create the atmosphere of the Peranakans, we have dressed him in the traditional Peranakan clothing. The techniques for creating our Virtual Tour Guide are specified below.

3.2.1 Face Modeling

The face was created using the nurbs modeling technique in Alias Wavefront Maya™. We chose this technique because nurbs modeling provides a better organic surface modeling and it also provides better techniques for creating the base phoneme sets. The faces were then exported into a polygon mesh. We have created 1 base face and 15 phoneme faces that are the basic morph-targets for lip syncing. The morph targets are essentially the state of the face that represent a particular phoneme and is later used to blend into the other faces with the audio sound input. We have used Ventriloquist™ from LipSinc to automatically generate the channel settings for the morph targets. The face is then animated in real-time.

Figure 3. depicts the creation of the Virtual Tour Guide and the creation of the basic phoneme sets.

Figure 3. Phoneme templates

3.2.2 Character Modeling

The body of the Virtual Tour Guide was modeled using the subdivision surface modeling technique also in Alias Wavefront Maya™ since the body and clothing did not require high-level organic modeling. For optimization purposes, we did not model any part of the body that is not shown. We then used Character Studio™ from 3D Studio Max™ to lay out the base hierarchical skeleton that is able to generate the weight influence from each bone of the skeleton to each vertex of the geometry. Using this information, the character is exported to VRML2 format which will then use an extension of the H-ANIM to define the geometry, skeleton, and the weights of the model for real-time animation. Figure 4. shows the development of the Virtual Tour Guide.

Figure 4. The Virtual Tour Guide

3.3 Calligraphy Brush Interaction

Calligraphy is an art dating back to the earliest day of history, and widely practiced throughout China and other parts of the world to this day. It is a very familiar tool to the Asian culture since they are exposed to it an early age whether it be at school or other environments. We have chosen this tool as an interaction device for our project because it is very specific to the Chinese and Asian culture thus fitting well into our overall interface and the Peranakan-specific content. Many people in Singapore are of Chinese descent and are also very familiar with Chinese calligraphy. This is an advantage because it provides intuitive interaction by presenting the user a familiar device they can immediately bond with and they do not have to spend time learning how to use this interaction device

Currently, we have finished the first stages of connecting the brush to the Flock of Birds™ electromagnetic tracking device. We have successfully been able to recreate the patterns drawn on a piece of paper with the calligraphy brush on the screen. Figure 5. shows the early stages of the brush interaction.

Figure 5. Calligraphy brush interaction

4. Results

Although we are in the early stages of our project, we have very promising results. We have built the Virtual Tour Guide and all its morph targets and he is able to generate facial animations with appropriate sound files. We have also started to select and build a Peranakan heritage object library and started early implementation of the Chinese calligraphy brush interaction.

5. Conclusions and Future Work

There are many digital heritage projects that are in progress world-wide. What makes each digital heritage project unique giving it its own flavor is the content that the heritage application presents to the audience.

For our work, the Peranakans have been selected as the cultural heritage topic to be reconstructed in an immersive 3D environment. A 3D avatar of an Asian Virtual Tour Guide has been built to guide the visitors through the environment and interaction with a real Chinese calligraphy brush is also provided. We are well under way for implementing and realizing the project. Since the project is still in its infancy stage, lots of future work needs to be carried out. Included in this future work are : develop more natural faces and character animations for the Virtual Tour Guide, develop a storyboard and build the overall environment where we can bring and tie all the elements together, and most importantly, develop advanced brush interaction techniques that are capable of recognizing user input for manipulating the Virtual Environment and work on natural and friendly ways of interaction.

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Interacting with the Virtually Recreated Peranakans

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Abstract

Virtual Reality (VR) technology opens up many new possibilities. One of the new and upcoming areas this VR technology is rapidly being used for is in the Digital Heritage domain. With the abundant content and the need for preservation and conservation for cultural heritage, there has been an explosion of Digital Heritage projects worldwide. VR technology provides an important educational tool to recreate the cultural heritage content in an immersive high-quality 3D environment for the users to enter and experience the culture in real-time. Intuitive interaction techniques providing users other tools as an alternative to the conventional mouse and keyboard input also add to enhanced educational value. Here, we present a Digital Heritage project focusing on the Singapore region. We have selected the *Peranakans and their Culture* as the main topic for reconstruction using the VR technology. Innovative interaction techniques specific to the selected Digital Heritage content is also under development. This paper outlines the motivation, early developments, and implementation currently in progress.

CR Categories: I3.6 (Computer Graphics): Methodology and Techniques – Interaction techniques; I3.7 (Computer Graphics): Three-Dimensional Graphics and Realism – Animation and Virtual Reality

Keywords: Digital Heritage, Virtual Reality, Interaction, Virtual Tour Guide, Peranakan, Chinese Calligraphy Brush, Recognition

1 Introduction and Motivation

Singapore is a diverse city-country with many different ethnic groups living together. It has a very rich culture that is a mixture of different ethnicities with its own unique identity. To better understand the Singaporean history, we cannot dismiss the impact of the Peranakans (which in Malay means 'born here'), also known as the Straits-Chinese. A Peranakan man is called a *Baba* while the ladies are known as *Nyonya*. The Peranakans are descendants of an early Chinese community that settled in the Malay archipelago at least since the 17th century [Peranakan Association]. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the indigenous Malay since the Chinese women were not allowed to leave the country until the 19th century.

This unique community developed distinct customs, cuisine and even their own language, as they blended Chinese and Malay ways of life to form a new and rich culture adding another dimension to the Singaporean society. They played a key role in bringing Malaysia and Singapore to independence [Chin 1991].

With this abundant culture slowly fading away with modernization and other factors, it can be seen that there is a dire need to preserve and recreate this important part of the Singaporean culture and provide new and innovative methods to increase the awareness and educate the public.

1.1 Virtual Reality, Cultural Heritage, and the Peranakans

Virtual Reality technology is becoming widespread for reconstructing cultural heritage sites over the past few years. A diverse range in the field of heritage preservation is using this technique for heritage applications - ranging from digital archives, archaeology, architecture, museums installations, augmented reality and VR, virtual GIS, to 3D image reconstruction. Creating fully immersive 3D environments presents to the public new possibilities to experience and interact with the cultural heritage site in a different setting.

Due to the mixture of the different cultures, the Peranakans have a diverse assortment of a rich material culture offering a distinct aesthetic in their silverware, porcelain, beadwork and embroidery, jewellery, furniture, and architecture.

In our project, we will be presenting the Peranakan digital heritage environment. The main focus of our project is the users. Therefore, we have put special attention on creating attractive high-quality 3D models capable of optimal real-time rendering and providing innovative user interaction techniques where the visitor will be given the option to explore and navigate through their specific needs. To reconstruct the Peranakan culture, we have selected to focus on digitally recreating the different types of furniture, ceramics, porcelain, and silverware. We will also present some of the artwork from the Peranakans.

A Peranakan Virtual Tour Guide will guide the visitor and provide more information about the Peranakan culture while the visitor will also be able to directly interact with the environment by using an actual Chinese calligraphy brush to write Chinese characters and other symbols to directly manipulate the virtual scene.

1.2 Objective

The objective of this project work is to digitally recreate the Peranakan's cultural heritage incorporating intuitive interaction techniques using Virtual Reality (VR) technology. For the

interaction techniques, a Peranakan Virtual Tour Guide has been created to guide the visitors through the virtual environment and a Chinese Calligraphy brush interaction technique has been developed providing the visitors with a familiar and easy-to-use interaction device. These techniques offer the visitors the option to explore and navigate through their specific needs reaching a wide range of audiences.

This paper is organized as follows. In Section 2, we will give a brief overview of the current state-of-the-art on digital heritage, interaction techniques, and recognition. In Section 3, we will introduce the development and implementation of our concept followed by Section 4, which describes and evaluates the early results of our project. Finally in Section 5, we will conclude our work and present future work.

2 State-of-the-Art

2.1 Digital Heritage

Over 100 Virtual Heritage Projects have been developed over the past 4 years. Virtual Reality technology is actively being used in the virtual heritage fields of digital archiving, surface model generation, laser scanning, integration of VR and AR (Augmented Reality), museum installations, colour restoration, and reconstructing cultural heritage environments. In Singapore, a Singapore National Project that emphasizes socially responsible entertainment based on communication, collaboration, and construction rather than violence, competition, and destruction called HistoryCity [HistoryCity] was developed. HistoryCity was modelled on 1870 Singapore and is a collaborative distributed environment for children that aims to teach children about the Singapore history. Some examples of high-quality 3D cultural heritage reconstructions using Virtual Reality technology projects are listed below. Victor et al. [1999] digitally recreated Notre Dame Cathedral of Paris using high-quality 3D modelling also incorporating the idea of a Virtual Tour Guide and presenting their work on CD-ROMs and the internet allowing for the global access of this beautiful cathedral. Cremer et al. [2001] reconstructed a 3D model of turn-of-the 20th century Cedar Rapids, Iowa and installed the exhibit in the museum. They incorporated a "time machine" where the visitors sit and operate it to go back in time. Behr et al. [2001] presented a digital model of one of the most picturesque cathedrals in Europe – the Dome of Siena during the EXPO 2000 in Hannover, Germany incorporating a Virtual Tour Guide and a ancient book as a touch screen navigation for the general public. Sanders et al. [2001] developed a digital reconstruction of the ancient archaeological site from the Northwest Palace of Ashur-nasir-pal II. They used a 3D avatar of the King Ashur himself to present the historical information on the Palace.

2.2 Virtual Reality Interface and Interaction Techniques

Many studies have been carried out in the field of Virtual Reality interaction techniques. Some examples of interaction in VR include hand gestures, virtual walking through specialized slippers, natural speech, virtual humans, fragrance, and touch screen kiosks among others. Here we present a few examples of interface and interaction techniques employed by other heritage and art-related environments.

Lutz and Weintke [1999] presented an intuitive interaction technique appropriate to the cave context by using a virtual flashlight connected to real flashlight to navigate through the Virtual Dunhuang Art Cave. Behr et al. [2001] integrated a Virtual Tour Guide and a touch screen book interface to guide the

visitors through the Dome of Siena during the EXPO 2000 in Hannover, Germany. This is a good example of using a virtual human capable of natural speech interaction as an interaction tool for users in real-time. Refsland et al. [2000] constructed a model of the Golden Temple (Kinka Kuji) in Kyoto, Japan and designed artificial life "fireflies" to inhabit the neighbouring temple gardens. They connected the fireflies in real-time to the actions of the Nasdaq stock market to simulate night. Not only did this provide a means to 'light-up' the virtual scene in real-time, it also added to the magical quality when visiting a temple. As with the 'virtual flashlight' this project, this project shows innovative ways of transparent context-specific interface. Hirayu et al. [2000] are developing a system where not only are they reconstructing the historic villages of Shirakawa-go, they are also teaching the techniques from the craftsmen by letting the users interact with sensor-inserted ropes and are planning to simulate weather conditions. On the art front, a CavePainting system, which uses the entire CAVE as an artist's canvas, was developed by Keefe et al. [2001]. They used physical props such as a paint brush, bucket, and cups.

2.3 Recognition

Adapting the 'pen and paper' metaphor by using pens or styluses and electronic digitising tablets as an alternative input to using the keyboard and mouse have been around for quite some time now. This type of input that uses pattern recognition techniques to process the inputted data allows the user the freedom to input characters, symbols, drawings, and gestures directly into the computer by writing directly on to the electronic tablet, providing a more natural way of interaction with the computer. It is able to accurately capture the x,y coordinates of the pen tip positions as well as other dynamic data described above. There are numerous applications to date using this technology in the pen computing industry – the most wide-spread commercial application being the Personal Digital Assistants (PDA) that combines agenda, address book, and telecommunications facilities (email, mobile phone, fax).

Generally pattern recognition can be divided into 2 stages: pre-processing and classification/recognition. In pre-processing, the x,y locations, writing speed, direction, and pressure of the user's pen movements are captured. One approach is to capture and represent the raw data in a form of 'chain-codes'. Xue et al. [2000] proposed an off-line character recognition method that uses dynamic programming to find the best match between 2 contour sequences of pseudo-stroke positions and directions. They used a method called 'chain-coding' to represent the binary image. Singh and Amin [1999] also used 'chain-coding' to obtain the raw handwritten data before applying a dominant point algorithm and matching the results to 6 primitive features they defined. To implement segmentation of on-line freehand sketches, Qin et al. [2001] used the drawing position, direction, speed, and acceleration information to detect the corner points with adaptive thresholds. They observed that the drawing speed for each curve will increase, remain steady, and then decreases when a segmentation point is approached. Since so many different recognition methods exist, building a system that is able to process multiple recognition methods is very practical. Alpaydin et al. [2000] proposed a multistage method called cascading. In their approach, a sequence of classifiers are ordered in terms of complexity where more sophisticated recognition methods are used only after the simpler ones fail. In Dang's [1998] dissertation work's Appendix A, he used 10 fundamental strokes of the Chinese character and recognized the characters by using different combinations with different relative positioning to determine the different characters.

As we can see from some of the examples of related work, the selection of an interesting cultural heritage topic as well as using transparent context-specific user interaction techniques friendly to the user is very important. We can see that little work has been carried out on the Peranakans in the digital heritage context incorporating a Chinese calligraphy brush as an interaction device with an Asian Virtual Tour Guide. From the technology point of view, using a Calligraphy brush provides a natural way of interacting within a Virtual Environment. Since the users are already familiar with the brush, they are also less likely to be apprehensive of the new technology. Therefore, we have selected this combination of presenting the Peranakans heritage using an Asian Virtual Tour Guide and a Chinese calligraphy brush as our main interaction method.

3 Development and Implementation

The development and implementation of the project can be divided into several stages. First we have to use novel modelling techniques to model attractive 3D representations of the Peranakan culture. Part of this process will include the modelling of the Virtual Tour Guide. The Virtual Tour Guide is an Asian-origin avatar created specifically for this project. He will give the visitors real-time feedback with audio output and guide the visitors through out the environment and at the same time provide historical information.

Second, we have to export the 3D models into a real-time engine that is able to animate and display the 3D models in real-time. Lastly, we have to develop intuitive ways of interacting with the Chinese brush within the environment. For the VR projection, we will use a VR system called Virtual Design II™ [Virtual Design] developed by vrcm GmbH and Fraunhofer-IGD. Virtual Design II™ features many different control and output devices as well as different lightning simulations. Please see Figure 1. for the overall workflow of the project. The sections below describe the stages in detail.

Figure 1. Overall Workflow

3.1 3D Modelling of Material Culture

To create high-quality models capable of fast real-time rendering, we have to pay special attention to the polygon count while maintaining the high quality. We are using extensive textures to present the 3D models. For data acquisition, we have gathered information on the Peranakan material culture by visiting the Peranakans museums, through specialized books on the Straits - Chinese, and through actual heritage site visits. Figure 2. shows some examples of the heritage objects.

Figure 2. Examples of Peranakan material culture

3.2 Virtual Tour Guide

The Virtual Tour Guide we have created for our project is of Chinese ethnicity to fit the Peranakan profile. To further create the atmosphere of the Peranakans, we have dressed him in the traditional Peranakan clothing. The techniques for creating our Virtual Tour Guide are specified below.

3.2.1 Face Modelling

The face was created using the nurbs modelling technique. We chose this technique because nurbs modelling provides a better organic surface modelling and it also provides better techniques for creating the base phoneme sets. The faces were then exported into a polygon mesh. The phoneme faces that have been created are used as the basic morph-targets for lip syncing. Morph targets are essentially the state of the face that represent a particular phoneme which is used to blend into the other faces with the appropriate audio sound input. The face is then animated in real-time.

Figure 3. depicts the creation of the Virtual Tour Guide and the creation of the basic phoneme sets.

Figure 3. Phoneme templates

3.2.2 Character Modelling

The body of the Virtual Tour Guide was modelled using the subdivision surface modelling technique. We chose this technique over nurbs modelling since the body and clothing did not require high-level organic modelling. For optimisation purposes, we did not model any part of the body that is not shown. The body was then mapped to a base hierarchical skeleton capable of generating the weight influence from each bone of the skeleton to each vertex of the geometry.

Using this information, the character is exported to VRML2 format, which will then use an extension of the H-ANIM to define the geometry, skeleton, and the weights of the model for real-time animation. Figure 4. shows an example of the Virtual Tour Guide in the Peranakan chamber.

Figure 4. The Virtual Tour Guide and the Peranakan Chamber

3.3 Brush Interaction

The virtual tour guide will present information on the cultural site while showing the audience around the virtual environment. In addition, an innovative interface was realized to give the user the possibility to interact with the virtual tour guide and the virtual environment. The interface consists of a Chinese Calligraphy brush and a small board with paper fixed onto it. The user interacts with the virtual environment by writing specific Chinese characters and symbols.

Although the user is familiar with the brush, the user does not know which Chinese characters and symbols the system understands and what their effects are. Therefore, the virtual tour guide introduces new users to the interface. He will show the users how to use the brush and the board, as well as explain the Chinese characters and symbols that the system understands along with their effects.

An example for using a brush as an interaction technique is the "Sichuan Virtual Dig" [Oppenheimer et al 2001]. In this project a real brush is used to uncover and examine artefacts. The user removes layer by layer by 'brushing' on a projection table.

3.3.1 Methodology

While looking at the screen and interacting with the system, the user holds the small board in one hand and the brush in the other. The Calligraphy brush and the board have virtual models as their counterparts. The virtual model of the brush and the board can be seen as a part of the virtual environment while the user writes with the real brush. Position and orientation of the virtual counterparts are synchronised to the real brush and board with the

help of a tracking system. The user only moves the Calligraphy brush but does not use ink to write. The system provides feedback of what the user writes by showing the writing on the virtual board. To increase the realism, a deformable model based on a damped Mass-Spring system is used for the tip of the virtual brush. The physical attributes of the deformable model were chosen so that the deformation of the virtual brush tip corresponds to the one of the real brush. The deformable model is also used to obtain realistic images on the virtual board. The imprint of the deformed virtual brush on the board is used to display on the virtual board whatever the user writes on the real board. The imprint defines the area of the board that has to be coloured black. Transparency is used to fade the border of the imprint. Spaces between consecutive imprints are filled by drawing a line between them. A modified Bresenham algorithm [Bresenham 1965] is used to draw the line that consists of adjoining and overlapping imprints. Figure 5. shows the Calligraphy brush and the board and their virtual models after the user has drawn the Chinese character "Zhong" meaning "middle".

Figure 5. Calligraphy brush interaction

3.3.2 Cascading Recognition

The system tries to recognise each Chinese character and symbol that the user writes. An online recognition is used that obtains data while the user draws on the board. A recent example for an online recognition can be found in [Calhoun et al 2002]. The data is stored in a so-called Chain code. Each element of the Chain code contains the position, time, and pressure of one imprint. The pressure is derived from the deformable model of the tip of the brush. A cascading recognition method similar to the one described in [Alpaydin et al 2000] is used for its flexibility and extensibility. It consists of several recognition methods that work in parallel or successively, allowing for the implementation of different recognition methods and giving us the advantage of using the potency of each one. Each method has its own database of characters and symbols that it can recognize. This is necessary because each recognition method analyses the same Chain code in different ways. The database consists of pairs of data. The first element of each pair is an ID. The ID identifies the character or symbol. The second element describes the way the character or symbol is composed. After the completion of the analysis, the recognition method compares the acquired data to the data stored for each character and symbol in its database. A character or symbol has been successfully recognized when the acquired data matches the data stored in the database. An example of a recognition method is given in 3.3.3.

The system is able to recognize a set of predefined characters and symbols. However, it is not necessary that each recognition method can recognize all of them. The database of a recognition method may only contain a subset of all the characters and symbols. A possible scenario is to use some recognition methods to recognize characters and others to recognize symbols. In order to save time, we start recognition methods that are able to detect characters and symbols that are simple and frequently used first. Only if the recognition fails, a more complex recognition method is started. Alternatively, recognition methods can work in parallel. In this case, a so-called decision maker algorithm starts and controls all recognition methods and chooses the best result if more than one recognition method was successful. For this purpose, each recognition method has a priority assigned to it and returns the ID of the recognized character and symbol as well as the percentage that indicates how accurate the result is.

3.3.3 Detection of strokes

An example for a recognition method that we use is the detection of strokes. Each Chinese character is composed of a sequence of basic strokes. Information about the type of each stroke as well as their order and total number is used to identify Chinese characters. This simple method cannot recognise all Chinese character clearly without ambiguity. However, we are only using few characters to interact with the system and we chose characters that differ in the type and number of strokes. In addition, the user must draw the strokes in the correct order. Examples for recognition methods that utilize the detection of strokes can be found in [Amin and Sum 1993; Calhoun et al 2002].

The main part of the analysis of this simple recognition method is segmentation. During the segmentation, the Chain code is subdivided into smaller parts so that each part describes one stroke of the Chinese character. When the user writes a Chinese character, there is a small break between two consecutive strokes. The user also has to lift the brush to move it to the next starting point of the new stroke which changes the pressure. Therefore, strokes can be detected by searching for changes in the position, speed, and pressure in the Chain code. After the segmentation, the relative position, size, and orientation of each stroke are calculated. During the last step of each recognition method, all the acquired data is compared to the data stored in its database.

The database of this recognition method contains the ID of each character that has to be recognized by our system. Information about the number of strokes, the type of strokes, their relative position, size, orientation, and their order is stored together with each ID. The comparison is done according to predefined priorities. For instance, the correct number of strokes is more important than their correct order. If all data matches clearly without any ambiguity, the result is then returned to the decision maker. However, a result is also returned to the decision maker when only the data with the higher priority matches. In this case, the percentage of the matches is calculated and returned. The decision maker chooses the result with the highest percentage.

3.3.4 User interaction

To interact with the virtual environment, the user only needs to know a few simple Chinese characters and symbols that are easy to memorize and write. They are even suitable for users who are not familiar with the Chinese language. We do not use complicated characters and symbols because it would take too long to learn and write them thus making the interface an inconvenient one. An example is the Chinese character for "person". This is used to call the virtual tour guide and only consists of two strokes.

Although it is possible to interact with the system using interaction devices like a SpaceMouse, our main aim is to exploit the possibilities of the Calligraphy brush interaction. Therefore, the user can navigate through the virtual environment by drawing on the board. For this purpose, we have introduced simple symbolic Chinese characters like up, down, and middle to go upstairs, downstairs, or back into the main building. The user can also write simple pictorial symbols like arrows to indicate the direction in which he/she wants to move in the virtual environment.

4 Results

We have built the Virtual Tour Guide and all its morph targets and he is able to generate facial animations with appropriate sound files. We have also started to select and build a Peranakan heritage object library and started early implementation of the Chinese calligraphy brush interaction. We modelled the virtual counterparts of the Calligraphy brush and the board and are able to control them using the tracking system. We have also developed the cascading recognition and the decision maker and added a first recognition method that recognizes Chinese characters that we use for the interaction by detecting the strokes they are composed of.

5 Conclusions and Future Work

There are many digital heritage projects in progress worldwide. What makes each digital heritage project unique giving it its own flavour is the content that the heritage application presents to the audience.

For our work, the Peranakans have been selected as the cultural heritage topic to be reconstructed in an immersive 3D environment. A 3D avatar of an Asian Virtual Tour Guide has been built to guide the visitors through the environment and interaction with a real Chinese calligraphy brush is provided. We are well under way for implementing and realizing the project. Since the project is still in its early stages, lots of future work needs to be carried out. This future work includes the development of more natural faces and character animations for the Virtual Tour Guide and the development of a storyboard and the overall environment where we can bring and tie all the elements together. Most importantly, we need to focus on the development of advanced brush interaction techniques capable of recognizing user input for manipulating the Virtual Environment and work on natural and friendly ways of interaction. This includes further recognition methods that recognize currently defined Chinese characters and symbols as well as new ones. In order to obtain important feedback, we will carry out user test studies to test the brush interaction with inexperienced users. We are especially interested in the acceptance and usability as well as in the Chinese characters and symbols the users would prefer to use in order to perform a given task in the virtual environment.

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Novel Interaction Techniques for Virtual Heritage Applications using Chinese Calligraphy Brush and Virtual Avatar

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Abstract

In this paper, we present a digital heritage project incorporating novel interaction techniques in an immersive virtual heritage application. Virtual Reality (VR) technology enables us to digitally recreate immersive and interactive cultural heritage sites that no longer exist or are inaccessible. It is an excellent educational tool providing for a 'hands-on' application suitable for a wide range of audiences. Here we present the development and implementation of the virtual heritage application with early results and future work and specifically focus on the two interaction techniques – the Virtual Tour Guide and the Chinese calligraphy brush.

1 Introduction and Objective

Virtual Reality(VR) technology is widely being used in a diverse range of heritage applications providing a fully immersive 3D environment presenting to the public new possibilities to experience and interact with the cultural heritage sites. Using this VR technology, we have selected to recreate and explore the Peranakans and their culture. The Peranakans are descendants of an early Chinese community that settled in Singapore and Malaysia since the 17th century. They developed a rich culture by blending the Chinese and Malay cultures thus adding another dimension to the Singaporean-Malaysian society. For the interaction techniques, a Peranakan Virtual Tour Guide has been created to guide the visitors through the virtual environment and a Chinese Calligraphy brush has been incorporated providing the visitors with a familiar and easy to use interaction device. These techniques offer the visitors the option to explore and navigate through their specific needs reaching a wide range of audiences.

2 Development and Implementation

The major components of this project are 3D modelling, development of interaction techniques, and high-end visualisation. Sophisticated 3D modelling techniques have been used to create the Virtual Tour Guide and selected cultural material from the Peranakan culture such as furniture, ceramics, silverware, and embroidery and beadwork. These models are capable of real-time rendering using in-house systems for the visualisation. The following sections describe the development and the implementation of the interaction techniques used within the Virtual Environment.

2.1 Virtual Tour Guide

The Virtual Tour Guide we have created for our project interacts with the visitors, shows them around the Virtual Environment, and also provides historic information on the Peranakan culture. He is of Chinese ethnicity and dressed in the traditional Peranakan clothing to fit the context of the Peranakan culture. Subdivision surface modelling technique was used to model the body of the Virtual Tour Guide. The body was then mapped to a base hierarchical skeleton in order to generate animation sets. The Virtual Tour Guide provides information by talking to the visitor. However, he can also show supplemental information in the form of text, images, and video. In order to achieve this, he must be capable of real-time facial animation for speech generation. For the face modelling, a base face was created and viseme face sets were derived from the base head. Visemes are the mouth positions/shapes of a particular sound in speech. The base head uses the different visemes as targets to 'morph' between the different mouth shapes according to the analyzed sound files.

The visitor has the option of whether he/she wants the help of the Virtual Tour Guide. For example, a visitor can explore the Virtual Environment and all its objects by walking through the virtual rooms by him/herself or also ask the Virtual Tour Guide for a complete guided tour. During the tour the visitor follows the Virtual Tour Guide automatically and gets additional information on important exhibits. The visitor can interact with the Virtual Tour Guide at any time. If the visitor wants additional information on an interesting exhibit, he/she simply selects the exhibit and calls the Virtual Tour Guide to trigger for more information.

The Virtual Tour Guide also introduces novel visitors to the Virtual Environment and shows them how they can use the Chinese Calligraphy brush for interaction. He explains the Chinese characters that the visitor can write with the brush as well as their associated functionalities.

Figure 1: Virtual Tour Guide Setup

2.2 Calligraphy Brush

An important aim of this project is to educate the public and to give an insight to the Peranakans. In order to reach a broader audience - including visitors with little to no experience with VR technology, the interaction method must be intuitive and easy to use. Furthermore, the interaction device should correlate to the context of the application. A good example of this is the Virtual Dunhuang Art Cave from (Lutz & Weintke, 1999). Here, one can use a real flashlight to navigate in the virtual cave. For these reasons, we have chosen to use a Chinese Calligraphy brush as an interaction device. Calligraphy is an art dating back to the earliest day of history and widely practiced throughout China and other parts of the world to this day. It is a very familiar tool to the Asian culture since they are exposed to it at an early age whether it is at school or in other

environments. This makes the interaction device an integral part of the culture that the visitor can additionally explore.

2.2.1 Writing with the Calligraphy brush

The visitor can use the brush to write simple Chinese characters that are associated to specific commands the system understands. For this purpose, the visitor holds the brush in one hand and a small board in the other. The visitor writes on the board by moving the brush on the board but not actually using any real ink. The virtual counterparts of the brush and the board are shown as 3D models in the Virtual Environment. They reflect the writing in black ink and provide visual feedback to the visitor. Only simple characters that are composed of a few strokes are used. They are easy to memorise and economical to write making them even suitable for visitors with no knowledge of Chinese. For example, by writing the simple Chinese character “Ren” 人 which means “Person”, the visitor calls the Virtual Tour Guide to request help or information.

Writing with the Calligraphy brush is realised by implementing a Chinese character recognition method. A tracking system is used to capture the position and the orientation of the real brush and board. This information is used to update the virtual models of the brush and board to correspond to the real ones. If there was an intersection between the brush and the board, the area of the imprint made by the virtual brush is coloured in black to simulate ink. The captured information is also passed on to the recognition method. An online Chinese character recognition method is used that gathers the relevant data such as the position, time, and pressure of each imprint while the visitor writes. All this data that belongs to one imprint is saved in one element of a Chain-code. After the visitor has written the complete character, the Chain-code contains as many elements as the number of captured imprints. These elements are concatenated and ordered by time. An example for an online recognition method can be found in (Calhoun, Stahovich, Kurtoglu, & Kara, 2002). The Chain-code is the basis for the actual recognition process. This recognition process analyses the Chain-code data to detect the Chinese character. The visitor only uses a few Chinese characters to interact with the system so that a simple recognition method is sufficient. The method used searches and identifies the strokes of the Chinese character. Each Chinese character is composed of different types of single strokes that vary in the position, orientation, and length. The types of strokes and their order identify each Chinese character. Examples for recognition methods that detect strokes are given in (Amin & Sum, 1993) and (Calhoun, Stahovich, Kurtoglu, & Kara, 2002).

The actual recognition process analyses the complete Chain-code and tries to detect the single strokes the Chinese character is composed of. For this purpose, the Chain-code has to be subdivided into parts so that each part only contains elements of one stroke. In order to find these elements, the recognition method searches for higher-than-average changes in the position, speed, and pressure in the Chain-code. These changes occur when the brush is lifted during the writing of the character to move from one end of a stroke to the beginning of the next. Afterwards, the type of each stroke has to be determined by calculating its length and orientation. The recognition method has a database where the number, type, and order of strokes are stored for each Chinese character. At the end, only the appropriate data that was determined during the recognition process has to be compared to the one stored in the database.

2.2.2 Navigating with the Calligraphy brush

The visitor can also use the calligraphy brush to navigate in the Virtual Environment by pointing with it to a specific direction to indicate where he/she wants to move to. This simple navigation method is sufficient because only walking and turning on the ground level is needed. Pointing

with the brush to the left or right side of the screen turns the visitor inside the Virtual Environment. Similarly, pointing the brush at the top or the bottom of the screen moves the visitor forward or backward in the virtual scene. Additionally, the visitor can point at an exhibit to get additional information. A cursor appears on the screen at the position where the visitor points to. In order to give the visitor better feedback, the shape of the cursor changes depending on which side of the screen the cursor is situated at. For example, when the visitor points at the left side of the screen, the cursor shows a left arrow and when he/she points to an exhibit, the cursor is changed to a hand.

In order to implement navigation with the Calligraphy brush, the position and orientation of the brush have to be known. This information is returned by the tracking system as described in section 2.2.1. In order to detect which side of the screen the visitor is pointing to, an invisible plane is defined and placed in front of the screen. The position of the brush and its roll axis define the starting point and direction of a ray. This ray is intersected with the plane in order to find the position of where visitor is pointing at. Figure 2. shows an exemplary setting. It can also be seen that partial areas are defined on the plane. After the position of the cursor is calculated, the partial area the cursor is situated in is determined. If it is one of the four areas at the side of the screen, the cursor is changed into an appropriate arrow and the visitor is rotated or moved respectively within the Virtual Environment. If the cursor is situated in the central area, the system checks if the visitor is pointing at an exhibit by intersecting the ray with the bounding box of all currently visible exhibits and changes the cursor into a hand if an intersection occurs. This action which rotates, moves, or selects an exhibit, does not occur instantly after the cursor changes to a hand. In general, the visitor has to keep the cursor within the defined area for a certain period of time. The visitor thus can cancel the action by moving the cursor to another position before the time elapses. The arrow cursor indicates the elapsing time by changing its colour from yellow to red. The hand cursor indicates it by closing the hand until it becomes a fist. The correct time period is crucial for smooth interaction. A large period will make the interaction slow and a short period can cause false execution of actions not intended by the visitor.

Figure 2: Navigation with the brush

3 Results

The Virtual Tour Guide and all its associated components have been modelled and it is possible to generate facial animations with the appropriate sound files. A selection of Peranakan material culture has been selected and an object library is under work. For the Chinese Calligraphy brush interaction, we developed the online character recognition method that recognizes all the Chinese characters we have defined by detecting the strokes they are composed of. The recognition method

is optimised for the defined characters therefore the characters are detected with a high success rate. We also implemented the navigation with the Chinese Calligraphy brush and conducted first in-house user test studies. They showed that the Calligraphy brush increases the edutainment value of the application. Users of Chinese background only have to be told the Chinese characters that the system understands and their functionality. Users of a non-Chinese background need more practice with writing the Chinese characters. The tests also pointed out that the system should display the Chinese characters that can be used as a memory aid. Users who are not familiar with VR systems are able to use the Calligraphy brush to navigate in the 3D environment after observing other users or receiving a short introduction. Some more experienced users prefer to use additional and more powerful interaction devices that offer more degrees of freedom.

4 Conclusions and Future Work

A digital heritage project distinguishes itself by its content. With the help of Virtual Reality technology, we have created a virtual heritage environment on the Peranakans where the visitors can virtually enter and learn new information on the Peranakans and their culture. The main focus of our research work is to provide for interaction techniques that are intuitive and easy to use. For future work, we will work on improving the Virtual Tour Guide by developing more natural facial expressions and animation sets and by making him more “intelligent”. To achieve this, we will utilise user profiles, a storyboard in the form of a database that contains prioritised information on all the exhibits, and a learning system that adapts the priorities and presents information that is dependant on who the visitor is and on the visitor’s behaviour observed throughout the exhibition. We will also further exploit the possibilities of using the Chinese Calligraphy brush as an interaction device and carry out extensive user test studies on users with different skills, knowledge, and culture to evaluate this interaction method.

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Using Virtual Reality to bring Singaporean Heritage to Life

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Abstract

Rapid advances in the field of Virtual Reality (VR) technology has opened up many new areas for research and development. One of the recent important research fields that has emerged is in the field of Digital Heritage. VR technology is an important educational tool that provides immersive and interactive qualities to the cultural heritage content thus enabling us to accurately represent digital reconstructions of heritage sites that are no longer in existence or are inaccessible. In this paper we present our project on the Digital Heritage scenario focusing on cultural heritage content specific to the Singapore region. Innovative interaction techniques specific to the selected Digital Heritage content will also be presented. This paper outlines the motivation, early developments, and implementation currently in progress.

1. Introduction and Objective

Virtual Reality (VR) technology is becoming widespread for reconstructing cultural heritage sites over the past few years. A diverse range in the field of heritage preservation is using this technique for heritage applications - ranging from digital archives, archaeology, architecture, museums installations, augmented reality and VR, virtual GIS, to 3D image reconstruction. Creating fully immersive 3D environments presents to the public new possibilities to experience and interact with the cultural heritage site in a different setting. This is becoming increasingly important since many heritage and cultural sites all over the world are being destroyed or lost to urbanization, pollution, neglect, and even tourism and the need to preserve, restore, and interpret cultural heritage sites has increased tremendously over the recent years. An important part of the Singaporean history and culture are the Peranakans also known as the Straits-Chinese. The Peranakans are descendants of an early Chinese community that settled in the Malay archipelago since the 17th century [7]. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the Malay. This unique

community developed distinct customs, cuisine and even their own language, as they blended Chinese and Malay ways of life to form a new and rich culture. They played a key role in bringing Malaysia and Singapore to independence [3]. Due to this mixture of the different cultures, the Peranakans have a diverse assortment of a rich material culture offering a distinct aesthetic in their cultural heritage and objects in silverware, porcelain, beadwork and embroidery, jewelry, furniture, and architecture. The objective of this project work is to digitally recreate the Peranakan's cultural heritage incorporating intuitive interaction techniques using Virtual Reality (VR) technology. A Peranakan Virtual Tour Guide has been created to guide the visitors through the virtual environment and a Chinese Calligraphy brush interaction technique is also being developed to provide the visitors with a familiar and easy-to-use interaction device. These techniques offer the visitors the option to explore and navigate through their specific needs reaching a wide range of audiences.

This paper is organized as follows. In Section 2, we will introduce the development and implementation of our concept followed by Section 3, which describes the early results of our project. Finally in Section 4, we will conclude our work and present future work.

2. Development and Implementation

The main sections for the development of this project includes the 3D modeling and creating basic animation sets for the Virtual Tour Guide, 3D modeling of the cultural heritage objects, and the development of the Chinese Calligraphy brush for interaction. The following describe each section in more detail.

2.1 3D Modeling of Material Culture

To create high-quality models capable of fast real-time rendering, we have to pay special attention to the polygon count while maintaining the high quality. We are using extensive high-quality textures to present the 3D models.

For data acquisition, we have gathered information on the Peranakan material culture by visiting Peranakan museums exhibits, through specialized books on the Straits -Chinese, and through actual heritage site visits. Figure 1. shows some examples of the heritage objects.

Figure 1. Examples of some Peranakan heritage objects

2.2 Virtual Tour Guide

The Virtual Tour Guide we have created for our project is of Chinese ethnicity to fit the Peranakan profile. To further create the atmosphere of the Peranakans, we have dressed him in the traditional Peranakan clothing. The techniques for creating our Virtual Tour Guide are specified below.

2.2.1 Face Modeling. The face was created using the nurbs modeling technique. We chose this technique because nurbs modeling provides a better organic surface modeling and it also provides better techniques for creating the base viseme sets. Visemes are the mouth shapes/position of a particular sound in speech. The faces are then exported into a polygon mesh. These faces that have been created are used as the basic morph-targets for lip syncing. The face is then animated in real-time.

2.2.2 Character Modeling. The body of the Virtual Tour Guide was modeled using the subdivision surface modeling technique. We chose this technique over nurbs modeling since the body and clothing did not require high-level organic modeling. The body was then mapped to a base hierarchical skeleton. Motion studies have been carried out in conjunction to generating basic animation sets. Using the above information, the character is exported to the VRML97 format, which will then use an extension of the H-ANIM [6] to define the geometry, skeleton, and the weights of the model for real-time animation. The H-ANIM working group developed a standard way of representing virtual humans/humanoids in VRML97 in real-time. Figure 2. shows an example of the Virtual Tour Guide in the Peranakan chamber.

Figure 2. Virtual Tour Guide and the Peranakan chamber

2.3 Calligraphy Brush Interaction

An important aim of our project is to educate the public and to give an insight into the Peranakans. The VR technology allows the visitors to immerse into the virtually recreated 3D environment of the Peranakans and experience their material culture. Once immersed, the visitor must be given options to navigate and interact with the virtual environment. We therefore utilize a Chinese Calligraphy brush as a novel interaction device. Calligraphy is an art dating back to the earliest day of history and widely practiced throughout China and other parts of the world to this day. It is a very familiar tool to the Asian culture since they are exposed to it at an early age. Therefore, this interaction device is an integral part of the culture that the visitor can additionally explore. The visitors can make use of the Calligraphy brush in the following two ways. The visitor can use the brush to write Chinese characters on a small board or to look and move around in the virtual environment by pointing with it in a certain direction.

In order to write Chinese characters, the visitor holds a small board in one hand and the brush in the other. He/she writes a character on the board by moving the brush on the board but not actually using real ink. Only a few simple Chinese characters that are easy to memorize and write are used. These Chinese characters are even suitable for users not familiar with the Chinese language. An example is the Chinese character for “person”. This is used to call the Virtual Tour Guide and only consists of two strokes. The complete interaction process is realized in three steps. First, the position of the Calligraphy brush and of the board is captured. A standard tracking system is used to obtain their position and orientation. In the second step, the virtual models of the Calligraphy brush and of the board are shown as a part of the virtual environment to provide feedback while the user writes with the real brush. In the third step, the Chinese character

is recognized. An online recognition method is used that obtains data while the user writes on the board. A recent example for an online recognition can be found in [2]. The gathered data is stored in a so-called Chain code. Each element of the Chain code contains the position, time, and pressure of one imprint created by the brush. Thereafter, the actual recognition process analyzes the Chain code. Since only a few Chinese characters are used, a simple recognition method was realized that detects the strokes of the character. Each Chinese character is composed of a sequence of basic strokes. Therefore, information about the type of each stroke as well as their order, position, and number is sufficient to identify a Chinese character. An example for recognition methods that utilize the detection of strokes can be found in [1]. The main part of the recognition process is segmentation. During the segmentation, the Chain code is subdivided into smaller parts so that each part describes one stroke of the Chinese character. When the user writes a Chinese character, there is a small break between two consecutive strokes. The user also has to lift the brush to move it to the starting position of the next stroke changing the pressure of the brush tip. Therefore, strokes can be detected by searching for changes in the position, speed, and pressure in the Chain code. After segmentation, the relative position, size, and orientation of each stroke are calculated. During the last step of each recognition method, all the acquired data is compared to the data stored in the database of the recognition method. The number of strokes, type of strokes, their relative position, size, orientation, and their order is stored for each character in the database.

As mentioned above, the visitor can also use the brush to navigate. To avoid having the visitor change from one interaction device to another and to make the application easy to use as possible, we extended the functionality of the Chinese Calligraphy brush. The visitor can use the brush to navigate in the virtual environment by pointing the brush in the direction he/she wants to go to. The direction is indicated by a cursor which appears on the screen of where the visitor points to. Instead of using one icon as a cursor, we use a small 3D arrow that always points in the same direction as the brush to give more feedback to the visitor. Moving the brush also moves the cursor and changes the direction of the 3D arrows accordingly. When the cursor is at the left side of the screen, the viewpoint of the visitor is rotated to the right side and vice versa. Similarly, when the cursor is at the top or the bottom of the screen, the visitor moves into the screen or out of it respectively. The brush has no button that the user can use to execute commands for moving into the selected direction. Fixing a button to the brush would degenerate the functionality of the brush. Instead, the user has to keep the cursor within a small area for a defined time period. The area makes the system more tolerant so the visitor does not have to hold the brush

absolutely still. The correct time period is crucial. A large period makes the interaction with the system slow. If the period is too short, the system might move into the wrong direction while the visitor is still pointing elsewhere.

Besides navigation, it is also possible to use the brush to interact with objects. When the visitor points to an object, for example – a vase, the cursor changes to indicate that an interaction with this particular vase is possible. Once again, keeping the cursor above an object for the defined time period executes this interaction command. After the selection, a closer view of the object is given as well as additional visual and audio information about the object.

Figure 3. Example of Calligraphy brush input

3. Results

We have built the Virtual Tour Guide and all its morph targets and he is able to generate facial animations with appropriate sound files. We have also started to select and build a Peranakan heritage object library and started early implementation of the Chinese calligraphy brush interaction. We modeled the virtual counterparts of the Calligraphy brush and the board and are able to control them using a standard tracking system. We have also developed the cascading recognition and the decision maker and added a first recognition method that recognizes Chinese characters that we use for the interaction by detecting the strokes they are composed of.

4. Conclusions and Future Work

We have selected the Peranakans as the cultural heritage topic to be reconstructed in an immersive 3D environment. A 3D avatar of an Peranakan Virtual Tour Guide has been built to guide the visitors through the environment and interaction with a real Chinese calligraphy brush is provided. We are well under way for implementing and realizing the project. Future work includes the development of more natural faces and character

animations for the Virtual Tour Guide and the development of a storyboard and the overall environment where we can bring and tie all the elements together. Most importantly, we need to focus on the development of advanced brush interaction techniques capable of recognizing user input for manipulating the Virtual Environment and work on natural and friendly ways of interaction. This includes further recognition methods that recognize currently defined Chinese characters and symbols as well as new ones. In order to obtain important feedback, we will carry out user test studies to test the brush interaction with inexperienced users. We are especially interested in the acceptance and usability as well as in the Chinese characters and symbols the users would prefer to use in order to perform a given task in the virtual environment.

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User-Centred Virtual Avatars in Real-time Virtual Heritage Tours

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Abstract. In this paper we describe innovative interaction methodologies utilizing a Virtual Avatar and a Chinese calligraphy brush in an immersive Virtual Environment (VE) scenario. Virtual Avatars are being widely used in many different Virtual Reality (VR) applications since they enhance the users' experience and add another dimension to the interactive VE scenarios. The Virtual Avatar that has been modeled for our research analyzes each of the user's behaviors and accordingly adapts the VE scenario content to each user's experience. The VE scenario as well as the system architecture design and the functionalities for the suggested interaction methods will be discussed and presented in detail. We will then present the implementation and the preliminary results.

1. Introduction and Motivation

Virtual Environments (VE) in conjunction with Virtual Reality (VR) technology provide important characteristics that are well suited for a diverse range of VE scenarios. The two main benefits of VEs are that they are immersive and interactive providing for a "learning-by-doing" scenario. VR technology is being widely used in a variety of applications including scientific visualization, medical training, and entertainment and edutainment applications. In this paper, we focus on the edutainment application, specifically on Digital Heritage (DH) – combining cultural heritage with the VR technology that aims to provide for a customizable virtual experience for every visitor/user to the DH application. In our research work, the Virtual Avatar is in fact the Virtual Tour Guide of the DH application that provides the visitors with information about the specific culture being displayed in the VE. The concept of a Virtual Avatar as a Tour Guide comprises of many ideas from real guided museum visits and new ideas that are adaptable to VR applications. In our system, we will be able to track the visitors, analyze his/her behavior, derive new facts about his/her interests and use the derived facts to personalize the guided tour. Our goal is to recreate a high quality 3D scenario/environment for a customizable real-time DH application and to develop and use transparent and intuitive, context-specific interaction techniques friendly to the user. The main components of our proposed DH application are novel 3D modeling and animation techniques to develop the Virtual Avatar and its VE scenario surroundings, digital storytelling techniques using the concept of user modeling to customize the content of the virtual visits to the users' experience, and the development of the Chinese calligraphy brush as the innovative user interaction device that is easy to use and intuitive.

The paper is organized as follows. In Section 2, we introduce our concepts behind our research work and in Section 3, we present our development and implementation. We will finally present results in Section 4 and conclude and discuss future work in Section 5.

2. Concept

2.1 Digital Heritage and Virtual Tour Guide

Many Cultural Heritage sites are being destroyed or lost to urbanization, pollution, neglect, and even tourism and the dire need to preserve, restore, and reinterpret cultural heritage in new ways is increasing. Combining this Cultural Heritage content with VR technology can help in preserving and restoring the Cultural Heritage sites and content that no longer exist or are inaccessible. VR technology can provide realistic high-quality VEs with cultural content that can be presented in a number of different ways and interaction methods such as the Virtual Tour Guide. Through a Virtual Tour Guide, personalized tours can be provided for the visitors throughout the VE. Personalizing a Virtual Tour is a complex process that involves the modeling of the visitor's profile, analysis of the visitor's behavior, and definition of the Virtual Tour Guide's responses and learning techniques.

Based on studies by Falk and Dierking [3], Leinhardt [5] and Serrell [9] on how the users' behavior and attention can be defined and tracked, we can help the user in his/her learning process by taking into account his/her behavior and dynamically adapting the Virtual Avatar's method of information presentation and user interaction.

For our research, we have chosen the cultural topic of the Peranakans specific to the Singapore region. Peranakans are an important part in the history of Singapore. They are descendants of an early Chinese community that settled in the Malay archipelago since the 17th century. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the Malay. This unique community developed distinct customs, cuisine and even their own language, as they blended Chinese and Malay ways of life to form a new and rich culture. We will delve into these areas of their culture and recreate their cultural history through VR technologies.

The following sections describe in more detail the different types of user interaction and user modeling for personalizing Virtual Tours and give a brief introduction to the Chinese calligraphy brush interaction.

2.2 User Interaction

The information that is stored in the system is divided in prioritized details that can include audio, text, images, or even video. The Virtual Tour Guide can play a passive role and the visitor only requests information to his/her needs. Alternatively, the Virtual Tour Guide can provide a guided tour of the VE. Here the visitor expects the Virtual Tour Guide to provide him/her with all the essential and important information on the Virtual Exhibits. It is also possible that both, the visitor and the tour guide play an active role. The visitor can request recommendations and advice from the Virtual Tour Guide but does not necessarily have to follow his guidance. In this case, the Virtual Tour Guide can learn the most about the visitors and even define new user profiles.

2.3 User Modeling

Users are modeled by using the concept of stereotypes. Each user has a user profile that describes, among others, interests, state of knowledge, methods of presenting information, age, and time. This profile allows for the presentation of information relevant to the user. For example, if the user is residing in the same city or country where the DH exhibition is being held, additional information that is applicable to real-life experiences such as traditional food and restaurant recommendations can be provided. Also, if the user is in a certain age profile, the information can be presented in alternative ways. For example, if the user is young, the Virtual Tour Guide can put priority on presenting the information in a more multimedia or game-oriented manner. Other customizations can include guided tours through only the important exhibits for time-constrained visitors.

2.4 Calligraphy Brush

The calligraphy brush is an integral part of the Chinese cultural heritage and offers new and extendible ways of exploring DH scenarios. It provides a natural way of interacting within a VE where it can be used as a writing tool and also as a navigational tool without much effort. It fits well into the Peranakan DH scenario where many users are already familiar with the brush in every day life and little time is needed to learn how to use this interaction device.

3. Development and Implementation

3.1 System Overview

Figure 1. shows the main components of our DH system. The following sections will describe the development and implementation of each section in detail.

Figure 1. System Overview

3.2 Virtual Tour Guide and Peranakan Object Library

The following sections describe the modeling techniques for creating the Virtual Tour Guide and his surroundings. The goal is to provide a high quality virtual environment suitable for real time rendering.

3.2.1 Virtual Tour Guide

The Virtual Tour Guide we have created for our project is of Chinese ethnicity to fit the Peranakan profile dressed in traditional Peranakan clothing. The techniques for creating our Virtual Tour Guide are specified below.

3.2.1.1 Face Modeling

The face was created using the nurbs modeling technique. We chose this technique because nurbs modeling provides a better representation of organic shapes. Moreover, it also provides better techniques for creating the base viseme sets. Visemes represent the mouth shapes/positions of a particular sound in speech. The basic viseme sets were then exported into a polygon mesh. The viseme faces that have been created are used as the basic morph-targets for lip syncing. Morph targets are the state of the face that represent a particular phoneme which is used to blend into the other faces with the appropriate audio sound input. The face is then animated in real time.

3.2.1.2 Character Modeling

The body of the Virtual Tour Guide was modeled using the subdivision surface modeling technique. We chose this technique over nurbs modeling since the body and clothing did not require high-level organic modeling. For optimization purposes, we did not model any part of the body that is not shown. The body was then mapped to a base hierarchical skeleton capable of generating the weight influence from each bone of the skeleton to each vertex of the geometry. Motion studies have been carried out in conjunction to generating basic animation sets. Figure 2. shows the skeletal setup of the Virtual Tour Guide.

3.2.2 Peranakan Object Modeling

The Peranakans have a rich material culture in a variety of areas such as ceramics, furniture, and embroidery and silverware. High-quality textures were used to present these 3D models in the object library. An extensive library of Peranakan objects are currently being built capable of fast real time rendering. For data acquisition, we have gathered information on the Peranakan material culture by visiting Peranakan museums exhibits, through specialized books on the Straits-Chinese, and through actual heritage site visits. Figure 3. shows some examples of the heritage objects.

Figure 2. Virtual Tour Guide Skeleton Setup and Motion Study

Figure 3. Examples of Peranakan Material Culture

3.3 Digital Storytelling Techniques

3.3.1 Providing Knowledge for the DH Scenario

Knowledge in the DH scenario is represented as a weighted graph of interconnected exhibits. The exhibits represent the nodes of the graph. An exhibit is either a detail that represents additional information or a neighbor that represents a similar exhibit (as shown in Figure 4). The more

interested the visitor is, more details are provided by the Virtual Tour Guide. The neighbors are used if the visitor wants to see or know more about similar or related exhibits. Through this categorization, it is possible to have a certain exhibit in many contexts, whereby the context is a story in which an exhibit is mentioned. For example, one context can have the exhibit as a detail while another context has the same exhibit as a neighbor. The context of the exhibit plays an important role in defining the routes and recommendations in the DH scenario. The main idea is to distinguish between the importance of an exhibit in the whole scenario and the importance of an exhibit in a particular context. If an exhibit has already been visited but its context importance is very high, the Virtual Tour Guide might mention that exhibit again in another context.

Figure 4. Knowledge represented as a graph of interconnected exhibits

3.3.2 User's Behavior Tracking and Virtual Tour Guide Learning

The behavior of the user is tracked by looking at the object holding power which is the time a user spends in front of an exhibit, the attention that a user gives to the avatar, and the requests for additional information. In interpreting the visitor's behaviors, two learning strategies are defined in this work: *positive* and *negative* learning.

If the visitor spends more time in front of an exhibit than the exhibit's holding time, attraction is detected and positive learning is established. Positive learning increases the weight of exhibits.

Negative Learning is established when the visitor requests assistance and/or recommendations from the Virtual Tour Guide but does not follow the recommendations. In this case the Virtual Tour Guide decreases the weight of the connection to the recommended exhibit since it did not attract the visitor. After more visits, the knowledge network refines its weights and becomes "smarter". The result of the learning is the *universal visiting path*. The universal visiting path is the path that is most likely to be suitable for new visitors since the majority of previous visitors selected this path. But as each visitor's interests may vary, the weighted network can be uniformly distributed. In such a weight-distributed network, it is hard to define the most visited path since all edges only have slightly different weights.

To avoid such problems, the groups of visitors with the most similar visiting paths are identified and a group profile of those visitors is created. In that profile, the weights of the knowledge network are saved as well as all other static information about the visitors such as the age, place

of residence, time for visit and area of interest. New visitors are then assigned to the appropriate profiles and the saved weights of the network are used for recommendations.

3.4 Interacting with the Virtual Tour Guide

3.4.1 Methodology

The interaction method has to support different kinds of user interactions with the Virtual Tour Guide such as the navigation, the access of additional information, and the selection of options. Among the visitors there will be users that have no experience with VR technology. Therefore, the interaction method has to be intuitive and easy to use. Users must be able to learn how to use the VR system within minutes by either observing other users or through an introduction. Furthermore, the interaction method should correlate with the content of the application making the DH application seamless. Examples for tangible interaction devices are the Virtual Dunhuang Art Cave [6] where the user uses a flashlight to explore the cave and Cave Painting [4] where an aerosol can is used.

For our DH application, a Chinese calligraphy brush is used as an interaction device. The visitor holds the brush in one hand and a small board in the other hand. The visitor can use the brush either to write Chinese characters and symbols on the board or to point with it at the screen for navigational purposes. The user writes specific characters and symbols to request additional information and to select exhibits or other options. It is also used to execute simple commands within the VE, for example to call the Virtual Tour Guide. Pointing with the brush at the screen indicates the direction the visitor wants to walk. Writing and navigating with the Chinese Calligraphy brush is described in more detail in the following sections.

Figure 5. Calligraphy Brush Interaction Setup

3.4.2 Writing with the Chinese Calligraphy brush

Whenever the visitor uses the brush to write on the board a virtual model of the brush and the board appears on the screen. The writing is reflected on the virtual counterpart board and provides the user with visual feedback. To match the content of the application, the visitor has to write a simple Chinese character in order to execute a command that is assigned to it. So far, very simple Chinese characters that are easy to memorize and use are defined. These characters are even suitable for visitors with no command of Chinese. The Virtual Tour Guide shows the visitors how to write these Chinese characters and explains their functionalities during the introduction. The

Chinese characters are also displayed on the screen as a memory aid. Visitors not familiar with Chinese can gain their first experiences in writing Chinese. Therefore, the interaction device itself can be regarded as an exhibit of the DH environment and it increases the edutainment value of the application.

3.4.3 Navigating with the Chinese Calligraphy brush

If the visitor does not follow the Virtual Tour Guide, he/she can alternatively use the Chinese calligraphy brush to navigate in the VE. Pointing with the brush at one of the four sides of the screen either rotates the visitor or moves her/him into the scene or out of it. Due to this simple navigation instrument, navigation is restricted to walking on the ground. The brush can also be used to select exhibits and get additional information about it. Figure 6. shows examples of the navigation with the brush.

Figure 6. Navigation with the Brush

3.5 Chinese Character Recognition

Writing with the Chinese Calligraphy brush is realized with the help of a tracking system and by implementing a Chinese character recognition method. The tracking system captures the position and orientation of the Calligraphy brush and the board. An online recognition method is used that receives data while the visitor draws on the board. An example for an online recognition method can be found in [2]. All the data that is collected online while the visitor writes is stored in a chain code. A chain code is a list of concatenated elements where each element describes data that was collected when an imprint was drawn on the virtual board. This data contains the position of the imprint, the time of when the imprint was drawn, and the amount of pressure used. The chain code is the basis for the actual recognition method. Since the system only has to detect a few Chinese characters the recognition method used is based on the detection of strokes. Each Chinese character is composed of a number of single strokes and the strokes vary in position, direction, and length. In addition, the order of the strokes must be kept. Therefore, a Chinese character can be recognized by recognizing the strokes it is composed of and their order. This simple method cannot recognize all Chinese character clearly without ambiguity. However, the characters used for this application were chosen so that they differ in the type and number of strokes. Examples for recognition methods based on the detection of strokes can be found in [1] and [2].

4. Results

Currently, the base components of the interaction methods for the Virtual Tour Guide and the Chinese calligraphy brush have been implemented. The Virtual Tour Guide and its morph targets for speech generation have been built as well as the library of Peranakan material culture objects. The User Models and the Data Models for user behavior tracking and the Virtual Tour Guide learning components have also been developed and will be used for dynamic context generation through the Virtual Tour Guide in the VE. For the calligraphy

brush interaction, we have implemented the first stroke-based recognition method for simple Chinese character recognition and navigational system using the calligraphy brush.

5. Conclusions and Future Work

Developing a DH application involves many areas of expertise, skills, and collaboration from many different backgrounds. To provide for a dynamic DH experience in the VE, close collaborations with cultural experts as well as a “smart” system that is able to track the user is crucial. Intuitive interaction devices specific to the DH scenario is also crucial in enhancing the VR experience of the users. In our research work, we have chosen to use a Virtual Tour Guide that can ‘learn’ the user’s behaviors and intentions and dynamically change the context of the visits personalized for each user. We have also chosen to enhance this experience with the Virtual Tour Guide with the use of a Chinese calligraphy brush to provide further freedom to the users. Future work includes developing more natural facial expressions and animation sets for the Virtual Tour Guide, further exploitation of the possibilities of using the calligraphy brush as an interaction device, implementation of the user tracking system for Virtual Tour Guide learning and personalized virtual tours, and to conduct user test studies to evaluate the proposed interaction methods.

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Cultural Agents and Avatars

expected to be completed in the first half of 2004. In the interests of improving communications with citizens further, the Scottish Executive has been investigating combining the success of Seonaid with the emerging possibilities of colour mobile devices. The pilot scheme has been conceived to test the efficacy, in terms of both technical feasibility and popularity among citizens, of multimedia messaging of Scottish Executive communications. There may also be the possibility to incorporate a range of languages (including sign language) into Seonaid's repertoire as the technology develops. In the words of the Scottish Executive's Finance and Public Services Minister Andy Kerr, 'Seonaid has the potential to... open up Scotland to the rest of the world, and to Scots whose first language is not English, at the touch of a button.'¹²⁰

The Peranakans Project¹²¹

The Peranakans are descendants of an early Chinese community that settled in the Malay Archipelago around the seventeenth century. This unique community developed distinct customs, cuisine, and even their own language, blending Chinese and Malay ways of life to form a rich new culture that enriched Singaporean society.¹²²

The Peranakans project is a digital heritage venture that employs 3D modelling techniques in order to integrate a virtual avatar tour guide with realistic Peranakan heritage objects. The project's objective is to combine state-of-the-art virtual reality (VR) and avatar techniques with the culture of the Peranakans in order to produce an application that will inform users about the history and culture of the Peranakan people. With many heritage and cultural sites being destroyed or lost to urbanisation, pollution, neglect, and even tourism, the need to preserve, restore, and interpret cultural heritage sites in new and innovative ways has increased tremendously over recent years.

The project, which began in late 2001, is likely to run for five years. It is the work of the **Centre for Advanced Media Technology (CAMTech¹²³)**, a joint research and development centre involving the **Fraunhofer Institute for Computer Graphics (IGD)** of Darmstadt, Germany, and the **Nanyang Technological University (NTU)**, Singapore. CAMTech is a member of **INI-GraphicsNet**,¹²⁴ and the CAMTech project team currently comprises two Directors, Dr Wolfgang Mueller-Wittig and Dr Tony K.Y. Chan, and two Research Engineers, Meehae Song and Thomas Elias. The CAMTech

Synchronising avatar lip movements with speech

120 <http://www.scotland.gov.uk/pages/news/2002/07/SENW058.aspx>

121 This case study is based on an e-mail questionnaire completed by Meehae Song and Thomas Elias of the Centre for Advanced Media Technology in November 2003, and on material available from the Web. All sources are given in footnotes.

122 http://www.inigraphics.net/publications/topics/2002/issue5/5_02a06.pdf

123 <http://www.camtech.ntu.edu.sg/index.html>

124 <http://www.inigraphics.net>

team has benefited from access to expertise developed on other INI-GraphicsNet digital heritage projects such as the *Dome of Siena* project, which was showcased at the *EXPO 2000* in Hanover, Germany.¹²⁵

The project has two chief research objectives:

1. To recreate a high-quality, three-dimensional scenario of a complex digital heritage environment, capable of real-time rendering using virtual reality technology;
2. To develop and use transparent and intuitive, context-specific, and user-friendly interaction techniques.

In developing a project of this type, a first step must be to select the cultural and historical content that will be digitally recreated and presented. Preliminary research has been carried out on Singapore-specific cultural and historical content, and this research continues via a collaboration between CAMTech and Peranakan experts.

The Virtual Tour Guide in his chamber

The Virtual Tour Guide in his chamber

Technical work on the project has so far centred on the development of a Virtual Tour Guide (VTG) for directing visitors around the virtual environment. In keeping with the Peranakan profile, the VTG is of Chinese ethnicity, and is dressed in traditional Peranakan clothing. The VTG interacts with visitors by showing them around the Virtual Environment and providing information on Peranakan history and culture. The VTG talks to the visitors, and also provides supplemental information in the form of text, images and video. A visitor can explore the Virtual Environment and all the objects it contains by walking through the virtual rooms alone, or the visitor may ask the VTG for a guided tour. During the tour the visitor follows the VTG and receives additional information on exhibits. The visitor can interact with the VTG at any time: if she wants additional information on an interesting exhibit, she simply selects the exhibit and calls on the VTG to provide further information.

As well as the avatar tour guide, a Chinese calligraphy brush has been implemented as an interface, allowing users to execute commands and move around the virtual environment. The VTG is used to introduce new visitors to the Virtual Environment, and to show them how they can use the brush for interaction. He explains the Chinese characters that the visitor can write as commands/instructions, together with their associated functionalities.

125 Behr, J., Fröhlich, T., Knöpfle, C., Kress, W., Lutz, B., Reiners, D., Schöffel, F. (2001) "The Digital Cathedral of Siena – Innovative Concepts for Interactive and Immersive Presentation of Cultural Heritage Sites", in *Proceedings of ICHIM 2001*, pp. 57–71.

Cultural Agents and Avatars

The impetus behind the decision to use avatars was based on the conviction that they contribute towards a much more compelling learning environment than static and passive interfaces. A virtual avatar seemed to be the natural interface for user interaction as it replicated real work modes of communication. Given CAMTech's expertise in VR technology, the team was able to recreate fully immersive environments of historical heritage objects and environments that can be entered and viewed in real-time. By providing innovative interaction techniques and methodologies that are specific to the reconstructed environment, a relevance of interface to content is created, which aids understanding of the historical and cultural content. This leads to a 'learning-by-doing' scenario, wherein the user is able to participate actively in the virtual environment rather than merely experiencing it as a passive observer. Learning-by-doing scenarios have been proven to be more effective than conventional (passive) learning techniques. The application's main goal is to educate the public effectively on the history of the Peranakans and their culture. By using VR technology with the tour guide and the calligraphy brush as the interface between the application and the user, the project allows users to 'enter and explore' the virtually recreated 3D environment, thus enhancing the learning curve.

Peranakans Chinese calligraphy brush

The Virtual Tour Guide and his moving parts

The 3D Modelling for the VTG and the various exhibits and architecture for the Virtual Environment was carried out using **Discreet's 3D Studio Max** and **Alias's Maya**.¹²⁶ The VTG's modelling is divided into two parts: face and body modelling. For the face modelling, a base face was created and viseme 'face-sets' were derived from the base head.¹²⁷ The base head uses the different visemes as targets to 'morph' between the mouth shapes to create an appropriate relationship between mouth form and the analysed sound files for speech generation. The VTG's body was modelled and mapped to a base hierarchical skeleton in order to generate animation sets to support movement such as walking and climbing stairs.

Both in-house software and *OpenSG* were used for the real-time visualisation. The source code of both systems is available to the programmers, and it can be adjusted to suit a range of needs. This made possible the skin and bones system, and the avatar's speech generation. The Chinese calligraphy brush was chosen for the interaction tool because it is unique, fun, and fits the Peranakan context well. The brush is tracked by an electromagnetic tracker, a device that the team has employed effectively on earlier projects. An interface for this tool had been developed for a previous project, and this code was reused without any need for modification.

126 <http://www.discreet.com/3dsmax>; http://www.alias.com/cng/products-services/maya/maya_unlimited/index.shtml

127 Visemes are the mouth positions/shapes of a particular sound in speech.

Real and virtual brushes

The only suitable alternative technology to OpenSG was Java3D. OpenSG offers superior performance and flexibility when compared with Java3D. So far, creation of the avatar has been the most challenging part of the project. The skin and bone system and speech generation required to realise the avatar were the deciding factor in the choice of C++ and OpenSG. All of the 3D models are exported to Virtual Reality Modelling Language (VRML¹²⁸) format.

As Maya's standard VRML exporter does not export the avatar textures (skin and bone, and other materials) satisfactorily, the team had to write their own exporter for this purpose.

The implementation of avatar technologies lies at the core of the Peranakans project. The VTG avatar increases the edutainment value of the application. It also establishes a user interface that is much more personal and natural than those driven by buttons or menus. The tour guide analogy makes his purpose immediately understandable. Visitors come with expectations of tour guides; for example, they know the VTG can show them around, give information on exhibits, and answer questions where conventional buttons and menus may not be so intuitive.

The CAMTech team has developed a demonstration program that shows a three-dimensional Peranakan chamber complete with selected furniture models. The purpose of this program is to test the real-time rendering of the 3D models, as well as the user interaction with the calligraphy brush. Visitors can use the brush to navigate around the environment by pointing with it at the screen, or they can write simple Chinese characters with it to execute commands. This is trickier, and visitors usually have to try it a few times before they can manage to form characters that the system recognises. This is due to the simple recognition method used by the system; visitors must write the character stroke by stroke, and lift the brush off the writing board between strokes.

Evaluation and user testing of the VTG remain to be done. Future evaluation will include analysis of user interaction with the avatar; visitors will be encouraged to select questions, ask the VTG for recommendations and advice, and follow him during a tour. Close collaboration with Peranakan content experts will continue in order to construct a detailed and content-rich portrayal of the Peranakan culture. Other development tasks include constructing a storyboard, the enhancement of the Peranakan object library with more digital cultural artefacts, improved natural behaviours for the VTG, and a more intuitive and seamless interface between the virtual and real environments. One major benefit of this avatar model is that it can be repurposed for other applications simply by changing its outfit, underlying information database, and behaviour settings.

There are many potential future application areas for this project. While the application serves as content for the local market in Singapore and the outlying regions, the intuitive character will make it an effective vehicle for reaching a global audience. Within the Singapore market, there are few ongoing digital heritage projects and almost none with CAMTech's extensive expertise. The team hopes to create a niche market for digital heritage applications specific to Singapore and its region, by diversifying its focus into applications such as museum installations, the World Wide Web, and games.

128 For more on VRML and Java3D, please see *DigiCULT Technology Watch Report 1* (pp. 98-100 and 102).

Digital Heritage Application as an Edutainment Tool

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Abstract

With the fast-growing technological advancements in Virtual Reality (VR) technology and easier access to more affordable computer graphics hardware, it has become possible to create a diverse range of VR applications that are not only geared towards scientific research and medical training applications but also for “edutainment” purposes for the general public. “Edutainment” is an upcoming field that combines education with entertainment aspects thus enhancing the learning environment to be much more engaging and fun-filled. In this paper, we describe a project on a Digital Heritage application aimed to serve as an edutainment tool. The visitors are able to virtually “enter and explore” the reconstructed heritage environment and learn more on the presented content through virtual experiences. We have incorporated a Virtual Tour Guide that presents the cultural and historical content through non-linear digital storytelling techniques for the dynamic content creation to fit the changing profiles and needs of the visiting audience.

CR Categories: I.3.6 [Computer Graphics]: Methodology and Techniques - Interaction techniques; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Animation and Virtual Reality; I.2.4 [Artificial Intelligence]: Knowledge Representation Formalisms and Methods - Semantic networks

Keywords: Digital Heritage, Non-linear Storytelling, Virtual Tour Guide, Virtual Reality

1 Introduction

Interactive storytelling techniques coupled with Virtual Environments (VE) provide the visitors a chance to explore the VE through an interactive scene. In an interactive scene, the virtual object the visitor interacts with has the ability to dynamically respond to the needs and profiles of the specific visitor/user. The content that is presented is highly customizable in the sense that the visitor’s profiles and the specific needs are considered in the content creation every time certain information is presented.

In our application, we have incorporated interactive storytelling techniques to a Digital Heritage application. Our main goal is to present historical and cultural content of the reconstructed 3D VE to the general public in a pedagogical and entertaining way. We believe interactive storytelling techniques can enrich the process of exploring the VE since each visitor can walk away with a different virtual experience. The reason we have chosen to develop a Digital Heritage application is because presently, there is a need to preserve heritage sites in new and innovative ways. Heritage sites are being destroyed to many factors including urbanization, neglect, pollution, and even tourism and new ways to conserve, preserve, and interpret cultural and natural history need to be employed. Many heritage sites are being reconstructed through VR technologies ranging from digital archives, archaeology, architecture, museum installations, augmented reality and VR, virtual GIS, to 3D image reconstruction. Most importantly, VR technology presents new and innovative ways to experience and interact with the reconstructed cultural heritage sites with many new possibilities.

In this paper, we present a framework for developing a Digital Heritage application. As part of the intuitive interaction, we have incorporated a Virtual Tour Guide who guides the visitors around the VE and presents customized content.

This paper is organized as follows. In Chapter 2, we present the concept of our application and in Chapter 3, we present our framework and a detailed view into the different sections of the framework. Finally in Chapter 4, we conclude and present future work.

2 Concept

Creating compelling stories that can constantly engage the visitor’s attention and participation in Virtual Environments is a challenge. In order to create a fully immersive and interactive Digital Heritage environment that can capture the visitor’s attention throughout the entire virtual experience, we need to not only create compelling and realistic 3D models of the heritage objects, we also need to present the content in captivating ways. This is where the interactive storytelling comes in.

Interactive storytelling is a form of non-linear storytelling. Non-linear storytelling techniques differ from the traditional linear storytelling techniques in that in a linear story, the story begins at one end and goes through a pre-defined sequence and ends at the other end. In non-linear stories, the story consists of a graph of multiple story “nodes” where each “node” is connected to one or more other “nodes”. [Parise]. The connections between these “nodes” represent possible directions the story might take

and the branching from one “node” to the next can be either being random or be based on some sort of division system.

Cavazza [2001] presents the different approaches to interactive storytelling that differ by the respective emphasis on the various aspects of the storytelling such as emphasis on the user [Cavazza et al. 2001, Perlin and Goldberg 1995], the plot [Sgouros et al. 1996], or the artificial characters [Mateas 1997]. In our paper, we have put the emphasis on the user through the implementation of User Modeling achieved through tracking each user and creating a unique profile for each user. Here, the users are modelled by using the concept of stereotypes. Each user has a user profile that describes, among others, interests, the state of knowledge, methods for presenting information, age, gender, place of residence, and time. This profile allows for the presentation of information relevant to the user. For example, if the user is young, the same information can be presented in a more game-like way according to the user model that has been created for that specific user.

Information on the different users and all the possible exhibits are stored in a database in the system. The information on the exhibits is represented as a weighted graph of interconnected exhibits where they are actually the different “nodes” of the graph. In the weighted graph, each of the nodes has a different prioritization which is constantly changing and set according to the profile of the visitor. Each exhibit is selected based on the user’s interests and needs thus this network of interconnected exhibits allows for the dynamic creation of stories unique for each visitor. Section 3.2.3 describes the non-linear storytelling technique in detail.

3 Framework

Figure 1 shows the overall framework for the Digital Heritage application. It is divided into Content Creation and Content Presentation. Content Creation component is the process of gathering information and generating a reusable library of realistic 3D models for the Digital Heritage scenario. All the heritage objects as well as the Virtual Tour Guide are created in this component. Additional information that is shown to the visitors are also created and stored in a database. The Content Presentation component is responsible for displaying the content to the visitors in a pedagogical and engaging manner. To achieve this goal, we have implemented a Chinese Calligraphy brush into the system as a user interaction device to aid the users in navigating around the scenario and executing commands to the Virtual Tour Guide. Non-linear storytelling techniques are incorporated in this component by tracking the visitors and creating the User Models. The following sections will describe the components in greater detail.

3.1 Content Creation

Interesting content selection in any Digital Heritage application is the core of the application. The heritage content has to be rich and abundant not only historically but also culturally, it has to be able to capture the curiosities of the general public and encourage them to come back for more. Being situated in Singapore, it was quite easy for us to select the rich culture of the Peranakans as the heritage content local to Singapore and its region. Peranakans are an important part in the history of Singapore. They are descendants of an early Chinese community that settled in the Malay Archipelago since the 17th century. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the Malay. This unique

community developed distinct customs, cuisine and even their own language, as they blended Chinese and Malay ways of life to form a new and rich culture.

The 3D models that have been created can be broadly categorized into dynamic models and static models.

Figure 1: Overall Framework

3.1.2 Virtual Tour Guide

The Virtual Tour Guide that has been modelled is of Chinese ethnicity and dressed in traditional Peranakan clothing to fit the Peranakan profile. For the face modelling, a base face was created using NURBS modelling techniques and from this base head, viseme face sets were derived. Visemes are the mouth positions/shapes of a particular sound in speech. The base head uses these different visemes as targets to ‘morph’ between the different mouth shapes according to the analyzed sound files.

The body of the Virtual Tour Guide was modelled using subdivision surface modelling techniques and then mapped with a base hierarchical skeleton in order to generate animation sets. The Virtual Tour Guide will have in its library a set of pre-spoken speech for the cultural and heritage content he will present to the visitors and a set of basic locomotion such as walking and climbing up the stairs.

3.1.3 Cultural Objects

The Peranakans have a rich material culture in a variety of areas such as ceramics, furniture, and embroidery and silverware. High-quality textures were used to present these 3D models in the object library. An extensive library of Peranakan objects are currently being built and these objects are capable of fast real-time rendering. For data acquisition, we have gathered information on the Peranakan material culture by visiting Peranakan museums exhibits, through specialized books on the Straits-Chinese, and through actual heritage site visits. Figure 2 shows the Virtual Tour Guide and a Peranakan hall.

Figure 2: Virtual Tour Guide and Peranakan Hall

3.2 Content Presentation

The content that has been created, including the 3D models of the exhibits, video sequences, images, and text spoken by the Virtual Tour Guide, is presented to the visitor in real-time. Visitors can walk through and explore the virtual rooms much like in a real museum. They can also request for more information on the exhibits from the Virtual Tour Guide. However, rather than duplicating the passivity of a museum, our goal is a system that is capable of learning the preferences and interests of the visitors and to show them the specific content they are interested in directly. This is achieved through visitor tracking and nonlinear storytelling techniques. Visitor tracking gathers information from the visitor that indicates the content she/he is interested in. The storytelling uses this information to learn about the visitor, select the right content, and compose a story out of small information chunks.

3.2.1 User Interaction

Visitors can interact with the system in various ways. They can navigate and walk through the virtual rooms and explore the exhibits inside them at their own pace. They can also select exhibits they are interested in to get more information. Visitors can also interact with the Virtual Tour Guide. They can call him whenever they need to ask him questions that they select from menus. Visitors can also follow the tour guide and take part in an interactive tour, stop the tour whenever they wish, and continue it later.

We utilize an interaction method that is easy to use, correlates with the content of the Digital Heritage application, and increases its edutainment value. Such interaction methods have been used in other Digital Heritage applications. An example is the Dunhuang Art Cave where a flashlight is used [Lutz and Weintke 1999]. We are using a Chinese Calligraphy brush as an interaction device. Calligraphy is an art dating back to the earliest day of history and a very familiar tool to the Asian culture. The visitor holds the calligraphy brush in one hand and a small drawing board in the other. She/he can use the brush either to write Chinese characters and symbols on the board or to point with it at the screen in order to navigate and select exhibits and menu items. The Virtual Tour Guide introduces new visitors to the usage of the brush and board and explains Chinese characters that the system understands. A tracking system is used to detect the position and orientation of the brush and board. A simple ray test shows whether the visitor points with the brush at the screen or writes on the board. The ray originates at the position of the brush and runs through its handle and tip. The navigation is restricted to walking on the ground. The visitor turns to the left or right when she/he points at the appropriate side of the screen and moves forwards and backwards when she/he points at the top or bottom of the screen, respectively.

Chinese characters can be written on the drawing board to execute commands. An example is the Chinese character “Ren” which means “Person”. It is used to call the Virtual Tour Guide. All Chinese characters consist of strokes that have to be written in a specific order. We utilize an online Chinese character recognition that analyses the strokes while the visitor writes them. Afterwards it looks up the Chinese character that matches the recognized stroke sequence. Examples for recognition methods based on the detection of strokes can be found in [Amin and Sum 1993] and [Calhoun et al. 2002]. We only use Chinese characters that consist of a few strokes and hence are easy to memorize and can be written quickly. The character

“Ren” for example only consists of two strokes. These characters are also suitable for visitors with no command of written or spoken Chinese. These visitors can gain their first experiences in writing Chinese which makes the interaction device itself a part of the culture to be explored.

Figure 3: Calligraphy Brush Interaction

3.2.2 Visitor Tracking and Visitor Profiles

In order to create a personalized tour with content that is interesting to the current visitor, the Virtual Tour Guide has to know who the visitor is and track his/her behaviour. Each new visitor is asked to fill out a short survey. If she/he is willing to complete it, the Virtual Tour Guide creates a profile from the obtained information such as age, gender, and place of residence. Besides this basic data, the Virtual Tour Guide constantly tracks the behaviour of the visitor. Tracking the way the visitor moves around and interacts within the virtual scene can provide information that shows if the visitor is bored, excited, or interested in a particular exhibit. The three most important parameters to track are Object Holding Power, Attention, and Request. The Object Holding Power as defined by Serrell [1997] is the time that a user spends in front of an exhibit. The Virtual Tour Guide assumes that the longer the time, the more interested the visitor is. The second parameter that is tracked is the attention that the visitor gives to the Virtual Tour Guide by following his recommendations. If a visitor follows a recommendation it can be concluded that she/he is interested in the appropriate exhibit or topic. The third parameter measures how often a visitor requests information from the Virtual Tour Guide and what kind of information she/he wants to know. A high number of requests indicate interest. All the gathered data, such as which rooms have been visited and which exhibits have been viewed are the tracked parameters that are saved in the profile and can be used immediately and thus affect the remainder of the tour or the next tour when the same visitor returns.

3.2.3 Nonlinear Storytelling

The Virtual Tour Guide imparts information to the visitor by using nonlinear storytelling techniques. Rather than following a predefined tour and listening to a story that is the same for all visitors, the visitor is allowed and encouraged to make choices that determine the development of the tour and story. This is made possible by segmenting the information in small and easily-understood information chunks. These information chunks can be combined according to the choices and preferences of the visitor that are stored in the profile and constantly updated by the visitor tracking. The result is a personalized tour. Nonlinear Storytelling techniques have been utilized in numerous systems. Examples can be found in [Braun 2002] and [Clanton et al. 1998].

The following two sections explain two integral parts of nonlinear storytelling. The first addresses the hierarchical

relationship between the information chunks and the second describes the learning system that enables the Virtual Tour Guide to select the relevant information chunks.

Nonlinear storytelling relies on a hierarchy of relationships between information chunks. The hierarchy defines in which way the information chunks can be combined. We chose a weighted, bidirectional graph of interconnected exhibits as the overall hierarchy for our Digital Heritage scenario. Each node of the graph contains all the prioritized information chunks about one exhibit. These information chunks can be text, that the Virtual Tour Guide narrates, or videos, images, and other media that can be shown to the visitor. The edges between nodes represent a relationship between exhibits. All edges outgoing from one node make up the various ways in which the story and tour can continue.

Figure 4: Information Hierarchy for Linear and Nonlinear Storytelling

The Virtual Tour Guide decides which of the information chunks of the current exhibit he presents. Depending on the interest of the visitor that can be one or more. He also chooses one of the outgoing edges to continue the story and tour with. The Virtual Tour Guide uses his learning system and the profile of the visitor to make these selections. In addition, the visitor can ask for specific information or exhibits directly.

Due to the chosen hierarchy it is possible that a visitor is presented with information about the same exhibit but at a different time and in a different context. We distinguish between the overall importance of exhibits and their importance in a particular context. An example is an exhibit like a silver plate. It can be shown and mentioned in the context of arts and crafts. If, at a later point in time, the story deals with the dining room, the Virtual Tour Guide may decide that it is important to show and give information about the same silver plate even though the visitor has seen it already. However, he will choose information chunks that were not presented to the visitor before.

The learning system of the Virtual Tour Guide uses the visitor profile and the information hierarchy to decide on how to proceed with the story and tour. The result of one learning step is a modification of the weights and priorities in the information hierarchy graph. The Virtual Tour Guide uses local and global learning. Local learning only uses data that the current visitor provides, whereas the global learning uses data collected from all visitors.

The local learning is a concept of an activation network. After the visitor tracking detects that the visitor is interested in an exhibit, the local learning increases the importance of this exhibit and also increases the importance of all exhibits that are near the selected one by increasing the weight of outgoing edges. The visitor's interest is detected when she/he either spends more time in front of an exhibit than the exhibit's holding time or request information on this exhibit. Learning by increasing the weights of exhibits is called positive learning. We also utilise negative learning whereby the weights and priorities are decreased. This happens when the visitor is obviously not interested in an exhibit. This is detected by the visitor tracking when the visitor passes by an exhibit or when she/he does not follow the Virtual Tour Guide's recommendation to take a look at an exhibit. The local learning can have an immediate effect on the visitor because the Virtual Tour Guide immediately uses the modified graph to decide on the next exhibit. The adjusted weights and priorities are stored in the visitor profile. They reflect the preferences of this visitor and have no immediate effect on other visitors. The next time this visitor uses the application, the values of the information hierarchy graph will be adjusted according to her/his profile. Other known visitors have their own version of the information hierarchy graph. New visitors start with the default one that is defined by the global learning.

The global learning analyses the profiles of all visitors. This is triggered whenever a visitor leaves or after a defined time period. Modifications of the global learning can have an effect on all visitors. One goal of the global learning is to verify and adjust the three parameters Object Holding Power, Attention, and Request that are tracked for each exhibit. The second goal is to adjust the weights and priorities of the default information hierarchy graph for new visitors. Since the Virtual Tour Guide does not know the interests and preferences of new visitors, he shows them the exhibits that were interesting to the majority of previous visitors by using the default graph and following the edges with the highest weights and presenting the information chunks with the highest priorities. The global learning is dependant on and improves with the number of visitors.

The Virtual Tour Guide also has a small set of behavioural states with transitions between them. These states are used to trigger different interventions of the Virtual Tour Guide. An intervention means that the Virtual Tour Guide appears in front of the visitor even if he was not called. This happens when he has to inform the visitor about important information. An example is when the visitor passes by an important exhibit that she/he has not seen. Another example for an intervention is offering assistance when the visitor seems to be lost or has problems navigating. The transition from one behavioural stage to the other is triggered and controlled by the visitor tracking.

4 Conclusions and Future Work

In this paper, we presented a framework for developing a Digital Heritage application. To achieve our goal of creating a dynamic Digital Heritage application that is both pedagogical and entertaining and one that is user-friendly to the general public, we incorporated intuitive interaction methods such as the Virtual Tour Guide and the Chinese Calligraphy brush and well as non-linear storytelling techniques that presents customized content based on visitor tracking and visitor profiles. The Virtual Tour Guide is able to 'learn' the user's behaviours and intentions and dynamically change the context of the visits personalized for each user. Integration of a Chinese calligraphy brush provides further freedom to the users.

Future work includes developing more natural facial expressions and animation sets for the Virtual Tour Guide, further exploitation of the possibilities of using the calligraphy brush as an interaction device, further implementation of the user tracking system for Virtual Tour Guide learning and personalized virtual tours, and to conduct user test studies to evaluate the proposed interaction methods.

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Using the Chinese Calligraphy Brush as a Tangible User Interface Tool in Virtual Heritage Scenarios

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Abstract

This paper first presents a Virtual Heritage scenario and then discusses the implementation of using a Chinese Calligraphy brush as a tangible user interface tool to fit the context of this scenario. It then closely looks at how the brush has been implemented with basic and extended functionalities to the man-machine interface of the presented virtual environment.

Keywords : Virtual Reality, Virtual Heritage, Chinese Calligraphy brush

1 Introduction

As Virtual Reality (VR) applications become more widespread and diverse thanks to the technical advances in VR technology and easier access to faster and more powerful computing power, researchers are constantly thinking of new ways to naturally interact within these Virtual Environments (VE). There exists a variety of input and output devices to interact with these VEs and many are commercially available. Such devices include the dataglove, spacemouse, and magic wand to name a few. [1] What is the overarching goal of a Virtual Reality experience? Many opinions exist but one can say the ultimate goal of a VR experience is to create a *seamless interface*, one the users feel so natural and comfortable with that they barely notice the existence of the intermediating interface. [2] We do not try to solve this overarching goal but attempt to come one step closer to it by using objects that we find in daily life such as props as an interface tool to create a more natural environment for interacting within the VE. Props are physical objects used as an interface tool to a virtual world. [2] Using props in VEs is advantageous since the physical properties of a prop often suggest its use in a VR experience and also can provide some kind of haptic information to the user.

In this paper we present a Virtual Heritage (VH) scenario on a Singapore specific cultural heritage model and propose a new interaction tool – the Chinese Calligraphy brush. We first present a framework for developing real-time Virtual Heritage applications and then present the Chinese Calligraphy brush that incorporates the idea of

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using the brush as a 3D interaction device both as a writing tool and as a navigation tool. Finally we present the conclusions and the future work.

2 Motivation

With many heritage and cultural sites all over the world being destroyed or lost to urbanization, pollution, neglect, war, and even tourism, there lies a great potential in utilizing VR technology to preserve, restore, and interpret cultural heritage. By using VR technology, fully immersive environments of historical heritage objects and environments can be digitally recreated and entered and viewed in real-time. Providing innovative interaction techniques where the users can directly interact within these environments aides in the understanding of historical and cultural content by providing the user with a 'learning-by-doing' scenario. 'Learning-by-doing' scenarios are proven to be much more effective than passive learning techniques.

We have selected the *Peranakans* as our heritage model because the Peranakans are an important part of understanding Singapore's history and little work has been carried out in the virtual heritage realm to recreate their identities as of yet.

The Peranakans are descendants of an early Chinese community that settled in the Malay Archipelago at least since the 17th century [3]. Peranakans evolved as a result of intermarriages between these early Chinese settlers and the indigenous Malay since the Chinese women were not allowed to leave the country until the 19th century. This unique community developed distinct customs, cuisine and even their own language, as they blended Chinese and Malay ways of life to form a new and rich culture adding another dimension to the Singaporean society. They played a key role in bringing Malaysia and Singapore to independence [4].

With this scenario serving as a basis, we then selected the Chinese Calligraphy brush as an interaction tool to fit the context of this VH scenario. The Chinese Calligraphy brush has been selected because not only does it offer direct control, it directly involves the user into the virtual experience by giving them an actual brush they can manipulate in the VE. Calligraphy is an art dating back to the earliest day of history, and widely practiced throughout China and other parts of the world to this day. It is a very familiar tool to the Asians since they are exposed to it an early age whether it is at school or other environments. This tool has been chosen as an interaction device for this project because it is very specific to the Chinese and Asian culture thus fitting well into the overall interface and the Peranakan-specific content. Many people in Singapore are of Chinese descent (around 70%) and are also very familiar with Chinese calligraphy. This is an advantage because it provides intuitive interaction by presenting the user a familiar device they can immediately bond with and they do not have to spend time learning how to use this interaction device. Using a calligraphy brush also provides the user with the freedom one is not able to experience when confined to using conventional interaction devices such as the 2D/3D mouse.

3 Framework

Figure 1. shows the overall framework developing real-time Virtual Heritage applications. It is divided into Content Creation Framework and Run-time Framework. The Content Creation Framework is where the process of gathering information and generating a reusable library of realistic 3D models for the Virtual Heritage scenario is carried out. A Virtual Tour Guide is added to this scenario to enhance the communication between the user and the environment. A good example of using Virtual Avatars in man-machine communication in real-time applications is presented in the work of Rieger[5]. In their work they use morphing techniques [6] for high-quality features. This Framework is responsible for displaying the content to the visitors in a pedagogical and engaging manner. In the Run-time Framework, Chinese Calligraphy brush is implemented and incorporated into the system as a user interaction device to aid the users in navigating around the scenario and executing commands to the Virtual Tour Guide.

Figure 1. Virtual Heritage Application Framework

The next two sections look at the implementation of the User Interface in detail.

4 Content Creation Framework : Virtual Heritage Scenario

The 3D content for the Virtual Heritage scenario can be further classified into the Virtual Tour Guide and the cultural artifacts of the Peranakans. All the 3D models have been created as reusable library objects. The Virtual Tour Guide has been modeled with a

base head, 15 viseme heads for speech generation, and several facial expressions such as blinking/smiling/frowning. Visemes are the mouth positions/shapes of a particular sound in speech. The speech is generated through morphing the viseme heads. A basic set of locomotion libraries have also been modeled for the Virtual Tour Guide including walking, climbing up/down stairs, and turning.

Figure 2. Virtual Tour Guide

The architecture to house all the rich material cultural artifacts has also been modeled in its own set of libraries. The reconstructed 3D objects must ensure fast real-time rendering thus high-quality texture maps were use to represent the different categories including ceramics, furniture, and embroidery and silverware.

Figure 3. Peranakan Shophouse and Sample Cultural Artifacts

5 Run-time Framework : Overview of the User Interface

We adopted a two-handed tangible user interface for our Virtual Heritage application. The user holds a Chinese Calligraphy brush in one hand and a small writing board in the other. The complete interaction can be done by writing simple Chinese characters on the board or by pointing with the brush at the screen to navigate or make selections in menus. Tangible user interfaces have been successfully used in other Virtual Heritage applications. An example is the Dunhuang Art Cave where a flash light is used to navigate around the scene [7].

We chose a Calligraphy brush because we wanted the interaction device to fit the content of the application. Calligraphy is a widely practiced art and a familiar tool in Asia. Therefore, the interaction device itself is an integral part of the culture that our application presents. Since most of the users are of Asian ethnicity they are already familiar with the brush and less likely to be apprehensive of the new technology.

The design and development of the user interface can be subdivided in the four parts “Physical Setup”, “Chinese Character Recognition”, “Navigation”, and “Menus”, all of which are explained in more detail in the following sections.

5.1 Physical Setup

We are utilizing an electromagnetic tracking system to detect the position and orientation of the brush and the board. Figure 4. shows a top view of the user (1) holding the brush (3) and the board (2) as well as the tracking system and emitter (4), and the screen (5). Two sensors are used for the brush and the board, respectively. Their movement is detected relatively to the position of the emitter. In order to calculate the position of the board and brush and to detect whether the user points at the screen or draws on the board, the position of the emitter, the position and dimension of the screen, the length of the brush, and the dimension of the board must be known and cannot be changed while the application is running.

This setup works well with any kind of screen. However, it is easier to use the brush to point at objects if the screen has a diameter of at least 70 cm. We are using back projection which allows for a sufficient big screen size and minimizes disturbances of the tracking system.

Figure 4. Schematic Physical Setup

5.2 Chinese Character Recognition

Using the brush and the board, users can write Chinese characters that are associated with specific commands that the system understands. We defined five simple Chinese characters that are easy to memorize and write and thus even suitable for users who are not familiar with the Chinese language. Four characters are for navigational purposes. The characters “One” and “Two” take the user to level one and two of the virtual house. The characters “Sun” and “Middle” take the user outside of the house or to the centre. The fifth character “Person” is used to call a Virtual Tour Guide. We found that making the user write Chinese characters increases the “Edutainment” – value of the application and gets the user in touch with the culture.

The user writes by moving the brush on the board but not actually using any real ink. While the user is writing, a 3D model of the board appears on the screen and gives the necessary visual feedback on what is being written.

We developed an online stroke-based recognition method to detect the Chinese characters. Modern Chinese characters are written by combining up to twelve basic strokes in a defined sequence. Thus, the complete character can be recognized by detecting each stroke, its relative position, and the sequence. An online recognition method obtains data while the user writes as opposed to an offline method that gets an image of the complete character. The online method has the advantage, that data on the order, writing speed, and pressure can also be retrieved and used to improve the recognition process. A recent example for an online recognition can be found in [8]. The following figure gives an overview of the most important components of our recognition method.

Figure 5. Cascading recognition method

The position and orientation of the brush and the board are queried within the main loop of the application that is also responsible of rendering the frames of the 3D scene. Based on these positions and the known length of the brush and dimension of the board, a simple ray test is used to determine if the user writes on the board and where the current imprint is. While the user writes on the board data is collected and stored in a chain code. A Chain code is a list of concatenated elements whereby each element describes data of one imprint. This data contains the position of the imprint and the time of when the imprint was made. We found it beneficial to add the amount of pressure used at the moment the imprint was made. Although we do not measure the pressure, we can get an estimate by calculating how much the ray intersects the board. Whenever the user lifts the brush a special element is added to indicate that a stroke has been completed. If the user does not write anything for a predefined period of time the recognition process starts.

We wanted to be able to work with and evaluate different recognition methods. Alpaydin et al. [9] proposed a multistage method called cascading. In their approach, a sequence of classifiers is ordered in terms of complexity where more sophisticated recognition methods are used only after the simpler ones fail. We adopted this approach and use a cascading recognition method that consists of several independent recognition methods that work in parallel or successively. Each recognition method gets the same chain code but analyses it in a different way. Each method tries to recognise the character and accumulates data during the analysis of the chain code. Afterwards, the accumulated data is matched against information stored for each character in its database. Each recognition method has its own database that consists of pairs of data. The first element of each pair is an ID that identifies the character. The second element describes how the character is composed. This is different for each database because it depends on the recognition method and on the data that was accumulated during the analysis of the chain code. The cascading recognition approach is extendable and flexible. It allows for the combination of simple recognition methods that are only able to recognize simple

characters and more complex methods for more complex Chinese characters. Recognition methods can run sequentially or in parallel. When run in sequence, simple recognitions are started first and only if they fail more complex recognition methods are started.

The decision maker controls all recognition methods and chooses the best result if more than one recognition method was successful. For this purpose, each recognition method has a priority assigned to it and returns the ID of the recognized character as well as the error percentage that indicates how accurate the result is. When recognition methods return different results, the priority and error percentage are used to resolve the conflict and to choose the most likely result.

We achieved very good results with a simple recognition method that detects the individual strokes each Chinese character is composed of. The method cannot recognize all Chinese character clearly without ambiguity. But it is more than sufficient for the five characters that we defined. Furthermore, we increased the error margins so that the recognition method works reliably for our character without any prior user training. Examples for recognition methods that utilize the detection of strokes can be found in Amin and Sum [10] and Calhoun et al. [8].

The recognition method subdivides the chain code into smaller segments so that each of them contains the data of one stroke. During this segmentation, comparatively large breaks or variations in pressure are searched. When the user writes a Chinese character, there is a small break between two consecutive strokes. The user also has to lift the brush to move it to the starting point of the next stroke which changes the pressure. Therefore, strokes can be detected by searching for changes in the position, speed, and pressure in the chain code. After the segmentation, the relative position, size, and orientation of each stroke are calculated. During the last step, all the acquired data is compared to the data stored in its database. The database of this recognition method contains the ID of each character that can be recognized and information about the number of strokes, type of strokes, their relative positions, sizes, orientations, and their order. The comparison is done according to predefined priorities. For instance, the correct number of strokes is more important than their correct order.

5.3 Navigation

Our Virtual Heritage application allows the user to move around freely inside historical houses and users can also point at exhibits to get more information about them. Since users should not have to change between interaction devices, we extended the functionality of the Calligraphy brush. In addition to writing on the board, the user can point with it at the screen. A context sensitive cursor appears at the position the user points at. Due to the simplicity of the brush we restricted the navigation to walking on the ground. Pointing with the brush at the left or right side of the screen rotates the user to the left or right. Pointing with the brush at the top or bottom part of the screen moves the user forward or backward. To guide the user, the side parts of the screen that activate the navigation are shaded differently. Figure 6. is a screenshot showing the navigation areas and the cursor while the user is moving backwards.

Figure 6. Navigation with the Calligraphy brush

The Calligraphy brush has no button that the user can press to execute movement in the selected direction. Fixing a button to the brush would degenerate it and make it look odd. Instead, the navigational actions do not occur instantly. Instead, the cursor changes its shape and color and highlights the direction of the movement. If the user keeps the cursor within the area for a defined period of time, the action gets executed. The delay gives the user time to place the cursor somewhere else if no action is desired.

We found that users generally don't have many problems with this kind of navigation. However, the amount of delay is crucial. A long delay makes the interaction with the system slow. If the delay is too short, the system might move into a wrong direction while the user is still selecting one. We are working with 0.5 seconds for experienced users and at least one second for users with little experience with VR technology.

Besides the navigation, users can use the brush to point at exhibits inside the house. Whenever the cursor is above an exhibit, the cursor changes its shape to indicate that it can be selected. If the user keeps the cursor above the exhibit, it becomes selected and information about it is shown.

5.4 Menus

The Virtual Heritage application can run in full stereoscopic 3D. Windows and pop-up boxes provided by libraries of the operating system cannot be used because they are not suitable for stereoscopic display and would only be seen by one eye. Furthermore, our unique interaction device requires special selection methods. These restrictions prompted us to develop our own menu hierarchy and elements.

We make use of menus to help the user navigate around, allow users to make selections, and show requested information. Figure 7. shows a screenshot with the navigation menu

at the bottom and an information menu on the upper right-hand side. The navigation menu shows floor plans of the current room and the position of the user. It also shows the five Chinese characters that the user can write and their name and function. When the user moves the cursor above any of the characters, the sequence on how the respective character has to be written is shown. Information menus show background information on exhibits that the user selects. Currently they can contain images and text and we intend to extend them by other media such as video.

Figure 7. Information- and Navigation-Menus

Each menu can have a set of activation areas. Activation areas are basic menu elements from which more complex ones are derived. They pass a signal to the menu whenever the cursor is above them. They are especially adapted for being used with the brush. The signal is only sent when the cursor was above the area for a specified delay time. Activation areas change their shape as soon as the cursor is above them to give feedback to the user. They can also change their shape at different intervals to show a sequence or indicated the elapsing delay time. Examples are the yellow arrow and the five Chinese characters in figure X.

One way of making menus suitable for stereoscopic 3D is to let them become a part of the 3D scene. Therefore, our menus and menu elements are textured planes that are placed in front of the camera. When the camera is moved, the same transformation is applied to the menu planes so that they always stay in front of the camera. Since they are a part of the 3D scene, correct stereoscopic rendering of the menus is guaranteed.

6 Conclusions and Future Work

In this paper, we presented a framework for developing real-time Virtual Heritage applications. To achieve our goal of creating a dynamic Virtual Heritage application that is both pedagogical and entertaining and one that can appeal to the general public, we incorporated new and intuitive interaction methods with the use of props. A Chinese Calligraphy brush was introduced as a 3D interaction tool as writing and navigation tool tightly integrated into the presented Virtual Heritage scenario. The integration of a Chinese calligraphy brush not only offers freedom to the users to navigate and interact with the VE, it also engages users of non-Chinese background into the VE as an active participant where they have a chance to learn and write simple Chinese characters. The interaction with the brush is kept simple to avoid changing the interaction device for a more seamless VR experience.

Future work includes further exploitation of the possibilities of using the Calligraphy brush as an interaction device and to conduct user test studies to evaluate the proposed interaction methods.

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Vitae

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Figure Captions

Figure 1. Virtual Heritage Application Framework

Figure 2. Virtual Tour Guide

Figure 3. Peranakan Shophouse and Sample Cultural Artifacts

Figure 4. Schematic Physical Setup

Figure 5. Cascading Recognition Method

Figure 6. Navigation with the Calligraphy brush

Figure 7. Information- and Navigation-Menus

Figures

Shophouse	Reclining Chair	Small Kuan Shaped Spittoon

Red Slippers	Sireh Casket Cup	Dressing Table