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Exploring the Use of Robots for Museum Settings and for Learning Heritage Languages and Cultures at the Chinese Heritage Centre

Abstract

In this article, the challenges facing museums to offer more ways to provide information for learning have been reviewed. The use of social robotics has been explored within a museum setting, for guiding tours as well as for learning heritage languages and cultures. The article focuses on the design and development of two social robots for a heritage museum. The first robot is a virtual human character mounted on a mobile robotic platform. It has been implemented to serve as a museum guide. The second robot is a humanoid. It is programmed for bilingualism, which injected elements of culture learning and education. The objective was to develop robots as well as robotic and virtual reality applications primarily, and to explore the usability of these technologies in a heritage museum. The implemented robots have been deployed to validate the development work and to evaluate the feasibility of using these robots for cultural education among young children. Finally, we discuss our deployment experiences and offer suggestions for future work to improve the viability of the robots for a more elaborated deployment at public museums.

1 Introduction

Two robots have been designed and developed for the Chinese Heritage Centre to explore the use of robotic technologies within heritage museum settings. The objective is to develop robots as well as robotic and virtual reality applications for guiding tours and encouraging learning in a museum. The software development of both robots is described in this article. Deployments have also been conducted to validate the implementation.

The motivation is to explore the possibility of using robots in mitigating the challenges faced by the museums—to offer more ways to provide information, particularly to young children for learning heritage languages and cultures. First, the background section describes the challenges in providing adequate museum guides, and the challenge of engaging young children for learning the heritage language in Singapore. Subsequently, related work is presented to highlight the various state-of-the-art robots that have been deployed in museums. The advantages of using robots for museums are also listed.

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Figure 1. *MAVEN—the robotic avatar used for the museum guide application.*

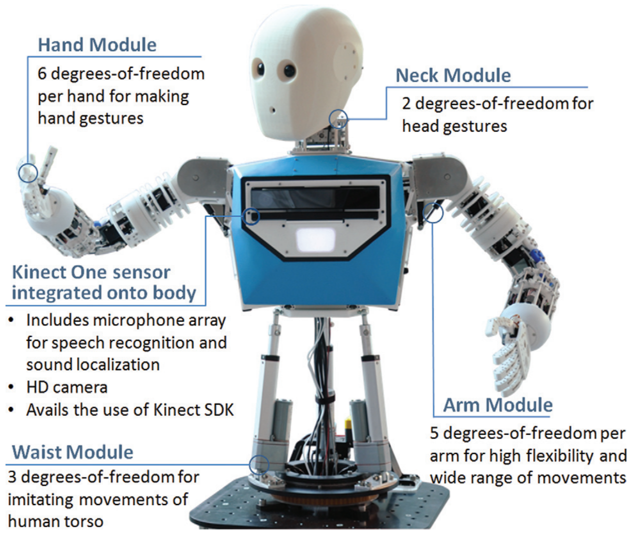

Figure 2. *EDGAR—the humanoid avatar used for the learning companion application.*

The article focuses on the design and development of the robots. The first robot, as shown in Figure 1, is called MAVEN, which stands for Mobile Avatar for Virtual Engagement by NTU (Seet, Pang, & Burhan, 2012). It is a virtual human character mounted on a mobile robotic platform and has been developed to serve as a museum guide. The software architecture of the museum guide application is described in Section 4.1.

The second robot, named EDGAR, is shown in Figure 2. EDGAR is an acronym for Expressions Display and Gesturing Avatar Robot (Pang, Wong, & Seet, 2016). It is a humanoid avatar that has been programmed to produce speech in English and Mandarin. EDGAR has been equipped with a novel storytelling module that enables Microsoft PowerPoint users to create content and program the robot to deliver a slide presentation. The software development is described in Section 4.2.

This article is organized as follows. Section 2 describes the background of the challenges. Section 3 presents the literature review, while Section 4 focuses on the design and development of the two robots, MAVEN and EDGAR. Section 5 discusses the small-scale trial deployments of MAVEN and EDGAR. Finally, the conclusion and recommended future work are given in Section 6.

2 Background

The fundamental purpose of museums and heritage centers is the exemplification, preservation, and dissemination of informative content to educate visitors. In order to provide visitors with more information, most museums or heritage centers have brochures, which contain limited information that orientate their visitors within the museum (Cohen, Winkel, Olsen, & Wheeler, 1977). However, these printed materials are limited in number, not always cost efficient, and can be quickly consumed by visitors (Rayward & Twidale, 1999).

Therefore, digital information technologies have been adopted to provide more guidance to the public. Visitors can access the information by browsing the museum website (Marty, 2008) or by installing an application (Economou and Meintani, 2011) on their mobile devices. These applications can be in a form of an audio guide (Gebbensleben, Dittmann, & Vielhauer, 2006) or an augmented-reality guide (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008; Miyashita et al., 2008). Personalized learning activities (Cabrera et al., 2005; Keil et al., 2013) are also incorporated within the application to enhance the visitors' learning experience. These digital applications are flexible, personal, and they can be switched off and back on as the visitors take detours. This allows visitors to access the information as often as needed. However, the content of the digital applications are prerecorded and fixed. This can be uninteresting as it only provides a one-way interaction (Rayward & Twidale, 1999).

Human museum guides, undeniably, still play an important role to the educational functions of the museum (Burcaw, 1997). The guides are able to engage and gain visitors' attention and interest directly. Human guides can answer and ask questions to encourage discussion or debate. They are more dynamic and interesting than what can be captured by a digital guide or any informative literature about the collections.

2.1 Challenges in Providing for a Museum Guide

However, the number of trained museum guides is limited and the selection as well as the training of these human guides can be time-consuming and demanding (Grenier, 2009; Rayward & Twidale, 1999). Therefore, it is not possible to provide each visitor or visitor group with a museum guide (Rayward & Twidale, 1999). In most museums, prescheduled tours can be conducted in different languages. However, this would depend on the availability of a human guide who can speak that language (Leslie & Sigala, 2005).

The tours offered by different human guides can vary in quality because each human guide has different personality, skill, and experience in leading a tour (Leslie & Sigala, 2005). The quality of tours can also differ despite being offered by the same human guide if human fatigue is considered (Rayward & Twidale, 1999). Most museum guides are volunteers (Orr, 2006; Rayward & Twidale, 1999), and they typically repeat the commentaries based on what they can recall, leading to a mechanical and boring presentation (Rayward & Twidale, 1999).

2.2 Challenges in Engaging Young Children for Cultural Learning

The knowledge of one's history, language, and heritage is deemed an essential to nation building (Fishman, 1968). However, among young children, there is a general disinterest in one's history and heritage. The move toward bilingualism and multilingualism is another aspect that is met with indifference and resistance among young children. In Singapore, more ethnically Chinese parents, being pragmatic, have been giving up their heritage language to ensure their children will survive with English, which is the working language of Singapore (Pakir, 1998). This has resulted in a generational change with more ethnically Chinese children coming from English-speaking homes (Tan, 2006). Many of these children dislike the Chinese language intensely (Wee, 2011).

Lastly, young children may perceive museums as boring or austere places, where they have to view glass-enclosed items passively or listen to historical accounts of the past without much active response (Hall & Bannon, 2005). Children's interests are diverse and they tend to recall large-scale exhibits, which are associated with kinesthetic or tactile experiences, more readily (Anderson, Piscitelli, Weier, Everett, & Tayler, 2002). It is also evident that children are able to recall and learn from live facilitator-led theater-based engagements (Anderson et al., 2002), such as storytelling, acts performance, and presentation talks.

2.3 Background of the Chinese Heritage Centre

The Chinese Heritage Centre (CHC) (Chew, 2014) is a compact museum and a resource center, featuring exhibitions of its collection that aim to promote Chinese cultures and traditions. It is situated within the campus of Nanyang Technological University, Singapore. A primary goal of the center is to impart knowledge of ethnic Chinese communities to visitors. It hopes to raise awareness of Chinese traditions and culture among people in Singapore and in different parts of the world.

Typically, visitors make only a cursory examination of the exhibits because they lack the tools to delve more deeply into the subject manner. There are guided tours, led by university students who volunteer to bring the visitors around as well as to give meaningful insight into the displayed collections. However, it is not possible for the center to provide a museum guide for every visitor on demand. Therefore, there is a motivation to introduce a robotic museum guide to aid in providing guided tours in the CHC.

Furthermore, the CHC has been called to participate in the Children's Season 2016 (Museum Roundtable, 2016), an event to promote heritage and cultural learning in young children. In order to exploit the element of fun and novelty in robots as well as the positive influence of robots in children's education, the event organizers requested a humanoid robot to conduct a storytelling session at the heritage center.

3 Literature Review

In the recent past, there has been an emergence of several commercial robots to extend robotics technology to service applications in human coexisting environments. Commercial robots, such as the Roomba (iRobot Corporation, 2017), Anybots QB (Anybots, Inc., 2010), Remote Presence (InTouch Technologies, Inc., 2011) as well as Robothespian (Engineered Arts Limited, 2017), have been developed to support an extensive range of applications like vacuum cleaning the house, conducting ad-hoc conversations in office environments (Guizzo, 2010), performing medical rounds in hospitals (Thacker, 2005), and acting in a theatrical performance (Jackson & Leahy, 2005), respectively. In the research domain, there have been many activities and experiments on using robots in public places, such as museums and exhibition halls, to study human–robot interactions as well as navigation in dynamic environments. Typically, in a museum context, robotic technologies are used for three different applications: museum guide, museum installation (or exhibit), and telepresence (Lupetti, Germak, & Giuliano, 2015). Museum guides can be further subcategorized into robotic museum guides and virtual museum guides.

Robotic Museum Guide: There are many examples of robots serving as guides, as exhibit instructors, and as greeters in museums. Minerva (Thrun et al., 1999) is one of the earliest and most famous museum guide robots. It was installed in the Smithsonian's National Museum of American History for two weeks. Other robots that have been installed in museums for longer periods include the Mobot Museum Robot Series (Nourbakhsh, Kunz, & Willeke, 2003), which was installed in the Carnegie Museum of Natural History for over five years as well as the Robovio humanoid robot (Shiomi, Kanda, Ishiguro, & Hagita, 2007), which was installed in the Osaka Science Museum for a period of two months. The literature has revealed that museum visitors have been highly impressed to see robots in museums. These robots have helped to stimulate the visitors' interest in the exhibits.

Virtual Museum Guide: With the advancement in virtual reality, virtual humans have been created and installed as museum guides, generating reports of having positive results in attracting and engaging visitors with museum content. For instance, Max is a life-sized virtual human that was installed in the Heinz Nixdorf Museum to provide information about the museum and exhibitions, as well as to engage visitors in conversation (Kopp, Gesellensetter, Krämer, & Wachsmuth, 2005). Tinker is an virtual conversational agent, installed at the Boston Museum of Science, which tracks engagement with the visitors by recognizing their hand shapes (Bickmore et al., 2008). A more advanced installation of virtual museum guide would be the InterFaces project (Swartout et al., 2010), which was installed at the Boston Museum of Science. It housed two virtual humans, Ada and Grace, who are able to interact in natural language and gesture nonverbal communication cues. Ada and Grace are more cutting-edge virtual museum guides because they are more photo-realistic, interactive, and do not require any keyboard or input interfaces for interaction. Although the literature described their virtual humans as museum guides, they are actually static installation or exhibits, and are unable to move around like an actual museum guide. Even the robotic virtual receptionist, Valeria (Gockley et al., 2005) is enclosed in a booth and is not moving around.

Museum Installation: Robots are also installed in the museums as exhibits and remote facilitators. One example of a robotic exhibit is the Personal Exploration Robot Rover (Nourbakhsh et al., 2006), exhibited at five US science museums. It demonstrated the rover missions in the NASA's Mars Exploration Program, as well as robot autonomy. This project has indicated that robotic technology has compelling value in a museum setting. The children were engaged by this robotic exhibit and they were able to learn more effectively about the rover missions. The remote facilitator robot (All & Nourbakhsh, 2001), which was installed in the Cleveland Museum of Natural History, allowed visitors to inhabit a camera-equipped robot and have face-to-face interaction with insects. This study showed increased time spent at the exhibits, leading to deeper learning about insects. Interactive robotic theatrical performances (Breazeal et al., 2003) as well as robotic acts and demonstrations (Verner et al., 2011) have been installed for effective learning and communication.

Telepresence: Robots can also be installed in the museum to serve as a mobile videoconferencing router so that school groups can remotely have a tour of the museum (CSIRO, 2016; Trahanias et al., 2005). Such a robot is known as a telepresence robot. It tracks and follows a human museum guide around the museum autonomously. The robot typically carries a panoramic camera which allows the visitors to have a wide field-of-view of the robot's surroundings. Furthermore, the remote visitors may click on the exhibits within the view of the robot's camera and additional information will be displayed on the browser.

3.1 Advantages of Using Robotic Technologies for Museums

Many mobile robots can be considered to be computers that are able to move around autonomously. As such, they can be well suited for use in museums to display information. Museum information, which has been gathered and stored in a database, can be extensive and described in disparate forms. Over the years, the prevalence of web publishing and information technology have enabled museums to provide access and to digitize this museum information (Blackaby & Sandore, 1997; Schweibenz, 1998). Besides text information, a museum repository database may now include 2D images, 3D models, graphical animation, augmented reality representation, videos, as well as audio clips of speech and related sounds (Addis et al., 2003). This information can be readily retrieved, via powerful information retrieval software (Liotta et al., 2005; Stuer, Meersman, & De Bruyne, 2001). The information can be displayed on a fixed display terminal or on moving computers with mobile robots. Such use of mobile robots potentially enables museum visitors to enjoy guided tours containing more content than a human guide can provide.

With the help of the on-board computer, the robotic guide is able to speak the user's language (Isard, Oberlander, Matheson, & Androutsopoulos, 2003) as well as various other languages depending on the availability of the text-to-speech languages and voices. In Microsoft Windows, there are more than ten text-to-speech languages available for download (Microsoft, 2017b, a). Additional text-to-speech languages can be purchased from third-party providers (Aylett & Pidcock, 2007; Harpo Software, 2017), and thus would provide more than forty languages, with a hundred voices to choose from.

A robot is able to operate on demand or for long hours and does not require rest in the human sense. This can alleviate manpower requirements. For instance, the Eldi museum robot is able to function eight hours daily at the Eldi Museum of Science and Technology (Domínguez Brito et al., 2001). If the cost is not prohibitive, multiple robots can be installed in the museum. This is similar to the concept of deploying a fleet of robots to sell coffee at various Nestle outlets (Nestle, 2014). In this manner, more people would be able to use the robotic guide service expediently. The performance of the robotic guide is also consistent and will not be affected by fatigue.

A virtual museum guide may be able to provide the aforementioned advantages, and may even outperform a robotic one in terms of appearance and interactivity. However, most virtual museum guides lack the ability to move around and project physical gesticulations. It has been evidenced in Hoffman and Ju (2014) that the addition of physical proxy motion with robots favorably influences the perceived involvement of the interaction. Robots can also perform physical gesticulations (e.g., pointing or facing in a certain direction), which helps to disambiguate ambiguous speech, such as "The exhibit is on that side" (Cabibihan, So, Saj, & Zhang, 2012).

Lastly, when the robot is not used as a robotic museum guide, it can function as a telepresence robot (Trahanias et al., 2005; Lupetti et al., 2015; CSIRO, 2016). This allows remote museum visitors to use a web browser and tele-tour the museum with the robot as an intermediary. This enables people who are geographically far away from the museum or with limited mobility to visit a museum.

3.2 Robotic Technologies for Learning Heritage

Robots have been previously deployed in museums relating to science and technology. For example, the Asimo robot has been used as a museum guide and as an exhibit in itself at the National Museum of Emerging Science and Innovation in Japan (Falconer, 2013). A number of robotics workshops have also been provided at the various science museums to offer hands-on learning activities using robot kits (Polishuk et al., 2012; Resnick & Rusk, 1996). While there are many examples of robots being used within a museum setting, not many robotic technologies have been deployed for learning heritage languages and cultures in museums. However, from the knowledge acquired through the review, robotic technologies can likewise be deployed in museums that are not science-themed, to deliver the same benefits of learning. For example, the Docent robot has been deployed at Daejeon Museum of Art as a museum guide, to provide young children with information on the art exhibits (Polishuk et al., 2012; CoreBell, 2014). Another example is that of the CSIRO robot (CSIRO, 2016), which has enabled students from rural Australia to visit the National Museum of Australia for remote learning via telepresence. Lastly, robot installations for interactive demonstration and theater performance have been found to be useful for engaging children in learning (Anderson et al., 2002; Polishuk et al., 2012). Robotic installations that relate to Chinese heritage include a calligraphy robot (Sun & Xu, 2013) and a robot performing Tai Chi exercises (Polishuk et al., 2012).

3.3 Summary of Literature Review

This literature review has listed various state-of-the-art robotic technologies that have been used within museums for applications such as museum guides, museum installations, and telepresence. The literature review has also provided information to demonstrate the advantages of applying robotics technology in museums to enhance visitors' experience. Although there are robotic installations related to Chinese heritage, literature on using robots to encourage the learning of heritage and culture is lacking. The authors also feel that a framework based on the different museum-robot applications would be beneficial and thus propose such a framework in Section 4.

4 Design and Development of Robots for a Heritage Museum

This section describes our effort in developing a robotic framework as well as two robots for a heritage museum. The aim is to utilize robotics technology to support and promote interest in learning heritage languages and cultures at the Chinese Heritage Centre. The implemented robotics avatars, as shown in Figures 1 and 2, would perform two different roles at the heritage center.

Robotic Museum Guide: This robot leads visitors around the heritage center and provides educational information regarding the displayed collections. It is also imbued with telepresence capability, such that when the robot is not used as a museum guide, it can be used as a telepresence robot to facilitate a remote visitor.

Robotic Learning Companion: This robot entertains visitors and teaches Mandarin through scripted storytelling stage performance.

Both robots have an identical software framework (see Figure 3) which has been implemented to allow

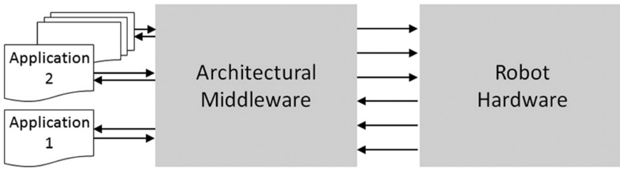

Figure 3. *Robotic framework for MAVEN and EDGAR.*

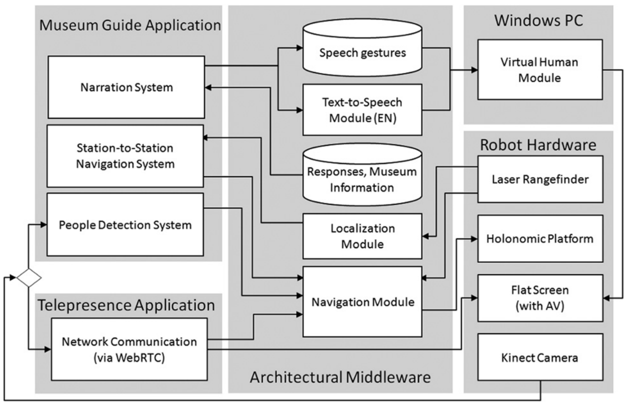

Figure 4. *Architecture of the museum guide application.*

different museum applications to be executed. It has an architectural middleware layer where multiple algorithms, modules, and information are encapsulated and provided to developers as reusable interfaces for implementing applications. This enhances software portability, reduces development effort, and simplifies subsequent modification of the robotic system. In this case, the museum guide application is implemented on MAVEN, which is capable of being autonomously mobile. The other robot, EDGAR, executed the scripted performance application, thereby performing the role of a learning companion.

4.1 Development of a Robotic Virtual Museum Guide

MAVEN, as shown in Figure 1, was developed to be a robotic museum guide. Figure 4 depicts its software and hardware configuration.

The virtual museum guide is a holonomic mobile robot, meaning it has three degrees of freedom of motion in the horizontal plane. The maximum forward and lateral speed of the robot has been limited to 0.6 m/s, while the rotational speed has been limited to 0.9 rad/s. A navigation module has been implemented to enable the robot to perform autonomous navigation with obstacle avoidance.

A flat 2D screen is installed on the robotic platform, and a virtual human or any media content can be projected on the screen. The Virtual Human Toolkit (Hartholt et al., 2013) has been utilized to generate a virtual character for the robotic museum guide application. This virtual character is able to perform text-to-speech and basic nonverbal gesticulations while speaking. The virtual human can be customized to provide information on the exhibits at each station during a tour and perform ad-hoc chat with the visitors. Currently, the virtual human toolkit has been implemented on an additional laptop computer that runs on the Windows operating system.

A Kinect RGB-D camera has been mounted on the robot, as seen in Figure 1. This sensor is used to track visitors and is connected to the museum guide module, which runs a person detection and following algorithm. The module is responsible for acquiring skeleton data from the Kinect sensor, running the algorithm, and sending velocity and control commands to the navigation module, which in turn controls the robot's movement.

The robot is also imbued with an optional telepresence module, such that the same machine can function as a telepresence robot, to enable visitors to visit the physical museum remotely. This module acquires the RGB imagery as well as the audio stream from the Kinect sensor and encodes the streams for video conferencing via WebRTC (Johnston & Burnett, 2012). Commands to control the robot can also be transmitted across the internet to control and move the physical robot in the museum during the conferencing session.

4.1.1 Implementation of the Museum Guiding Application. The state diagram for the museum guiding application is as shown in Figure 5. The states of the diagram correspond to the modes of operation that the robot would perform. There are five states in total and they have been implemented in the museum guide module.

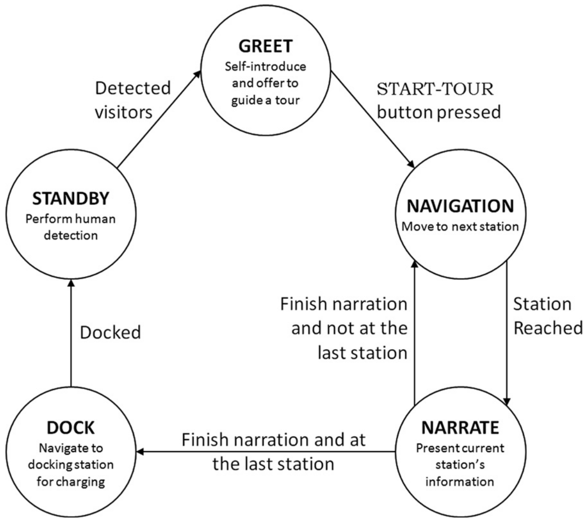

Figure 5. *State diagram of the robotic museum guide.*

The process begins in the standby mode, where the robot is installed at the entrance foyer, docked to a charging station. When in this mode, the robot executes the human detection routine by utilizing a Kinect RGB-D sensor. Once the robot detects people entering the foyer, it switches into the greet mode and tries to gain their attention by greeting them promptly. If the visitors show interest and move toward the robot, it would introduce itself and offer them a guided tour, as illustrated in Figure 6(a). The visitors are provided with a digital menu which can be installed on a touch screen tablet or similar device, as shown in Figure 6(b). If the visitors decide to engage the robot for a guided tour, they can use the menu to select their desired stations to visit during the tour. After making their selections, the visitors may click the start-tour button and activate the robot to begin the tour.

During the tour, the robotic avatar is first in the navigation mode where it plans the shortest path based on the selected stations and guides its visitors to each station efficiently. The robot is able to avoid both static and dynamic obstacles while navigating and adjusts its velocity accordingly to the visitors' pace (Pang, Seet, & Yao, 2013, 2014). This is depicted in Figure 6(c).

When the robot reaches the goal position on the selected station, it stops navigating and turns around to face the visitors, as seen in Figure 6(d). This is because the robotic avatar assumes that the visitors have been following from behind. When the robot detects a person, it stops turning and goes into the narrate mode. In this mode, the robot will present the station's information. This information would have been digitally prepared and loaded onto the robot. A virtual character, which has been projected on the screen (as shown in Figure 4), will gesture while reciting the prepared commentary. During the narration, the robot will also try to emulate human-to-human interaction by giving attention to each visitor who has been following the tour. First, the robot performs human detection and calculates a centroid position, based on the number and position of visitors that it detects. It then turns and faces this centroid position. Subsequently, the robot tracks the visitors and randomly selects to face individuals during its narration. This provides an impression that the virtual character is able to give attention to and gaze at each visitor while speaking, much like human guides often do. After the robot finishes its narration, it prompts the visitors to follow it to the next station. The robot continues to move and repeat the routine until it reaches the final selected station. After narrating at the final station, the robot will ask the visitors to continue their own activities while it navigates back to the entrance and docks for charging. It will then switch back to the standby mode.

4.2 Development of a Robotic Learning Companion

For the second application, a humanoid avatar named EDGAR has been deployed in the Chinese Heritage Centre as a learning companion. Figure 2 illustrates the hardware configuration of the humanoid, which is the second version of EDGAR. Figure 7 depicts the architecture of the robot.

EDGAR is a robotic humanoid developed for social applications. It has a total of 27 degrees of freedom (DOFs) and is able to mimic human movements from the waist up. The robot has a waist module with 3 DOFs and two arm modules, each with 5 DOFs. Each finger on the robot's two hands is capable of independent movement and the thumb has 2 DOFs. The robot's

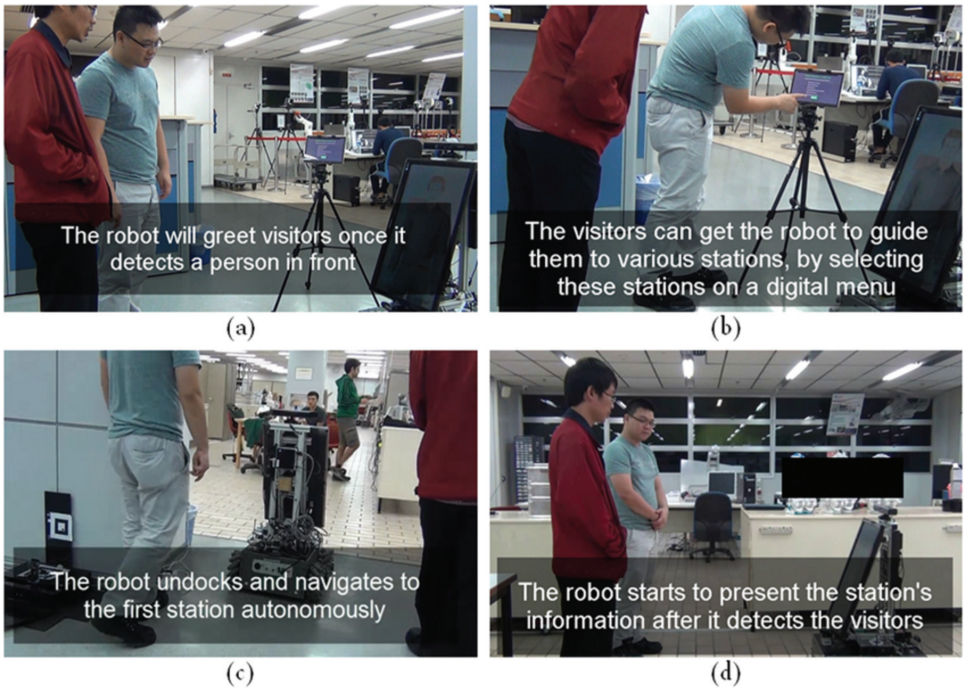

Figure 6. *The sequence of interactions between the visitors and robot during a guided tour session: (a) greeting mode, (b) usage of digital menu, (c) navigation mode, and (d) narration mode.*

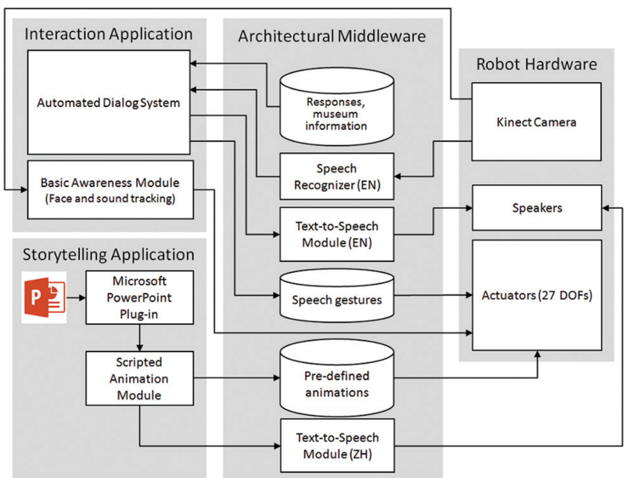

Figure 7. *Software architecture of the robotic learning companion.*

neck module allows the 3D-printed head to move with 2 DOFs, enabling EDGAR to nod and shake its head. Unlike some other life-sized humanoid robots that utilize pneumatic actuators, EDGAR uses electromechanical motors. This makes EDGAR more portable and easier to deploy.

The learning companion function is envisioned as an interesting method to boost interest of young children for their mother tongue through fun activities such as storytelling sessions, games, and songs. This would serve to dispel the bias in Singapore that learning a mother tongue is "uncool" or boring. The robot has been designed as an eye-catching, brightly-colored, interactive, and fun-loving character. The intention is to inculcate curiosity in children, hoping to strengthen their engagement in the storytelling sessions as well to motivate them to love their mother tongues. To do so, two applications have been implemented in this project and were added to the primary software architecture, as shown in Figure 7. They are the storytelling application as well as the social interaction application.

4.2.1 Implementation of the Storytelling Application. The storytelling application enables the humanoid to tell a story collaboratively with a human on stage. This can support live facilitator-led theater-based engagements, such as stage performance or presentation. Currently, a Chinese language pack has been utilized in a text-to-speech module, to enable the robot to speak in Mandarin.

An effective multimedia presentation system has been set up to allow the user to create presentation slides, as well as to program the robot's actions for storytelling. A storyteller is able to use an existing Microsoft PowerPoint Application on any Windows platform to prepare slides to illustrate the story. The script for the humanoid to narrate is then typed in the note section of each slide. The scripted lines can be annotated with instructions for the robot to act out while speaking. An example of an annotated text is "`Hello! ∧start(animations/hello_1) My name is Edgar.`" A plug-in has been developed to read the note section and pass the annotated text to the scripted animation module during the live presentation.

The scripted animation module splits the received text into chunks. In this case, the annotated text example is split into "`Hello!`", "`∧start(animations/hello_1)`", "`My`", "`name`", "`is`", "`Edgar.`" Then, the module analyzes the text chunks and assigns contextual motions to the text it could recognize. For instance, the module is able to recognize the text chunk "`∧start(animations/hello_1)`" as a motion animation and assigned it to "`Hello!`" during narration. A list of animations has been predefined within the architecture and new motion animation can be created and added to the list subsequently. Finally, the module enables the robot to execute each instruction by synchronizing the speech with the motion animations. In this example, the robot would say "`Hello!`" and start the `hello_1` animation concurrently. Subsequently, it continues to narrate the script by saying "`My name is Edgar.`"

4.2.2 Implementation of the Social Interaction Application.

The humanoid avatar is also equipped with a social interaction application, which allows visitors to interact with it in natural language. The social interaction application is made up of two subsystems, which are the automated dialog system and the human tracking system.

First, audio data is acquired by the Kinect sensor and transmitted to a speech recognizer, which converts spoken words to textual strings. The strings are then processed in the automated dialog system, which searches the in-built database and generates an appropriate response for the robot to vocalize. A Wikipedia API is also implemented within the automated dialog system to search Wikipedia for content should a suitable response not be found on the robot's embedded database. Finally, the humanoid avatar vocalizes the generated reply via its text-to-speech module while its arms concurrently perform some human-like gestures to accompany the speech.

During the interaction, the robot is able to engage visitors by establishing eye contact with them autonomously. A basic awareness module has been implemented to enable the robot to be aware of the stimuli coming from its surrounding environment. When the robot has gotten one stimulus (together with the source position), it turns toward the origin of the stimulus and performs human tracking. Currently, the humanoid avatar is able to track people by responding to the "sound" and "face" stimulus.

Human Tracking via Sound Localization: Using the Kinect sensor, the humanoid avatar is able to identify the direction of sounds which are audible. The sensor is equipped with an array of four microphones. Sounds reach each of these microphones with slight delays. These delays are then used to ascertain the source of the sound. The robot uses this information to turn its head toward the direction of the sounds, giving the impression that it is interested in the sound or the person who is speaking.

Human Tracking via Face Tracking: At the same time, the camera image from the Kinect sensor is analyzed by the robot so that face tracking can be performed. In this manner, the humanoid avatar deduces the head positions and facial expressions of the people who are standing in front of it. If there is only one person in the view, the robot will turn its torso to face that person. When there is a group of people within the field of view, the robot first turns its torso to face the centroid of the cluster of faces. If no one is speaking, the robot moves its head to face each individual in the group randomly. However, when someone in the group speaks, the humanoid avatar gets this "sound" stimulus and rotates its head to face the speaking individual.

5 Discussion

In this work, two different robots have been designed and developed for museum settings. The first one serves as a robotic museum guide, while the second robot functions as a companion for learning heritage and culture. The two robots have been deployed at two separate occasions, and observations have been conducted to evaluate the system design, the performance of their designated roles in real context, as well as the feasibility of using the robots to encourage visitors for learning.

5.1 Discussion on MAVEN as the Robotic Museum Guide

Figure 6 illustrates the deployment of MAVEN as a museum guide in the Robotics Research Centre. The developed framework has been configured to enable the robot to guide a group of ten visitors around six different research areas in the center. The performance of MAVEN as a robotic museum guide has been noted for discussion. All the visitors were confident that MAVEN had done its part as a museum guide. The visitors found the touch screen digital menu for selecting stations simple to use. The MAVEN robot was able to navigate from one station to another with no collisions. There were, however, two occasions when the robot moved close to obstacles and came near to collisions, causing some alarm to the visitors.

At each station, the robot was generally able to face and engage the visitors. However, the robot did not properly face the visitors because a passerby walked past the robot while it was visually searching for its users. The passerby caused the robot to assume that the visitors had been detected and it began its narration prematurely. Despite this, most users felt the robot reacting to and establishing eye contact with them. Therefore, they perceived that the robot had acted intelligently and according to their expectations. All visitors were able to hear and follow the instructions given by the robot. However, two visitors mentioned that the robot's voice was lifeless and not as expressive as a human's. All visitors stated that they had enjoyed the tour, although only two of them commented that they have learned more about the Robotics Research Centre during this tour. It is unclear if this was due to the content of the narration or MAVEN's aptitude in delivering the content. When asked if they would be willing to pay for the use of a museum guide robot, most visitors said that they would be willing to pay up to 7.00 Singapore dollars (or approximately 5.30 US dollars at the time of this article).

5.2 Discussion on EDGAR as the Robotic Learning Companion

Figure 8 shows the deployment of EDGAR at the 2016 Children's Season event. The framework has been configured to include the storytelling content for EDGAR to collaborate with a human storyteller to tell a story based on a Chinese idiom. Storytelling has been chosen as the means to enhance learning heritage language because children involved in storytelling programs exhibit better listening skills and increased language appreciation (Speaker, 2000). Furthermore, "the Chinese idioms (or *chengyu*) lies near the heart of the Chinese language" (Wu, 1995) since most of them are derived from literary works that have deep cultural traits or historical background.

In total, two storytelling sessions were conducted during the Children's Season event with approximately one hundred parents and children at each session. The children were mainly preschoolers and students from primary schools, ranging approximately from four to eight years of age. Storytelling was done by EDGAR in collaboration with a human storyteller in Mandarin. This is shown in Figure 8(a). After each performance, EDGAR interacted with the children through a simple game (see Figure 8[b]), followed by photo-taking. Only the crowd from the second session had the opportunity to chat and ask EDGAR questions (see Figure 8[c]).

The robotic performance and interactions were well received by the children and their parents. Most of the audience, including the Chinese-speaking and

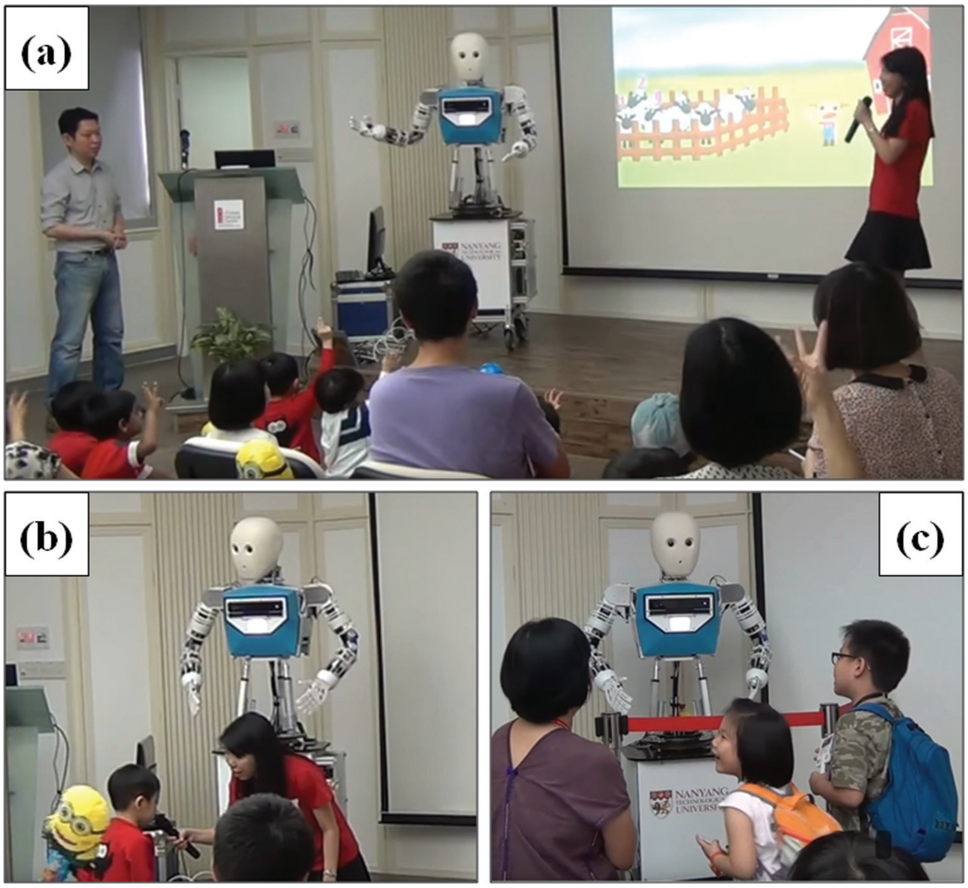

Figure 8. *Children's Season 2016 at the Chinese Heritage Centre: (a) storytelling performance, (b) game interaction, and (c) question-and-answer session.*

non-Chinese-speaking children as well as their parents, were willing to participate in interacting with EDGAR during the storytelling session (see Figure 8[a]). The human storyteller was able to complement the robot by providing more dynamic interactions and expressive gesticulations during the performance.

It has been observed that the children approached the robot on their own and initiated conversations with EDGAR without their parents' supervision. The same did not occur with the human storyteller. Several parents commented that they brought their children to the event as they were curious about the robot and wanted to see EDGAR. The children were enthusiastic to answer the questions that EDGAR posed during the game interaction even when they did not know the answer. As the idiom taught during the sessions may have been too difficult for young children, many parents wanted to participate in the game interaction. Some parents took the opportunity to explain the idiom to their children. These observations demonstrate the potential of using robots to promote the learning of heritage and cultural learning in young children.

6 Conclusion and Future Work

The trial deployments of MAVEN and EDGAR have not only offered operational services and extended education pedagogy; they have provided an element of novelty to excite adults and, in particular, the younger visitors. Through the experience, it is envisaged that curiosity and academic interest would be kindled toward a more deliberated interest in the subject matter. Future work includes generating more content for heritage language and culture learning, as well as improving the robotic systems for a more elaborated deployment.

The deployments have also highlighted areas of possible improvement for MAVEN and EDGAR. The envisioned enhancements include the following:

- Enabling the robots to explain some exhibits while moving between stations. This keeps the visitors engaged even when navigating between stations.
- Improve the speech recognition capability to enable the robot to reliably recognize speech within noisy environments. This capability can be further enhanced to work for multiple languages.
- Make display height adjustable to enable engagement at eye level. For MAVEN, this means adjusting the screen's height so that the virtual human can be easily viewed. For EDGAR, this means raising or lowering the upper body so that both children and adults can visually engage with EDGAR easily.
- Increase expressibility. This is to be achieved via a larger repertoire of gestures and facial expressions (for MAVEN) and more gestures (for both MAVEN and EDGAR)
- Improve the navigation module on MAVEN to increase its dependability as well as to produce fast, safe, and human-aware navigation (Kruse, Pandey, Alami, & Kirsch, 2013).
- Generate more museum-related content for the robots.

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