Intelligent virtual rehabilitation system for the elderly with memory deficits

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An Intelligent Virtual Rehabilitation System for the Elderly with Memory Deficits

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SUMMARY

The application of virtual reality (VR) technology in rehabilitation has significant advantages over the conventional rehabilitation methods. However, VR applications for the dementia patients are few and in their earliest stage. **A** number of problems need to be studied and clarified. This project has developed a new memory rehabilitation methodology for the dementia elderly. The methodology explores the conventional memory rehabilitation theory and approaches, the advanced virtual reality (VR) technology, and fuzzy logic theory to develop an intelligent approach.

To study the proposed methodology, this project has developed a methodology for building the virtual environment suitable for the dementia patients with memory deficits. This project has also developed a method to capture the therapist's knowledge and experience to establish a fuzzy-based Intelligent Assistant for assisting the patient training in the virtual environment. Test results fiom the therapists, healthy old persons, and patients proved the effectiveness of the methodology for building virtual environment and the knowledge acquisition method.

Test results fiom the dementia patients also showed that patients gained more benefits when they were trained in the virtual environment than in the real world. The skill trained in the virtual environment was transferred to the real world. This transfer problem is commonly encountered in the conventional method. Therefore, it is believed that the virtual rehabilitation has the potential to provide a better approach for memory rehabilitation for the dementia patients.

LIST OF PUBLICATIONS

Guo, W. H., Lim, S.Y.E., Fok, S.C., and Chan, G.Y.C. (2004), "Virtual Reality for Memory Rehabilitation", International Journal of Computer Applications in Technology, Vol. 21, No. 1, pp. 32 - 37.

Guo, W. H., Lim, S.Y.E., and Fok, S.C., (2001), "Fuzzy-Based Control In a Virtual Rehabilitation System", Proceedings of the 5th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2001) and the 7th Internal Conference on Information Systems Analysis and Synthesis (ISAS 2001), Orlando, Florida, U.S.A., July.

CHAPTER 1 INTRODUCTION

1.1 Background and Motivation

The population of old people has increased significantly around the world due to the advancement of medical technologies and a decline in the birth rate. The aging population is a major concern in Singapore. It has been estimated that the proportion of senior citizens, who are aged 60 and above, would increase from 10% today to 26.1% in the year 2030.

Alzheimer's disease (AD) is an age-related and irreversible brain disorder that occurs gradually and results in memory loss, behaviour and personality changes, and a decline in thinking abilities. The course of this disease varies from person to person, as does the rate of decline. AD is the most common cause of dementia among those age 65 and older. AD alone is believed to have affected at least fifty thousand people in the UK and over four million in the USA. The prevalence of AD increases exponentially with age and roughly doubles for every five years increase in age (Brookmeyer et al., 1998).

Memory impairment is usually the first observable symptom of AD (Chui, 1989). For example, AD patients often misplace items or forget name. As the disease progresses, judgement and reasoning deficits emerge, and eventually, language deficits and apraxia appear. The memory is targeted for early intervention because memory deficits are the first to appear, while other cognitive functions remain intact in the early stages of AD. Rehabilitation of memory impairment will have an impact on the rehabilitation of all other cognitive deficits and virtually all aspects of daily life.

A variety of interventions for the rehabilitation of memory impairments have been invented and developed due to the demand of the large number of memory-impaired people requiring assistance in their daily lives. These interventions differ in terms of their goals, which can be categorized as (a) repair of damaged memory processes, or (b) alleviation of functional disabilities (Glisky, 1997). The first goal assumes that if damaged processes are repaired, general memory ability will be re-established and memory functionality will return to normal. The second goal is to overcome problems caused by memory deficits and improve performance on specific everyday memory tasks. The assumption here is that performance might be improved even though the underlying memory ability remains unchanged.

As yet, there is little evidence that memory ability can be restored in the general sense. The success of memory rehabilitation has been primarily in the achievement of improved behaviour or performance. Different methods to achieve functional or behavioural outcomes have shown different effectiveness (Glisky, 1997; Glisky, 2001). **A** number of new technologies have benefited functional memory rehabilitation. **As** in the other areas, computers have been increasingly incorporated into the rehabilitation process due to its rapid growth in technology and decrease in cost.

The primary uses of computers in memory rehabilitation are as a tool for the presentation of mnemonic strategies, for use as an external aid, or for teaching patients domain-specific knowledge (Glisky, 1995). For example, computers have been used as Interactive Task Guidance Systems to provide a set of cues to guide patients through sequential steps of an everyday task such as cooking or cleaning (Kirsch et al., 1987). The computer merely acts as an external aid providing step-by-step instructions in these applications.

Computerized memory rehabilitation has shown some distinct advantages over non-computerized memory rehabilitation. Computers are able to give accurate and rapid feedback and inform the patient of an incorrect response. The computerized programs are capable of motivating the patient by changing displays and providing novel tasks. These programs can also flexibly adjust the task's level of difficulty and select its alternative forms without the therapist's intervention, based on a range of criteria such as speed of response, number of errors, and type of response.

However, computerized rehabilitation systems have their limitations. Firstly, the problems of transfer and generalization from rehabilitation environments to the real world seem to plague all rehabilitation methodologies to some degree. The ultimate aim of memory rehabilitation should be to increase the patient's functional independence. An issue that has concerned therapists is the extent to which computerized tasks differ from everyday tasks. It has been argued that generalization of learning from lab to everyday performance is reduced if there is an absence of strong relationship between the two tasks. Glisky (1995) discussed the problems of transfer and generalization in the use of computers for memory rehabilitation.

Secondly, AD patients have difficulty in remembering which keys are available for use in a given task or in learning to press a sequence of keys. For example, in many cases the "Enter" key has to be pressed to initiate a response and if this is forgotten the patient may have no idea why the computer is failing to respond to an entry. The use of keyboard or mouse can distract the patients' attention from the tasks. Patients may not be able to attend to stimuli and this may impact on the effectiveness of the rehabilitation.

Thirdly, AD patients have difficulty of keeping their concentration on a training task for a certain time. The training programs therefore are required to be realistic and motivating. Computer programs can only restrictedly present the patient with visual and auditory feedback. They cannot provide other sensations such as touch. The lack of these feedback sensations makes the computer programs less realistic and motivating.

In recent years, virtual reality (VR) technology has increasingly been explored for cognitive rehabilitation (CR) applications (Rizzo and Buckwalter, 1997; Riva, 1998; Wann, et. al., 1997). In the application of VR to memory rehabilitation, it is essential to look into the basics of memory preservation and its learning abilities following certain brain trauma or dementia. The use of intact memory processes to compensate for those that have been disrupted or lost has often been suggested as an appropriate strategy for rehabilitation (Wann et al., 1997). Procedural or implicit memory, which involves acquired skills or actions like sewing and cooking, is one such preserved memory. For example, an Alzheimer's patient may be unable to recall factual information or personal events, but can perform over-learned tasks such as combing hair or brushing teeth (Gourlay et al, 2000a).

VR could provide a training environment which foster cognitive improvement by exploiting the person's preserved procedural abilities. VR-based rehabilitation has the ability to offer the user computer-generated 3D environments that simulate the real world. VR-related technologies such as the head-mounted display (HMD), dataglove, and position trackers can further enhance the immersion, interaction, and navigation characteristics of VR (VREPAR, 2000). Therefore the virtual rehabilitation environments can be made contingent on the response of the patient. People with motor disabilities restricted in real life environment can still interact with the virtual environments (VE).

Based on the advanced features of VR technology, the VR-based rehabilitation could not only enrich the advantages of the above computer programs, but also serve to overcome their major weaknesses. First, VR is generally recognized to possess the potential in resolving the problems of transfer and generalization in rehabilitation. Reports from some empirical investigations appear to support this assumption. For example, the training of spatial skills (Arthur et at., 1997; Waller et al., 1998) and procedural learning (Rejian, 1997; Brooks et al., 1999a) showed clear evidence of positive transfer from virtual to real environments. However, it should be noted that these findings might not apply to other training tasks. Future research should be directed towards establishing a comprehensive knowledge of what is being transfenred to real world performance in different VE training tasks.

Patients can interact with VE more naturally through advanced VR-related technologies such as dataglove and position tracker. Patients can touch, grasp, and move virtual objects in VE as they do in the real world. They do not need to press keys or click mouse to go though the rehabilitation processes. VR technology can also provide richer sensations through visual, audio, touch, and force feedback. These sensations will make VR exercises more engaging, such that the patient feels immersed in the simulated world. This is extremely important in terms of maintaining the patient's motivation (Popescu et al., 2000), which, in turn, is the key to recovery. Therapists can also accurately evaluate patients' performances based on the recorded behavioural responses.

Safety is another major benefit of VR rehabilitation. Even under the close supervision of a therapist, the patient may still be exposed to some hazards such as scalding when being trained to perform a daily living task such as cooking. However, if the cooking task is performed in a virtual kitchen, the virtual fire will not hurt the patient.

AD patients are heavily dependent on the therapists for assistance while being rehabilitated for activities of daily living (ADL). Therapists must consistently monitor the patients, and are often required to repeat instructions while trying to get the patient to perform an ADL. This will cause a great burden for a therapist assisting several patients at the same time. In order to reduce the dependence of patients and the burdens of therapists, the system should be capable of automatically altering the parameters such as stimulus exposure time and level of difficulty to suit the patients. This means that feedback should be used to monitor the patient's response so as to adapt the VE to the patient. The system will need to possess certain intelligence to make the appropriate responses, including assessing the performance of the patient in the treatment and controlling the treatment processes. To make the system intelligent, artificial intelligence **(AI)** technologies could be introduced to further enhance the VR system.

In the clinical environment, a patient is usually asked to repeat the same rehabilitation task during the rehabilitation session. The therapist will use his knowledge and experience to assist the patient to complete the task by issuing timely instructions. The timing and type of instructions are determined by the considerations of the patient's situation, the on-site performance, the task difficulty, and many other factors. Since different therapists have different level of knowledge and experience, the timing and type of instructions given will also differ from therapist to therapist. **As** a result, there exist vagueness in the assistance. Among the **AI** technologies, fuzzy logic is excellent at manipulating vague data. Fuzzy logic is therefore a good approach for incorporation of intelligence in such rehabilitation system.

The problems faced by conventional memory rehabilitation and the advantages offered by VR technology provided the motivation for this research. This work constitutes initial efforts to utilize VR and **AI** technology for memory rehabilitation of the elderly with AD. The project will examine the use of fuzzy logic in the development of an intelligence virtual rehabilitation system.

1.2 Objective

The overall objective of the project is to establish a new methodology for intelligent approach to memory rehabilitation for the elderly with AD. The methodology explores the integration of VR technology and Fuzzy Set theory with the knowledge and experience of conventional approaches in memory rehabilitation. It aims to overcome the difficulties faced by using the computer programs and conventional approaches to memory rehabilitation and to enhance the effectiveness of rehabilitation.

To support the new methodology, an intelligent virtual rehabilitation system (IVRS) is developed. Figure 1.1 outlines the structure of Intelligent Virtual Rehabilitation System (IVRS). It consists of three main subsystems: human subsystem, interface subsystem and assistant subsystem. In the human subsystem, the therapist is responsible for monitoring the performance of the patient and the operation of the virtual rehabilitation environment. The virtual environment provides the training environment for the patient to perform the assigned rehabilitation tasks. The performance of the patient is captured and the data is transmitted to the intelligent assistant. The data are analysed, evaluated, and processed. The results are used to adaptively modify the virtual rehabilitation environment and provide the appropriate stimulus and instructions to the patient. A record of the rehabilitation status of the patient will be kept in the database of the information system.

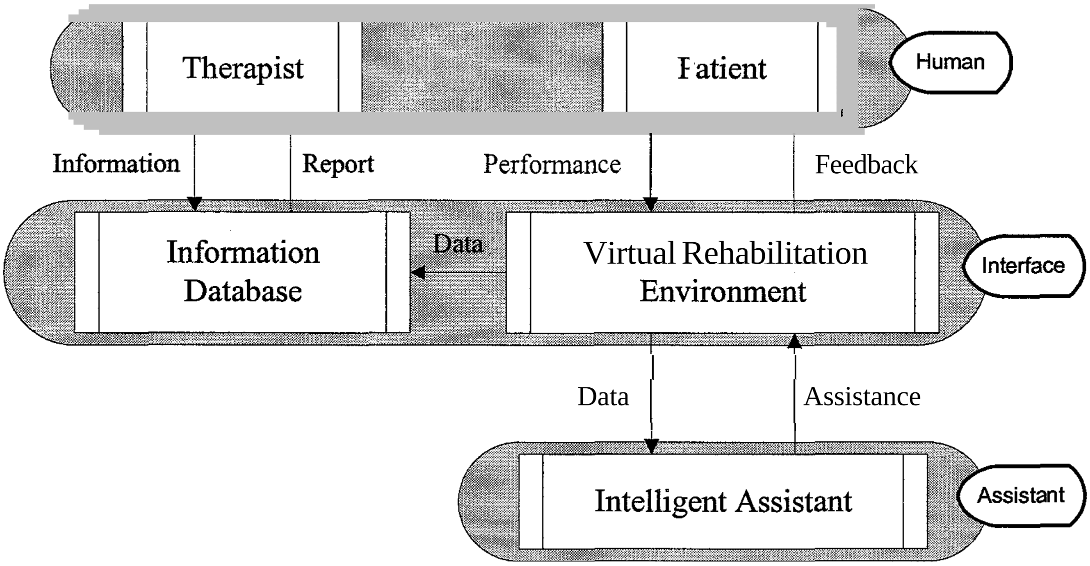


Figure 1.1 IVRS **Architecture**

The objectives of the project are:

- **To establish an appropriate methodology for the design of a virtual functional rehabilitation environment suitable for the elderly with AD**

For the elderly with AD, functional rehabilitation approaches are widely used due to their effectiveness. The work will rely on this conventional wisdom and focus on the methodology for the design of the virtual functional rehabilitation environment. Currently, there is no reported methodology for the design of such virtual functional rehabilitation environments (VEs). The designs of the few VR applications in the rehabilitation area mainly relied on traditional human-computer interface (HCI) techniques. These methodologies may not be appropriate for the AD patients, as other considerations may have to be taken into account. For example, it would be more desirable for AD patients to intuitively operate computer-generated objects. This means that grasping using data gloves would be preferred over data manipulation using keyboard and mouse.

The methodology for the design of the virtual functional environment should be based on careful analysis of the clinical protocols, considerations of the users, and HCI techniques. The methodology to be developed should result in a well-conceived and well-constructed virtual functional rehabilitation environment. A good design not only would encourage the patients to concentrate on the training tasks, but also enhanced immersion and intuitive interaction without imposing extra cognitive burdens on the patients. The proposed methodology will be studied based on activities appropriate for patients with mild-to-moderate AD such as cooking.

- **To investigate a new application of fuzzy logic in the Intelligent Assistant.**

The Intelligent Assistant aims to assist the patients to complete the rehabilitation tasks independently. This would reduce the burden on the therapists. In the clinical environment, a therapist would give the patient suitable instructions at appropriate time to help the patient to complete the task. These instructions can be vague. Although fuzzy logic is ideal for handling this type of data, a suitable approach to incorporate fuzzy logic to intelligently assist the patient has yet to be developed.

- **Based on the propose methodology, to investigate whether the skills gained in the virtual rehabilitation environment can be transferred to real-world conditions.**

Computer programs and conventional rehabilitation approaches encounter the problems of transfer and generalization from rehabilitation environments to the real world. Some researchers of virtual rehabilitation have showed clear evidence of positive transfer from virtual to real environments. However, others have showed that although subjects trained on a motor task in a virtual environment demonstrated the ability to improve performance on the task in that environment, the learning did not always transfer to the real-world task (Kozak et al., **1993).** This conflict in findings indicates that the transfer problems in virtual rehabilitation approaches still need to be studied. This research will study whether the skills old patients gain in the virtual training environment can be transferred to the real world. It is anticipated that even with effective transfer of learned skills from virtual to real world environments, the patient's performances in VE and clinical setting may not matched perfectly.

1.3 Organization of the Thesis

This report is organized in 7 chapters. Chapter **1** gives a brief introduction of memory rehabilitation. The descriptions of the existing problems lead to the outline of the objectives, contributions, and the scope of the project. Chapter 2 discusses memory rehabilitation and provides a literature review of VR and fuzzy logic in rehabilitation. Chapter **3** introduces the development of virtual rehabilitation environment. It focuses on the methodology to design and implement the virtual functional rehabilitation environment. Chapter 4 presents the methodology to develop the proposed intelligent assistant using fuzzy logic. Chapter 5 describes three phases of the initial evaluations of the proposed rehabilitation methodology. The test subjects of the initial evaluations were graduate students, therapists, and normal old persons. Chapter *6* describes a case study for the further evaluation of the new rehabilitation methodology, using two dementia patients as test subjects. Chapter 7 provides the conclusions **and** recommendations for future work for developing intelligent virtual rehabilitation for the elderly.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter consists of five sections. Section 2.2 describes the conventional memory rehabilitation approaches for functional improvement of the patient's daily activities of living. Section **2.3** reviews the studies in computerized memory rehabilitation, which indicates distinct advantages over the conventional methods, such as allowing the development of tasks that would otherwise be very complicated to administer to patients. However, computerized memory rehabilitation is still unable to retrain the patients in open-ended daily living, but nonetheless safe and controlled situations. Section 2.4 first introduces the characteristics of VR technology that possesses the potential to develop the enhanced immersion and interactive training environments. It also reviews studies in VR-based memory rehabilitation. These studies point to the VR potential in memory rehabilitation. They also provide useful suggestions for further developing VR-based memory rehabilitation and reveal the problems that require further investigations. Finally it analyses the need for intelligent VR-based rehabilitation. Section 2.5 introduces the methods and knowledge acquisition for developing fuzzy models. It also reviews applications of fuzzy logic in rehabilitation. Section ***2.6*** summarizes the gaps between existing rehabilitation methods and states the objectives of this study.

2.2 Rehabilitation of Memory Deficits

2.2.1 Memory Process

Memory can be divided into two main components: *working memory* and *remote memory*. *Working memory* or *short-term memory* is the hypothetical process in which information is briefly but actively processed or held before encoding (Pliskin et al., 1996). Rehearsing a telephone number before dialling is an example of working memory.

In *remote memory*, the information is believed to be organized, categorized, and stored for later use (Pliskin et al., 1996). For example, the telephone number rehearsed earlier can be organized and then stored as individual called, place called, or strictly as a number. It has been hypothesized that different types of remote memory exist and that these types are accessed through retrieval processes. *Semantic memory* (also referred to as declarative or explicit memory) involves the storage of factual information and learned knowledge. This type of memory is illustrated by asking the person to answer the question, "Who was the first Elected President of Singapore?" *Episodic memory* is related to semantic memory but involves personal facts or events directly related the individual. This type of memory is illustrated by asking the person to answer the question, " What did you do on your vacation?' *Procedural **or** implicit memory* involves acquired skills or actions. This type of memory can be inferred from the observation of behaviours or activities such as sewing, cooking, or brushing hair.

Every memory component and process can be affected by Alzheimer's disease (AD). The extent and severity of memory deficits vary with each individual, and not every memory area is impaired. For example, AD patients have retrieval problems with information from semantic and episodic stores but commonly have intact procedural memory. They may be unable to recall factual information or personal events, but can perform over-learned tasks such as walking, combing hair, or brushing teeth.

2.2.2 Conventional Methods of Memory Rehabilitation

As described in Chapter 1, rehabilitation of memory deficits generally focuses on one of two goals: repair of damaged memory processes or alleviation of functional disabilities. Although both goals represent desirable outcomes for therapeutic intervention, the first has so far remained elusive. For example, ***exercise and drill*** is commonly used in an attempt to restore general memory. Patients spend hours trying to remember arbitrary lists of words, pictures, digits, and locations, which have little relevance to real-world functional cognitive challenges. However, it has been shown that repetitive practice at remembering meaningless lists of numbers, letters, shapes, or locations has no beneficial role in memory rehabilitation, whether the materials are presented in paper-and-pencil format or on computer (Glisky and Schacter, 1989b; Wilson, 1991). This is because "memorizing" increasingly difficult lists of words or activities within a therapy or school environment does not support the transfer or generalization of memory ability to the real-world situation of the patient (Chase and Ericsson, 1981; O'Connor and Cermack, 1987).

Most of the successful remedial work has been in the area of functional improvement such as mnemonic strategies, spaced retrieval, errorless learning, vanishing cues, and external compensation (Glisky, 1997). *Mnemonics strategy* provides patients with a fixed method, for example, the pairing of visual imagery, of categorizing and organizing new information on more than one cognitive level to assist in the encoding and retrieval of that information (West, 1995). However this method may only be appropriate for the younger adults and the older adults with good cognitive function, as the effort needed to learn the mnemonic technique is heavy for the old adults with impaired cognitive function (Wilson, 2001; Pliskin et al., 1996).

Spaced retrieval is a relatively simple rehearsal method in which to-be-learned information is rehearsed repeatedly at gradually increasing intervals. Camp and colleagues (Camp 1989; Camp and Stevens, 1990; Camp and Mckitrick, 1992) have demonstrated its effectiveness with AD patients, who were able to leam people's names and the locations of objects and to retain them over a period of several weeks. They speculate that learning by this method, which appears to be relatively effortless, may rely on automatic or implicit memory processes.

Errorless learning was suggested by Baddeley and Wilson (1994) who demonstrated that memory-impaired patients can learn people's name and other pieces of factual information more readily. The study showed that avoiding errors early in the learning process is important for patients who rely on implicit memory processes to leam new information. If errors are generated during initial learning, they may be difficult to be eliminated without access to explicit memory.

Vanishing cues method was designed specifically to take advantages of the preserved implicit memory processes demonstrated by amnesic patients (Glisky et al, **1986).** The technique involves the use of partial information as a cue or prompt, which is gradually withdrawn across learning trials. It has been used primarily to teach memory-impaired patients complex domain-specific knowledge relevant to a variety of everyday tasks (Glisky et al., **1994).** It was speculated that this method may be useful only for individuals with severe impairments in explicit memory, such as amnesic or dementia patients (Glisky, 2001).

External compensation method was developed in an attempt to help patients compensate for lost memory function and achieve meaningful behavioural outcomes. These aids include relatively simple environmental restructuring such as labels on cupboards and instructions on appliances (Craik et al., **1995)** and external aids such as alarm watches and notebooks (Kapw, **1995).** For the elderly with AD, external memory aids may be more useful because they target behaviows that may improve the patients' adaptive functions. They also enable patients to cope with the sophisticated demands of daily living without trying to rely on memory systems that have ceased to function adequately to meet those problems (Bourgeois, **1990;** Sohlberg and Mateer, **1989;** Glisky et al., **1986).** Many of these aids, however, require extensive patient training.

2.3 Computerized Memory Rehabilitation

With the rapid growth of computer technology, evidence have shown that computerized interventions, like other forms of cognitive rehabilitation, can provide benefits, given that they are based on good psychological principles (Glisky, 1995).

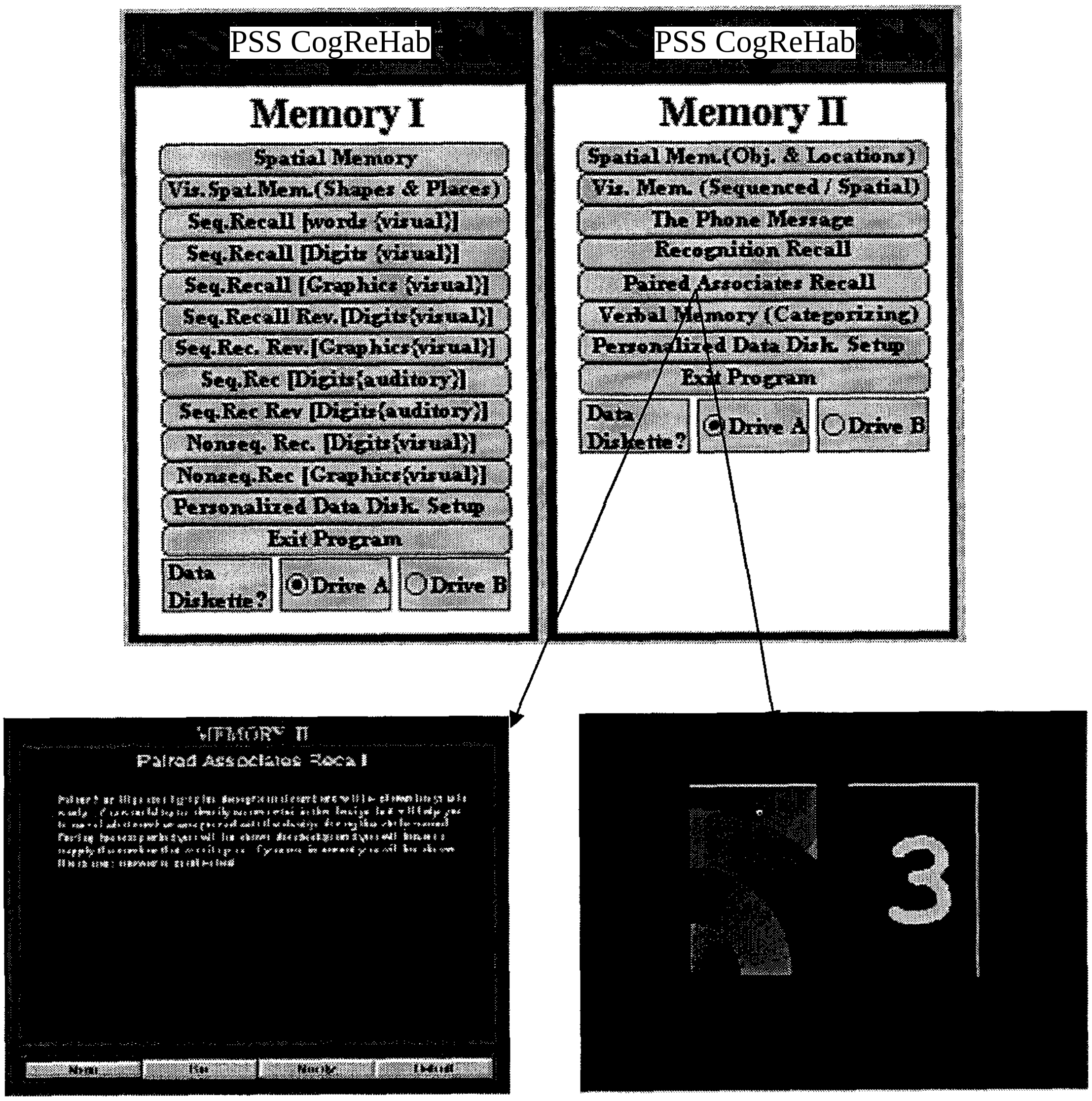


Figure 2.6 PSSCogReHab Version 95 (PSSCogRehab, 1998 online)

Figure 2.1 illustrates a software module designed for rehabilitation of memory deficits (PSSCogRehab, 1998). This module consists of two stages: Memory I and Memory II. Each stage has a list of tasks displayed as menu bars. Further information concerning that task will be displayed when the appropriate menu bar is clicked. In this module, computer is used as a tool for exercises and drills and as the display for mnemonic strategies. This module showed that the computer can be an ideal medium for presentation of repetitive exercises. But this module is not suitable for an elderly with AD as there is little evidence that the patient can use such symbolic information as numbers, letters, shapes, or locations spontaneously either in the clinic or in everyday life (Glisky and Schacter, 1989b; Wilson, 1991).

Computer has also served as an external support. Kirsch et al. (1987, 1992) have demonstrated that even with very little training, some patients with severe memory disorders were capable of using the computer as an "interactive task guidance system" to cue their performance **of** real-world tasks, such as baking or other simple tasks. The computer acted as a compensatory device for providing a sequence of steps for patients to follow when performing certain tasks. The patient need not possess knowledge of computer operation, but only required to respond with a single key-press to indicate that he had followed the instruction.

Bergman and Kemmerer (1991) described the case of a 54-year-old woman with a number of cognitive problems who learned to use a computerized task guidance system. The patient had a left-sided neglect, so only the right side of the screen was employed. She also had poor visual acuity, so the colours of the screen were adjusted to make it more discriminable. An audible tone was included to enhance arousal and attentiveness. The patient learned to use the computerized system in three one-hour training sessions and employed it for: (1) writing lists of things to do or buy; (2) writing instructions or requests to her companion helper; (3) making notes about telephone calls and letters; and (4) money management, such as printing out cheques to pay her electricity bill. Bergman and Kemmerer reported that the patient's self-sufficiency increased and her emotional distress decreased as a result **of** the system. In this case, the computer was modified to simplify these tasks and to bypass the particular cognitive deficits that were problematic for the patient.

The computer has also been explored to teach patients to function without external support (Glisky, 1992b). In the method **of** vanishing cues described in Section 2.1.2, the computer serves the role of teacher, presenting information and feedback in a consistent manner, controlling the amount of cue information in accordance with the patient's needs and prior responses, and allowing patients to work independently in their own pace. Using this method, Glisky and colleagues successfully taught memory-impaired patients information associated with the operation of a computer (Glisky et al., 1986), the names of various business-related documents (Butters et al., 1993), and a number of vocational tasks including computer data entry (Glisky, 1992a; Glisky and Schacter, 1989a) and database management (Glisky 1993). However, one of the concerns of this method is that patients cannot readily access newly acquired knowledge on demand or use it flexibly in novel situations. In other words, transfer beyond the training context cannot be assured (Wilson 1992).

Computerized memory rehabilitation shows distinct advantages over the conventional methods, such as allowing the development of tasks that would otherwise be very complicated to administer to patients, providing accurate and rapid feedback, enhancing task motivation, and flexibly changing the task difficulty to suit individual patients. However, the problems of transfer and generalization have somewhat dampened these computer applications. Key-pressed or mouse-driven operations in these applications can also distract the patient's attention. There is a lack of efficient instruments to retrain the patients under everyday life, open-ended, but nonetheless safe and controlled situations. Thus more effective ways for solving these problems should be developed. Virtual reality (VR) technology may offer such potential capability to solve above problems (Rizzo and Buckwalter, 1997; Riva, 1998).

2.4 Virtual Reality (VR) and Rehabilitation

2.4.1 Virtual Reality

Virtual Reality (VR) is a set of computer technologies which, when combined, provide an interface to a computer-generated virtual world. It can provide such a convincing interface that the user would believe he is within a 3D computer-generated virtual world. This computer-generated world may be a model of a real-world object, such as a house. It might also be an abstract world that is readily understood by humans, such as a chemical molecular chain or a representation of a set of data. VR can also be extended to a completely imaginary science fiction world.

A key feature of VR is that the user believes that he is within this different world. Another key feature of Virtual Reality is that if the user moves his head, arms or legs, the shifts of visual cues are similar to those he would expect in a real world. These represent the immersion, navigation, and interaction characteristics of VR. The sense of immersion is identified as the most important feature **of** VR, separating it from other forms of computer-assisted simulation. Further discussions on VR can be found in Ellis (1994) and Machover and Tice (1994).

Different kinds of VR technology support different modes of interaction. On the basis of realism that hardware produce, at least six interaction styles **of** simulated/virtual environment can be identified, namely: desktop, projected, immersive, Cave, telepresence, and augmented VR (VREPAR, 2000 online). Desktop VR and immersive VR are the types frequently being developed for the rehabilitation application. In desktop VR, the user interacts with the computer screen without being fully immersed and surrounded by the computer-generated environment. However, the feeling of subjective immersion can be improved through stereoscopic vision (such as CrystalEyes from StereoGraphics) and operative action effected via pointing devices (mouse, joystick) or other VR peripherals such as Dataglove (Burdea, 1996). In immersive VR, the user appears to be fully inserted into the computer generated environment. This illusion is rendered with 3D viewing head-mounted display (HMD) and a system of head tracking to ensure exact correspondence and co-ordination of user's movements with the feedback of the environment. Figure 2.2 shows an immersive VR system model. More details of VR-related hardware can be found in Gobbetti and Scateni (1998) and Zheng et al. (1998).

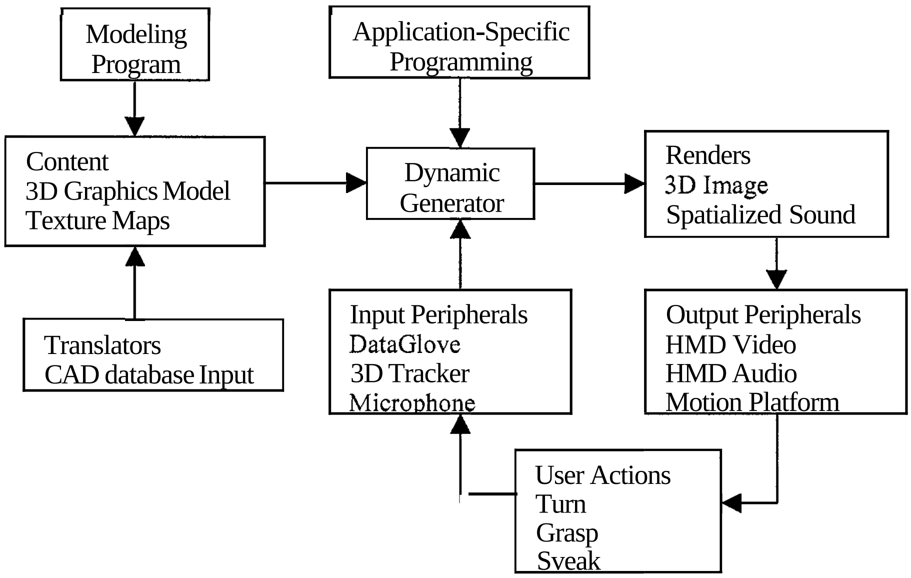


Figure 2.2 An Immersive VR System Model (Greenleaf, 1997)

Besides computer-generated 3D images, VR technology brings about other two noticeable characteristics.

- **Total Control:** Most computer access systems accept only one or at most two modes of input at a time, such as inputs fkom a keyboard, pointing to an on-screen keyboard with a mouse, or hitting a switch when the computer presents the desired choice. They also cannot recognize gestures, nor capable of monitoring actions from several body parts simultaneously. Virtual reality systems open up the input channel. They can monitor movements or actions from many body parts at the same time while the user dynamically interact with 3D stimuli. Actions can be amplified or attenuated into more precise control of the finger actions. Thus therapists can present a wide variety of controlled stimuli to the patients and monitor a range of their responses.

- Variety **of** Immediate Feedback: Vision is the primary feedback channel of present-day computers. However, the message can be distorted and alienated through text representation. It is also very difficult to represent physical phenomena such as force, resistance, density, temperature, and pitch through vision alone. VR techniques such **as** dataglove and datasuit can provide the users with the sense of force and tactile feedback. They also allow the users to touch computer-generated objects, to feel the material and to experience the weight of the objects, just like in the real word.

It is these characteristics of VR technology that offer the potential to develop the enhanced immersion and interactive training environments for VR-based rehabilitation (Rizzo and Buckwalter, **1997;** Riva, **1998). Rizzo** et al. (2000) argued that VR technology is capable of creating dynamic 3D stimulus environments, within which all behavioural responding can be recorded and measured. This will offer clinical rehabilitation options that are not available using conventional methods. Patients that could benefit from VR-based rehabilitation include those with traumatic brain injury (TBI), neurological disorders, and learning disabilities. Elderly with AD can be categorised under patients with neurological disorders.

2.4.2 VR-based **Cognitive** Rehabilitation

VR technology was originally developed by the military in the 1960s to assist in the training of air-force pilots. It was used to simulate dangerous situations without the fear of risking personnel injuries or the loss of expensive equipment. In the wake of the military success, many VR applications have emerged in the areas of entertainment, education, physical rehabilitation, and medicine (Greenleaf, 1997; Satava and Jones, 1998). In recent years, researchers began to explore the use of VR for rehabilitation of human cognitive and functional activities (Riva, 1998; Rizzo and Buckwalter, 1998; Rizzo et al., 2000, Khan et al. 2003). VR technology has been used for rehabilitation in such areas as attention (Wann et al., 1997, Cho et al. 2002, Rizzo et al. 2004), executive functioning (Pugnetti et al., 1995a, b), spatial ability (Arthur et al., 1997; Regian, 1997; Waller et al., 1998), motor skills (Inman et al., 1997; Gourlay et al., 2000b; Jack et al., 2001), and hemispatial neglect (Baheux et al., 2003). VR technology has also been used for memory rehabilitation (Attree et al., 1996; Rose, 1996; Pugnetti et al., 1998; Grealy et al. 1999; Brooks et al., 1999a, b; Rose et al., 2000a, 2000b, 2002, Rizzo et al. 2002).

Among the VR applications on memory research, a useful finding emerged from the studies of Attree et al. (1996). The researchers used a non-HMD flat screen system with a joystick interface to allow one subject to navigate the house (active condition), while a yoked subject was simply exposed to the same journey but has no navigational control (passive condition). Both subjects were divided into two groups. They were directed to seek out an object (toy car) during the exploration. Different memory performance between the two groups on spatial vs. object memory was tested. It was observed that the spatial memory of participants was enhanced by active exploration. The beneficial effect on spatial memory of active exploration in a VE is presumed to be attributed to spatial information being encoded procedurally during performance of the task. This finding was also reported by the study of Brooks et al. (1999b). The finding indicates that if

1

active VE participation is encoded as a motor task that taps into procedural memory, this could be particular useful in the rehabilitation of patients with memory impairments since such patients often have preserved procedural learning (Chamess, et. al, 1988).

Brooks et al. (1999a) reported the case of an amnesic patient who was trained on routes around a hospital rehabilitation unit using a non-immersive VE based on the actual hospital unit. They encoded the routes as a motor task to maximise any learning potential as patients with amnesia have been found to show preserved learning of some motor task (Baddeley and Wilson, 1994). They conducted two phases of training. In the first phase, the patient practised on two of ten routes in VE. In the second phase, she practised one of the remaining routes in VE and another in the real unit. All two phases showed positive results. In the first phase, the patient successfully performed the two virtually trained routes in the real unit and could retain her knowledge of these routes for the remaining study. In the second phase, the patient learned the route practiced in VE, but not the route trained on the real unit, and this learning was maintained throughout the course of the study. Brooks et al. (1999a) concluded that the knowledge the patient gained in VE was transferred to the real unit. Learning a route in VE was even more effective than that in the real unit. A factor of this success was attributed to VE for providing quicker traversing of the environment than in the real world, which allowed for more efficient use of the training time. Another factor in this success may be that the VE training did not contain the typical distractions normally present when real world training is conducted that might have impeded route learning. In their study, they used a colour monitor to display the images, as the non-immersive VE was less expensive and easier to set up. However, with the development of HMD and graphic cards, immersive VE has become less costly and relatively easy to set up. Immersive VE is also capable of offering users with better depth perception for better exploration of the environment and the manipulation of objects. Therefore, patients in the immersive VE should be less distracted than in a non-immersive VE.

In the study of Brooks et al. (1999b), there have been no systematic, parametric studies to assess the feasibility or the potential benefits of the widespread use of VEs in the field of memory rehabilitation. Rose et al. (2000a) conducted a preliminary investigation in the use of non-immersive VE with a wide range of vascular brain injury patients. They focused on specifying the types of memory such as spatial and object memory that might be enhanced during a four-room virtual house navigation task. Forty-eight patients were randomly allocated to active and passive groups. The virtual environment ran on a desktop computer and depicted four inter-connected rooms in a bungalow with 20 objects distributed in those rooms. Active group used an analogue joystick to navigate through each room, studied the objects they saw, and attempted to find a toy car. Passive group watched the exploration of the VE undertaken by the preceding active participants on the monitor and were also asked to search for the toy car. After the patients finished the task, they performed spatial layout recognition test and the object recognition test. All responses from the patients were scored on test sheets and statistically analysed. Firstly, this study showed that the use of VE in memory rehabilitation was a feasible proposition as far as those patients were concerned. All the patients performed the VR task adequately and were able to provide useful data on spatial and object memory of the

VE. Secondly, statistics of the test scores showed that active participation in the VE enhanced recognition of the spatial layout of that VE, when compared to passive observation of the active participation's progress. Conversely, active participation in the VE did not enhance recognition of objects fiom the VE compared to passive observation, as active and passive patients showed no differences in object recognition. This result showed that patients did benefit fiom exploring a VE, for recognition of the spatial layout of the VE was better within active exploration than passive observation. Finally, in terms of object recognition, unlike the spatial recognition task, there was no enforced procedural component in the active exploration condition which might have overcome any memory impairments, therefore a target for the future research might be to see if requiring patients to actually touch the virtual objects as they explored the VE would improve their performance in the object recognition test.

The studies of Brook et al. (1999a) and Rose et al. (2000a) may imply that one way to enhance memory for those with memory impairments is to use motor task encoding in a VE to tap into the spared procedural memory. However, to be maximally useful, this strategy should result in memories transferring to a real world situation. Wilson et al. (1999) studied children with a variety of disabilities and found that internal representations resulting fiom exploration of simulated space do transfer **to** the real environment. Other studies on the training of spatial skills and procedure learning reported such positive transfer fiom virtual to real environments (Arthur et al., 1997; Regian, 1997; Waller et al., 1998; Brooks et al. 1999a, b). An investigation on the equivalence of real world performance derived from virtual and real training regimes can be found in the study of Rose et al. (2000b).

However, in the case of procedural learning, early studies (Kozak et al. 1993) suggested that transfer fkom virtual to real environments might not occur. Jack et al. (2001) developed **a** PC-based desktop VR system with force feedback for rehabilitation **of** the hand function in stroke patients (Figure 2.3). Four rehabilitation routines were used, each designed for a specific parameter **of** the hand movement. After a two-week training, improvements seen in the VR-based exercises were also observed in the activities of daily living. However the researchers were uncertain that the improvements were due to the VR-based exercises, the real world tasks, or the combination of the both. It indicates that training and transfer of that task to the real-world environment have not been fully understood.

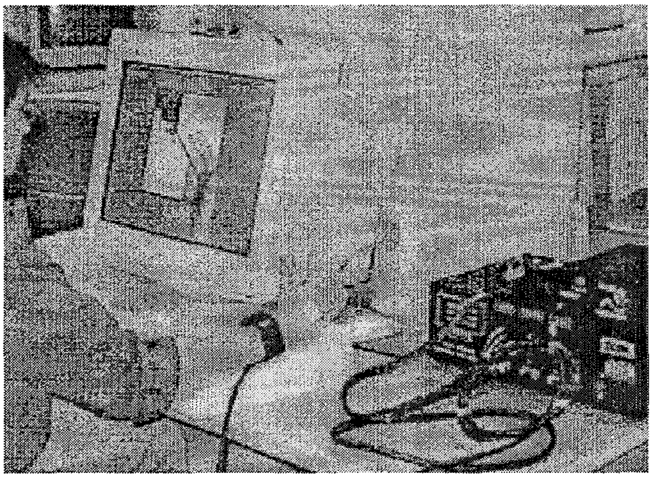


Figure 2.3 PC-based VR rehabilitation system. The user is wearing a CyberGlove with force feedback RMII glove (Jack et al., 2001).

2.4.3 Virtual Reality Systems For Neuropsychological Rehabilitation

When devising memory rehabilitation techniques using VEs, it is important to establish that patients with different cognitive impairments are capable of negotiating in a VE and that their participation can result in enhanced memory functionality.

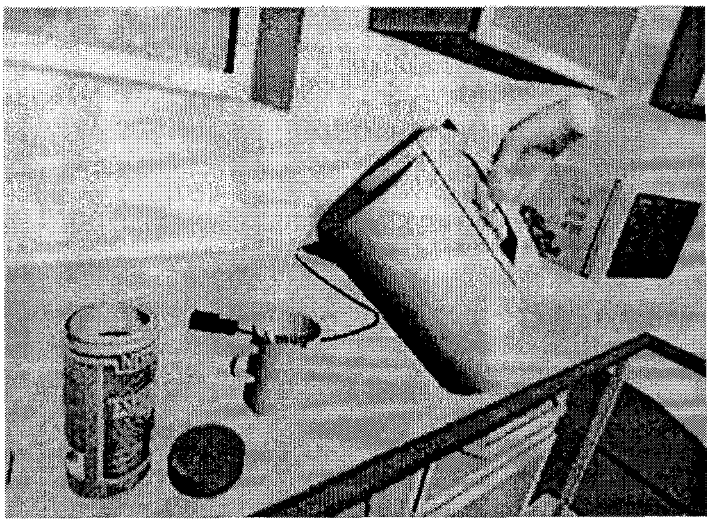


Figure 2.4 VR kitchen (Gourlay et al., 2000a)

Gourlay et al. (2000a, b) used VE technology to train stroke patients and victims of traumatic brain injury to re-learn daily living task. They developed a VR kitchen (Figure 2.4) in which a patient could become familiar with important tasks in a safe learning environment. **A** kitchen environment can present considerable dangers to a cognitively impaired individual, such as the danger of being scalded while boiling water, switching on a kettle containing no water or forgetting to switch off an oven or kettle. The virtual kitchen contained a sink, kettle, cup, coffee jar, microwave, power sockets, cupboards, and drawers. **A** patient could use the virtual kitchen unsupervised with the program monitoring the patient's progress **and** giving prompts as required. The researches also developed a VR glove to enable the patient to pick and move objects in the VE so that the path of the patient's movement could be recorded, displayed, and analysed. **A** preliminary case study involving nine patients who had mild to moderate degrees of cognitive impairments was implemented to monitor the patients' ability to navigate and interact with the VE using a computer mouse and their VR glove. Most, especially the younger patients, were able to adapt and use both devices satisfactorily after some practise. Selection using the mouse presented few problems than those encountered with the glove. These were due to problems perceiving depth caused by a lack of immersion, and therefore depth-cues. However, Gourlay et al. did not report quality or quantity testing data to discuss how and why younger patients had the better performances.

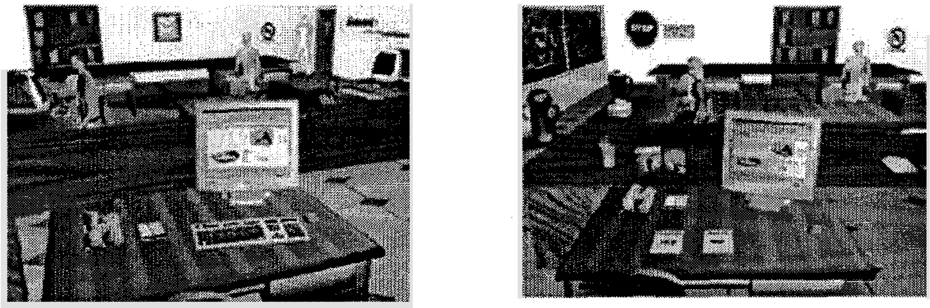


Figure 2.5 Virtual Office (Rizzo et al., 2002)

Functional work performance challenges typical of what occurs in the real world can be systematicallypresented within a realistic office VE. The initial. Rizzo et al. (2002) developed a virtual office to evaluate VR neuropsychological applications designed to target memory process in persons with TBI. The virtual office presented within the HMD simulated a standard office setting containing a phone, computer monitor, message pad, a virtual clock ticks in real-time, and a variety of human avatar representations of co-workers/supervisors can be actively engaged (Figure 2.5). Various performance challenges can be delivered via a “virtual” computer monitor (visual mode), a phone (auditory mode) and from the avatar “supervisors” verbal directions. These commands can direct the user to perform certain functions within the environment that can be designed to assess and rehabilitate attention, memory, and executive functions. For example, to produce “prospective” memory challenges, the user might receive a command from the virtual supervisor to “turn-on” the computer at a specific time to retrieve a message that will direct a response. This would require the user to hold this information in mind, monitor the time via the wall clock and then initiate a response at the appropriate time. By adding multiple concurrent instructions, both attention and executive functioning can be addressed. When testing their system, they designed the methodology based on the traditional neuropsychological measures. The researchers argued that this testing methodology was a more direct comparison between memory performance measures in both the Virtual Office and on standard neuropsychological tests. Twenty individuals with moderate to severe TBI and twenty healthy control participants, matched on age, gender, and education participated the test. Dependent variables for the Virtual Office task include total number of learning trials required to meet criterion and total number of items recalled and recognized at the designated time delays were serve to quantify the use of spatial strategies to assist in memory performance. However, the researcher only reported the observed results including low incidence of self-reported cybersickness and the different strategies for recalling the objects between clinical and normal subjects.

VR rehabilitation system should be made to be engaging, such that the patient feels immersed in the simulated world. This is extremely important in terms of the patient motivation (Popescu et al., 2000), which, in turn, is key to recovery.

Brooks et al. (2002) described a virtual environment used to assess stroke patients' and age-matched control participants' performance of realistic event-based, time-based and activity-based prospective memory tasks. The researches found that the stroke patients were not impaired compared to the controls at the real prospective memory task of asking for the return of their property, but they were impaired at asking for a written explanation of the study, indicates how important motivation is in prospective memory performance. If rehabilitation strategies can encourage stroke patients to be more motivated to remember, it follows that their prospective memory abilities would improve.

Inman et al. (1997) also emphasised the important role of the motivation factor when they developed a VR training platform (Figure 2.6) and three training scenarios to teach children with learning disabilities to operate motorized wheelchair. They first used actual wheelchairs and worked with the kids in relevant real-world situations. The result was disappointing. Then they moved to virtual environment. The scenarios have different levels of difficulty and complexity. They found that these children could concentrate on the task, follow instructions, and demonstrate gains in operating skills in the virtual world. The children were unable to attain these in real world training.

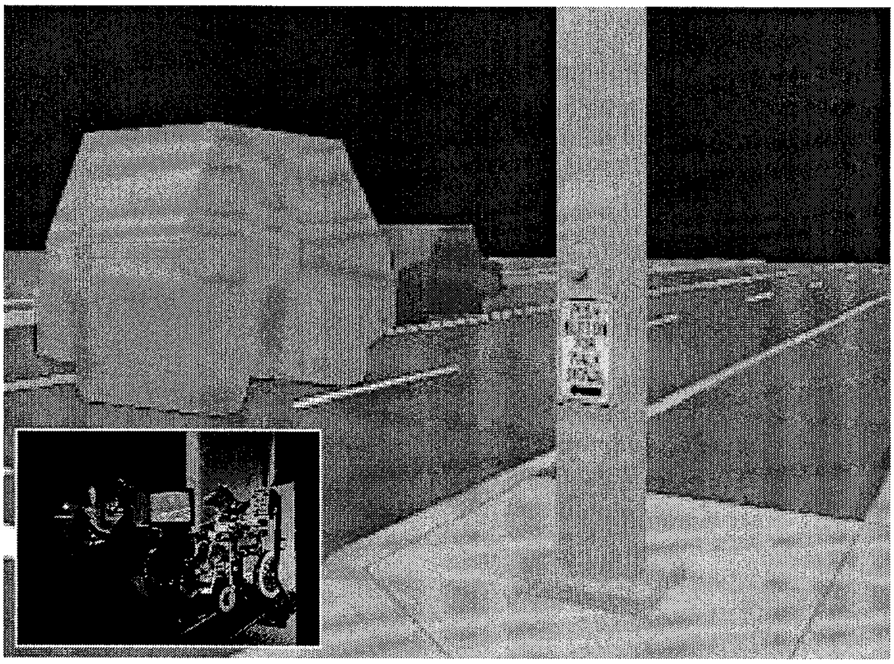


Figure 2.6 A child using the virtual world (Inman et al., 1997)

Wann et al. (1997) embedded the training task into a stimulating game format to motivate the patient toward engaging extended practice in a guided-learning setting for their VE rehabilitation dealing with attention and movement disorders. **A** series **of** open or enclosed VE presented patients with tasks requiring different levels of attention and decision making in their navigation. Figure 2.7 shows the world **of** mazes where its navigation requires a patient to follow a colour sequence that is either prompted or need to be recalled from memory. Figure **2.8** shows the world of mazes where its navigation requires a patient to recognize letters in the presence of non-letter distracters.

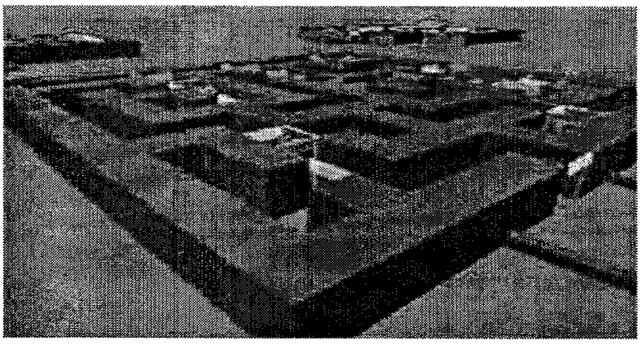


Figure 2.7 World of Mazes (color sequence) (Wann et al., 1997)

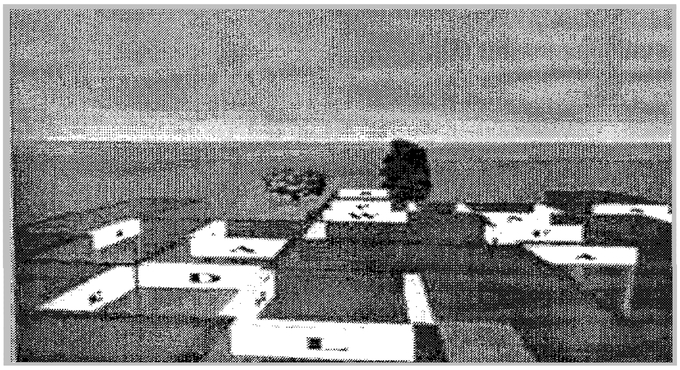


Figure 2.8 World of Mazes (letter sequence) (Wann et al., 1997)

Building on the power of VR technology, non-immersive VR-based rehabilitation presented distinct advantages over conventional and computerized rehabilitation. The positive results further underscore the potential value of immersive approaches that promote "procedural" involvement in the design of better rehabilitative memory approaches.

2.4.4 The Need for Intelligent VR-based Rehabilitation

A feature that is apparent in VR-based rehabilitation discussed above is that a patient would perform more poorly than a cognitive healthy person. They would ask for more instructions to complete the tasks. Therapists will have to accompany them during the entire training processes and to monitor the patient's performance at all times. If the system can take over the therapist's task in monitoring the patient's performance and to offer instructions timely to correct hisher errors, it can reduce the burden on the therapist while at the same time increase the independence of the patient.

In the study of Wann et al. (1997), the system provided the therapist with the ability to adjust the task's complexity to match the different levels of attention and decision making capability of the patient. If the system can dynamically set the tasks at a level appropriate for the patient based on his/her performance, it can also relieve the burden on the therapist and increase the independence of the patient.

In the study of Brooks et al. (1999a), errorless performance training was used in accordance to the suggestion of Baddeley and Wilson (1994) that patients with amnesia rely on implicit memory to acquire new information but that implicit memory does not have the same potential as explicit memory to correct errors. During the training, the patient therefore was corrected as soon as she began to take an erroneous turning so that her performance of the route was always correct. A series of single case studies comparing trial and error and errorless learning with amnesic participants, errorless learning consistently resulted in superior performance, including assisting a stroke patient to learn the names of people (Wilson et al, 1994). In a subsequent study (Evans et al, 2000) in which nine different experiments were completed with amnesia, errorless learning was found to be the superior method for tasks and situations dependent upon retrieval of implicit memory. In the study of Connor et al. (2002), the haptic-guided errorless learning was compared to trial and error learning on a perceptual motor task with twelve patients who had visuoperceptual deficits following stroke. The researchers concluded that using a haptic guidance joystick would result in faster and more direct movements to targets in a visuospatial training task for stroke patients with visual perceptual deficits.

For errorless training to be successful the procedures need to be "foolproof," with learning tasks kept simple, guessing discouraged, and correct responses provided before the individual has a chance to make an error. **A** variety of techniques have been employed to prevent errors from being made during the learning process. For example, "forward chaining" involves learning the first step of the task correctly before the second and subsequent steps are taught. "Backward chaining" takes a reverse approach in which all steps of the task are completed with prompts followed by gradually withdrawing prompts from the last step then subsequent steps in reverse order of their occurrence in the task. "Vanishing cues" is similar to backward chaining in that cues or prompts are progressively removed. Those methods were pre-programmed and unable to dynamically provide the prompt or cues in response to the patient's performances. The new technique is still needed to be studied and be applied in the memory rehabilitation.

To realize the above, the system should be endowed with intelligence. The system should have the knowledge of therapists and process the patient's response as the therapists would do. However, intelligence in a virtual rehabilitation system has not been adequately investigated in VR-based rehabilitation. Most of the virtual rehabilitation systems reviewed requires the therapists to continuously monitor the entire rehabilitation processes. Once the patient has achieved certain satisfactory progress, therapists would need to decide on the next stage of rehabilitation process. Instead of reducing the burden of the therapists, these systems may increase their load, as they also need to control the virtual environments. **A** virtual rehabilitation system that possesses certain experience and knowledge of therapists and have sufficient intelligent capability to control the rehabilitation processes will reduce the burden of the therapists and increase the acceptance of VR for rehabilitation.

Therapists use vague or approximate reasoning to assess **and** instruct the patient's performance in the clinical rehabilitation processes. As such, fuzzy logic will be ideal for incorporation into the VE. Knowledge acquisition and fuzzy models that are essential for developing a fuzzy system will be described in the next section. Some studies of applying fuzzy logic on rehabilitation will be reviewed.

2.5 Artificial Intelligence in Rehabilitation

Zadeh (1965) introduced the concept of the *fuzzy **logic*** that has since opened a new dimension in interpreting human expression within a mathematical formulation. He also introduced a theory called *fuzzy **sets**,* which are sets with boundaries that are not precise. The membership in a fuzzy set is not a matter of affirmation or denial, but rather a matter of a ***degree***.

Two concepts within fuzzy logic play a central role in its applications. The first is a *linguistic variable* whose values are words or sentences in a natural or synthetic language. The other is a *fuzzy if-then rule*, in which the antecedent and consequent are propositions containing linguistic rules (Zadeh, 1973).

Table 2.1 Generic Categories of Fuzzy System Applications

(Munakata and Jani, 1994)

Category	Examples of Application Area
Control	Control is the most widely applied category today
Pattern Recognition	Image, audio, signal processing
Quantitative Analysis	Operations research, statistics, management.
Inference	Expert systems for diagnosis, planning, and prediction; Natural language processing; Intelligent interfaces; Intelligent robots; Software Engineering
Information Retrieval	Database

Fuzzy models can be obtained by applying the principles of fuzzy logic to many areas such as fuzzy controller (Passino and Yurkovich, 1998); fuzzy knowledge-based systems such as fuzzy expert systems which may use fuzzy if-then rules; "fuzzy software engineering" which may incorporate fuzziness in programs and data (Zadeh, 1994); fuzzy databases which store and retrieve fuzzy information; fuzzy pattern recognition which deals with fuzzy visual or audio signals; applications in medicine, economics, and management problems which involve fuzzy information processing (Table 2.1).

2.5.1 Common Methods for Developing Fuzzy Models

Many methods have been used to design, develop, and implement fuzzy models. The basic principles of fuzzy modelling were formulated by Zadeh (1973). Other formulating methods based on system-engineering principles include direct approach and the use of input-output data (Yager and Filev, 1994a).

In the former approach the system is first described linguistically using terms from natural language and then translated into the formal structure of a fuzzy system model with the representational power of the theory of approximate reasoning. The linguistic rules are directly derived from the expert's knowledge of the system and represented in a fuzzy rule format of IF ***situation*** THEN ***action***. This approach has been successfully used in many applications, especially in duplicating operator's actions in the area of control engineering (Mamdani, 1974; Mamdani and Assilian, 1975). Experience gained by an operator in controlling a complex plant can be easily transferred into an algorithm using fuzzy logic principles and its architecture. What is being exploited is the knowledge gained through long observation hours, its synthesis for plant behaviour, and a controlling algorithm that provides adequate performance (Takagi and Sugeno, 1983). However, the direct approach has some inherent limitations for it is solely based on the use of expert's description of the functioning of the system. In this approach quantitative observations of the functioning of the system are not specifically used for the determination of the structure or parameters of the model. Faulty system knowledge of an expert will generate a bad model. Therefore, techniques that use available data to augment human knowledge, or even generate new knowledge are required.

The second approach for developing of fuzzy models is inspired by classic systems theory and recent developments in neural networks. It is based on the use of input-output data. In terms of systems theory, the whole approach consists of two major phases: structure identification and parameter identification (Yager and Filev, 1994a). Structure identification includes determination of the input and output variables, the relationship between the variables (the structure of the rules), the number of rules in the rule base, and the partitioning of the input and output variables into fuzzy sets (Sugeno and Yasukawa, 1993). Parameter identification is the estimation of the membership functions of the fuzzy sets or alternatively, the fuzzy relation associated with the fuzzy model.

Different approach may be used to obtain the structure of **fuzzy** models depending on the availability of some expert knowledge for the system. An approach is the template-based methods (Yager and Fileve, 1994b), which combines the use of expert knowledge and data. The system expert provides the template of linguistic values, which are used to partition the input-output space. Input-output data are then used to generate weights or probabilities associated with the importance of the potential rules. Thus the emphasis is on learning the weights (credibility) of the rules (Tong, 1978; Kosko, 1991). The other approach is based entirely on input-output data. By clustering the input-output data, the relationship between variables, rough estimates of the membership functions of the antecedent and consequent fuzzy sets, and the number of rules may be obtained. The mountain-clustering method provides a systematic approach for identifying the most important rules from the input-output data (Yager and Filev, 1994c).

In the second phase of obtaining parameter identification, the coupling of fuzzy logic with neural networks has supplied a powerful tool for parameter identification of fuzzy models with the use of the back-propagation method (Kosko, 1991). The combination is based on the Takagi-Sugeno-Kang method (Takagi and Sugeno, 1985) that demonstrates a way of developing fuzzy models through simplification of the Mamdani reasoning (Tanaka, 1997) by providing for more formal representations.

2.5.2 Knowledge Acquisition for Developing Fuzzy Models

Fuzzy models basically fall into two categories that differ fundamentally in their ability to represent different types of information. The first includes Linguistic Models (LMs) that are based on collections of IF-THEN rules with vague predicates and use fuzzy reasoning. The second category is based on the Takagi-Sugeno-Kang (TSK) method of reasoning. These models are formed by logical rules that have a fuzzy antecedent part and functional consequent. Mamdani (1974) and Takagi and Sugeno (1985) have further developed fuzzy representation algorithms for knowledge representation in the context of fuzzy systems.

Knowledge acquisition, in the context of fuzzy system, is similar to that of the expert system. The direct approach is to extract rules directly and solely from the expert's knowledge. The second approach is to use some expert knowledge about the system in conjunction with the observed data. Different learning techniques have been used for adapting primary expert information to the given input-output data. These techniques include learning based on fuzzy relational equation (Pedrycz, 1984), template-based methods (Yager and Filev, 1994b), learning via back-propagation (Tagaki and Hayashi, 1991), and learning via genetic algorithm (Lee and Tagaki, 1993). The third approach is that expert knowledge is unavailable and knowledge acquisition is only based on input-output data. The acquisition process is accomplished by a two-step procedure. The first step is the generation of the rules, which can be seen as rough estimates of the final rule base. The second step consists of an adjustment of initial rough rules to final rule-base. The tuning can be accomplished by some of the learning methods described above. Different clustering methods such as Fuzzy C-Means (Sugeno and Yasukawa, 1993) and mountain clustering (Yager and Filev, 1994c) can be used in this approach.

2.5.3 Applications of Fuzzy Logic in Rehabilitation

In rehabilitation area, fuzzy logic has been incorporated into studies for different purposes such as control, pattern recognition, and providing feedback. For fuzzy controller applications, fuzzy logic is readily applied to higher order nonlinear multiple-input/multiple-output (MIMO) systems. It does not require precise mathematical models with known inputs but rather describes system dynamics through membership functions and rules. Control rules are established based on operator experience and system knowledge. For example, Petroff et al. (2001) developed a fuzzy controller (Figure 2.9) to restore the hand grasp function for individuals suffering fiom upper extremity paralysis due to a spinal cord injury or other pathology. They built control rules fiom heuristic knowledge that is available on finger movements to perform grasps.

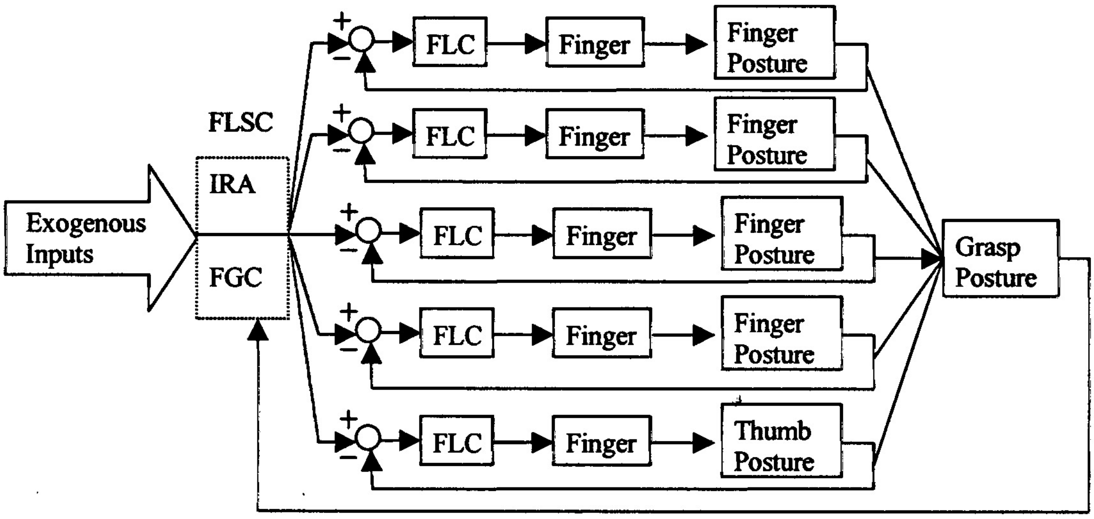


Figure 2.9 Hand orthosis control architecture consisting of a fuzzy logic supervisory controller (FLSC) and five lower level FLCs, one for each fmger and the thumb (From Petroff et al., 2001)

Kawamura et al. (1994) presented an intelligent system **ISAC** (Intelligent **Soft** Arm Control) designed to feed individuals with physical disabilities. To reduce the amount of mental activity needed by the user of these robots, the system needed intelligence to understand the user's intention. Since humans often think in fuzzy terms, additional mental load could be removed if the robotic system could accept fuzzy commands like "move closer" or "move faster". Therefore, they used fuzzy logic to realize the intelligence of the robot. The system consisted of several parts such as fuzzy command interpretation, object recognition, face tracking, and task planning and learning (Figure 2.10). In the system, the fuzzy command interpreter was implemented to provide the user with a natural way to command the system. **A** user can issue a command such as move closer. The command would then be translated into **a** quantitative distance or velocity. In addition, the target to move towards has to be inferred (e.g., move closer to what?).

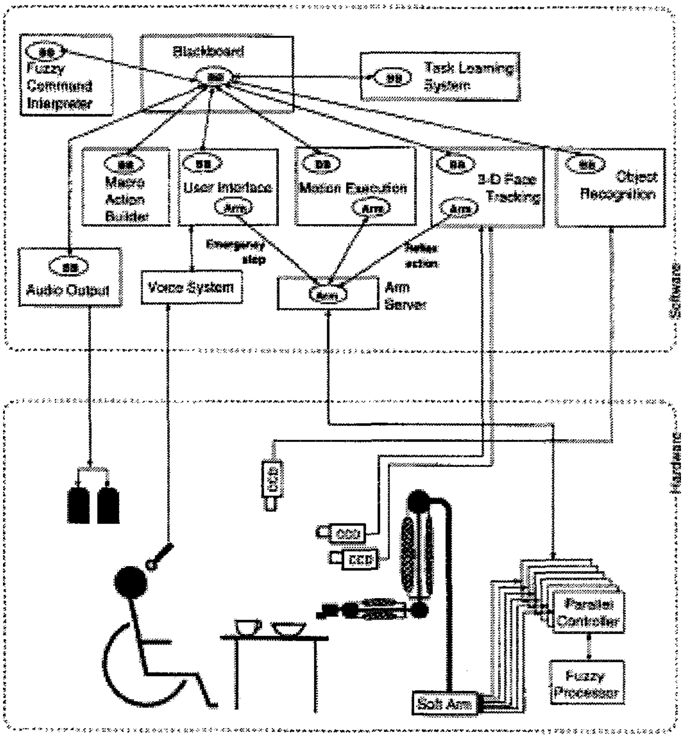


Figure 2.10 Software and Hardware Modules in the ISAC System (Kawamura et al. 1994)

Another application of fuzzy logic is pattern recognition. Choi and Ricci (1997) used sensor technology and fuzzy logic to develop an interface for basic human movements, natural stance and bipedal locomotion. The flow of signals in the foot-mounted gesture recognition system is given as a block diagram in Figure 2.11. The multiplicity of pressure signals from the foot provides a high-dimensional control source, while the modularity of the signals provides a means for differentiating human-determined motion patterns. Pattern recognition was implemented using rule-based inference based on fuzzy logic. The rule base was pre-defined ffom analyzing the walk pattern from the perspective of the sensors, combining the static and dynamic conditions set forth by fuzzy inputs. Another example is the study by O'Malley et al. (1997). They used fuzzy clustering technique to group temporal-distance parameters of the ambulation of neurologically intact children and those with cerebral palsy. Using information provided by the neurologically intact population and cluster validity techniques, five clusters for the children with cerebral palsy are identified. The five cluster centres represent distinct walking strategies adopted by children with cerebral palsy. The groupings established fuzzy rules, membership functions and their values.

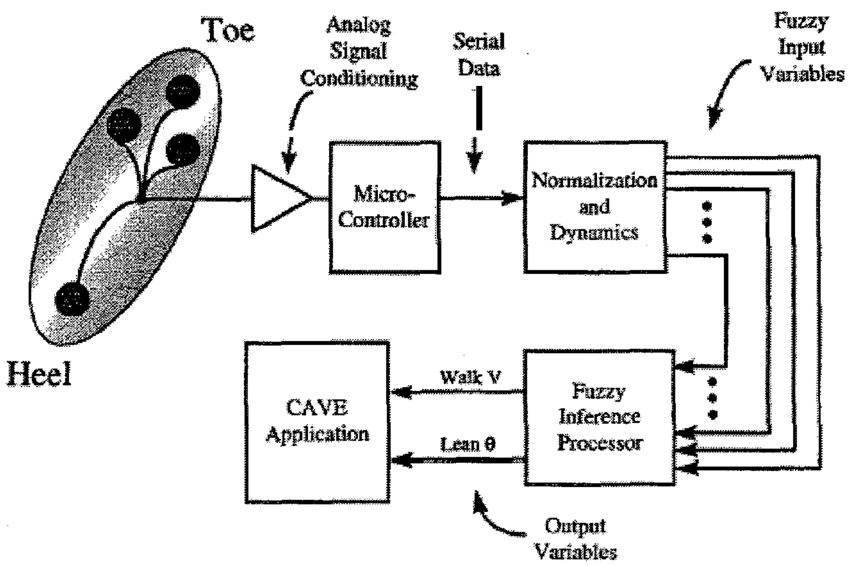


Figure 2.11 Signal Flow of the Foot-Mounted Gesture Detection (Choi and Ricci, 1997)

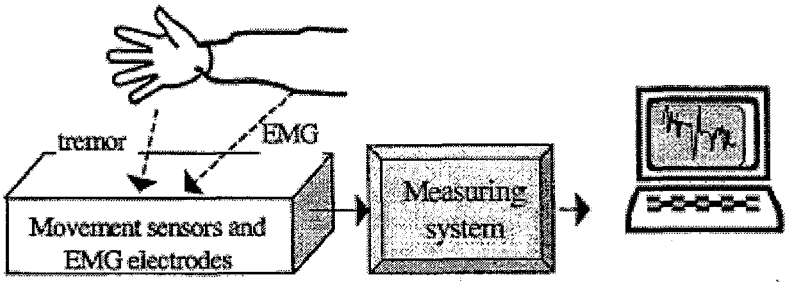


Figure 2.12 Sketch of the Measuring and Feedback System (Teodorescu et al., 1998)

Fuzzy logic has also been used to provide helpful feedback during the rehabilitation. Teodorescu et al (1998) developed a VR-type system to rehabilitate hand tremor resulted from injury (e.g., an accident, with hand fracture). Figure **2.12** shows the measuring system that is the basis of the whole system. The measuring system was used to analyze the chaotic movements during hand tremor such as frequency of tremor and tremor irregularity (input parameters) and the amplitude of the tremor (output parameters). The fusing of the numerical parameters derived from the analysis was performed based on fuzzy techniques of aggregation. Fuzzy rules and membership functions were derived from those data. The defuzzified result was used to decide the kinds of feedback controlling the movements of the hands for rehabilitation purpose.

2.6 Summary

As the theoretical and empirical foundations of cognitive rehabilitation are continuously being evolved, it is recognized that its ability to improve the quality of life of dementia patients will depend on a correct application of methodologies and technological aids. The application of VR technology in memory rehabilitation has a significant advantage over the conventional rehabilitation methods. VR technology can simulate a familiar, daily living, real-life environment. The practise material in such an environment can be items relevant to the patient's everyday life. This may improve the transfer and generalization from training environment to the real world. VR-related technology such as HMD and dataglove allow the patient to immerse into the virtual environment (VE) to touch and grasp these items as if he/she performances in the real environment. This would increase the patient's motivation that plays a key role in the rehabilitation. Moreover, most of the rehabilitation tasks require extensive practice and repetition. In the real environment, such repetitions may vary with differing lighting or background noise. This may produce some disturbances to the patient's rehabilitation process. In the virtual environment, however, these disturbances can be avoided because of the consistency in the VR system.

Fuzzy logic has also been applied to the rehabilitation regime, such as for providing control, pattern recognition, and feedback. The uncertain nature of the movements of patients provides the impetus for fuzzy methods to be introduced into rehabilitation, especially for measuring and controlling movements. These fuzzy models were developed from different methods in terms of their variables, membership functions, and rule bases. In this study, Fuzzy logic is applied to provide assistance to the patients during the VR-based rehabilitation for dementia patients. A different fuzzy model in terms of its variables and rules would be needed. This can be acquired through a suitable knowledge acquisition method.

The existing VR-based memory rehabilitation did not describe a methodology for the design of a virtual functional rehabilitation environment. Some studies showed the positive transfer from virtual environment to real world. Some showed that the learning did not always transfer to the real world. Therefore the transfer problems in virtual rehabilitation still need to be studied. Patients suffered from memory deficits require more assistance than normal persons when performing virtual tasks. This will cause a big burden over therapists who have to keep on assisting patients during the rehabilitation. And studies showed that dementia patients have better performances in the errorless learning environment. Current methods for errorless learning were usually pre-programmed and unable to dynamically provide assistance in response to the patient's performances. An intelligent approach should be a novel method for developing an errorless learning rehabilitation process.

The objective of the project is to establish a methodology for intelligent approach to memory rehabilitation for the elderly with AD. The methodology explores the integration of VR technology and Fuzzy Set theory with the knowledge and experience of conventional approaches in memory rehabilitation. It aims to overcome the difficulties faced by using the computer programs and conventional approaches to memory rehabilitation and to enhance the effectiveness of rehabilitation.

CHAPTER 3 DEVELOPMENT OF THE VIRTUAL REHABILITATION ENVIRONMENT

3.1 Overview

As discussed previously in Chapter 2, virtual reality (VR) technology has the potential for computer-based rehabilitation. However, the introduction of a patient into a virtual environment (VE) for the rehabilitation may raise other concerns. For example, delays between the monitoring of head (or limb) positions and the presentation of the corresponding image on the display may cause perceptual problems to the users. Special precautions are therefore needed during the design stage to ensure the effectiveness of the VE. These include the selection of appropriate VR devices, the consideration of the compatibility of hardware integration, and the design of the interactions. As VR technology is still new and being developed, not many precedent examples can be found on the specific development process for this kind of application. Stuart (1996) proposed a four-stage design approach, namely the requirement and task definition, design, prototyping, and evaluation. It follows a generic approach of iterative design used in designing many types of human computer interfaces (Stuart, 2001). However, there are more special challenges for designing a virtual rehabilitation environment for patients suffered from AD. Followed the philosophy of the generic approach, this chapter will systematically present the methodology for the development of the VE for this project.

3.2 Requirement and Task Definition

Requirements of the system are put forward based on previous discussion in Section 1.1 that functional approaches are clinically more suitable for the older patients with memory deficits. The scenarios for the rehabilitation training should simulate a familiar, home-like, and functional environment that exploits preserved procedural learning abilities of the patients. The patients should perform selected tasks for rehabilitation under the supervision of the therapists. These tasks should associate with the patients' daily activities and must maximize the training for independence while focusing on individual strengths and abilities.

For the elderly with dementia, the VE should minimize their learning required to operate within it, but maximize the information yield. The formats and contents of the information to assist and control the rehabilitation processes should be acquired through knowledge acquisition, carefully designed, and built. In addition, the patients should be capable of moving around in the VE and interacting with the virtual objects in a positive and natural manner as they do in the real world. That intuitive interaction can relief the patients' burden on learning how to navigate and interact within the environment. Meanwhile, an immersive VE can invoke the patient's motivation and eliminate external "distractions" in the training.

The virtual environment should be more flexible by adjusting the difficulty levels based on the patient's condition and performance in the virtual rehabilitation environment. The rehabilitation task should be decomposed into subtasks. The combination of those subtasks may be used to set up different levels of difficulty. The patients can learn to complete the task step by step.

Table 3.1 shows a summary of the design criteria for the discussed virtual environment.

Table 3.1 Design Criteria of VE

No.	Criteria Description
1	Simulate a functional environment
2	Design rehabilitation tasks associated with patient's daily activities.
3	Design tasks flexibly for customizing the difficulty level for patients
4	Provide assistance with animate format and foolproof contents to minimize the learning requirements for patients
5	Provide intuitive interaction for patients to operate VE

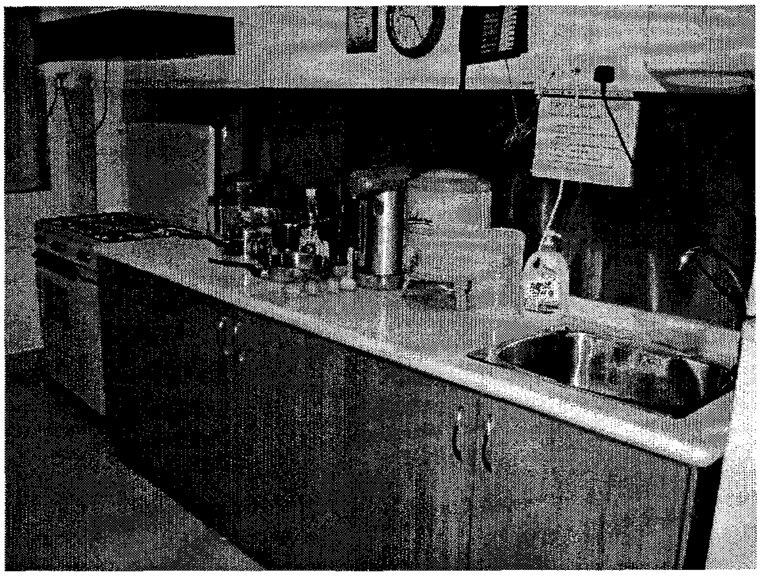


Figure 3.1 ADL Room in the Hospital

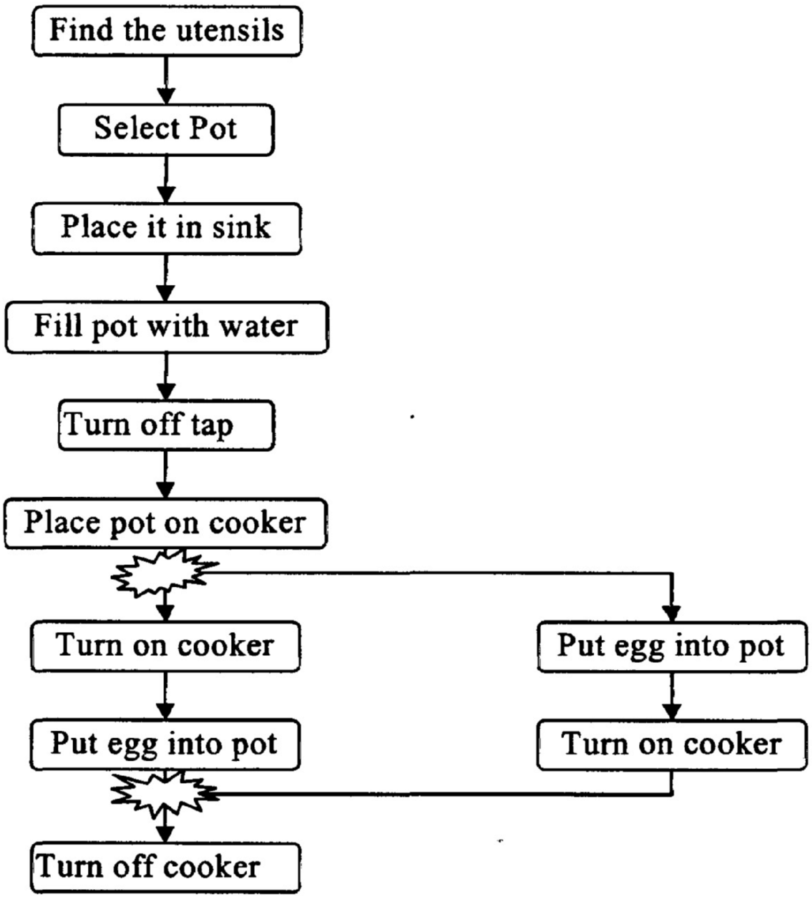


Figure 3.2 Two sequences of subtasks for cooking egg task

The case study of this project will be based on an actual rehabilitation exercise at the St. Luke's Hospital for the Elderly. The virtual environment will simulate the ADL (activities of daily living) room in the hospital. The clinical ADL room is set up as a kitchen (Figure **3.1)** where the patients are trained to perform daily activities, such as cooking. During the training processes, the entire task is decomposed into sequential subtasks based on the level of difficulty. The patient is allowed to complete the task procedurally. For example, the task of cooking eggs can be decomposed into a number of subtasks as showed in Figure **3.2.** The patient is required to complete these subtasks one at a time, until he/she can successfully perform the entire task. The cooking eggs task will be used as an example to explain the development of this virtual kitchen in the following section.

3.3 System Design

The purpose of the design stage is to specify the computing and communication hardware architecture and the modelling software architecture for implementing the VE. Unlike most human-computer interfaces, VE tends to have more levels of design requirement. In a typical human-computer interface, the input and display technologies are either standardized or already specified, and the designer needs to concern only with its content and interaction. For the VE, more issues need to be carefully considered. Those include the structure of system, the choice of sensory modalities and the information to be displayed through each of them, the objects, behaviours, and interactions in the VE, and the decisions to be made about input technologies and output technologies.

3.3.1 Hardware Architecture

3.3.1.1 Requirements Analysis

Based on the requirement and task definition, the following considerations have been made in the design of the hardware architecture.

(a) An Immersive VE

The therapists in the Hospital have expressed, from their clinical experiences, that providing treatment in an immersive VE would increase the emotional impact on the patient's motivation and isolate the patients from external distractions. An immersion-based rehabilitation system is, therefore, considered for the system. The HMD will be used in this study, as it is a relatively efficient tool to support the immersion-based component of presence (Gourlay et al. 2000a). However, to ensure safety and usefulness to the old patients, its potential for causing cybersickness needs to be carefully considered. Cybersickness is a form of motion sickness with symptoms reported as nausea, vomiting, eyestrain, disorientation, ataxia, and vertigo (Kennedy, et. al, 1994). Studies on the use of HMD for immersive VE have reported some incidences of side effects such as dizziness and headache (Lewis and Griffin, 1997). A common cause for the problem is the time delay in the update of the images seen by the user in the HMD with respect to the head motion of the user. However, a study by Pugnetti et al. (1995b) reported that there are no differences in the VR side effects between neurologically impaired and unimpaired subjects. A more conclusive research is required to study the effects of HMD on the subjects.

(b) Natural and Enhanced Interactions

Using traditional computer input tools for the old patients may be a problem. It would be unnatural for those unfamiliar with PC usage to interact with the VE by pressing buttons on a keyboard, moving and clicking with a mouse, or manipulating a joystick. This may also distract the patient's attention, and cause negative effects on the rehabilitation process. Therefore, unconventional computer input tools are used. A CyberTouch glove (Virtual Technologies, Inc., 2001) is used to enhance the interaction between patients and VE. An Ascension Flock of Birds position tracker (Ascension Technology, Co., 1999) attached to the glove monitors the position and orientation of the hand. The forearm posture will also be displayed in the VE to assist the patients in regulating their arm movements. A head tracker attached to the HMD provides data on general navigation. This enables visual displays to be updated in response to the patient's head motion and orientation. Proper integration of those sensors can also promote the sense of immersion by enabling the patient to touch, grasp, and move the virtual objects just like in the real world. Responses of the patient are feed back dynamically to the system for further control of the rehabilitation process.

(c) PC-based VR systems

Computer systems suitable for VR applications range from relatively inexpensive PC to the top-of-the-range SGI (Silicon Graphics Inc.) graphics workstation with multiple parallel processors and real-time image generators. The early VR systems were based on SGI workstations, mainly for their faster computing speeds and better graphics performance. However, the availability of powerful PC processors and the emergence of reasonably priced three-dimensional (3D) accelerator cards have enabled high-end PCs to process and display 3D simulations in real time. The virtual world generated by high-end PC can be as good as that generated by the SGI graphics workstation several years ago. Riva (1998) advocated that a standard Pentium 266 MMX with as little as 16M RAM could offer sufficient processing power for a bare bones VR simulation. A 350MHz Pentium II with 32M RAM can produce a convincing VE, while a dual processor 400MHz Pentium II configuration with OpenGL acceleration, 128M RAM and 24M VRAM running Windows NT, can match the horsepower of a graphics workstation. Therefore, a PC-based VR system running at Pentium IV 1.5 GHz has been adopted in this project.

Figure 3.3 shows the system hardware architecture, while Figure 3.4 shows the experimental settings. The major VR devices shown for this system will be discussed in the following section.

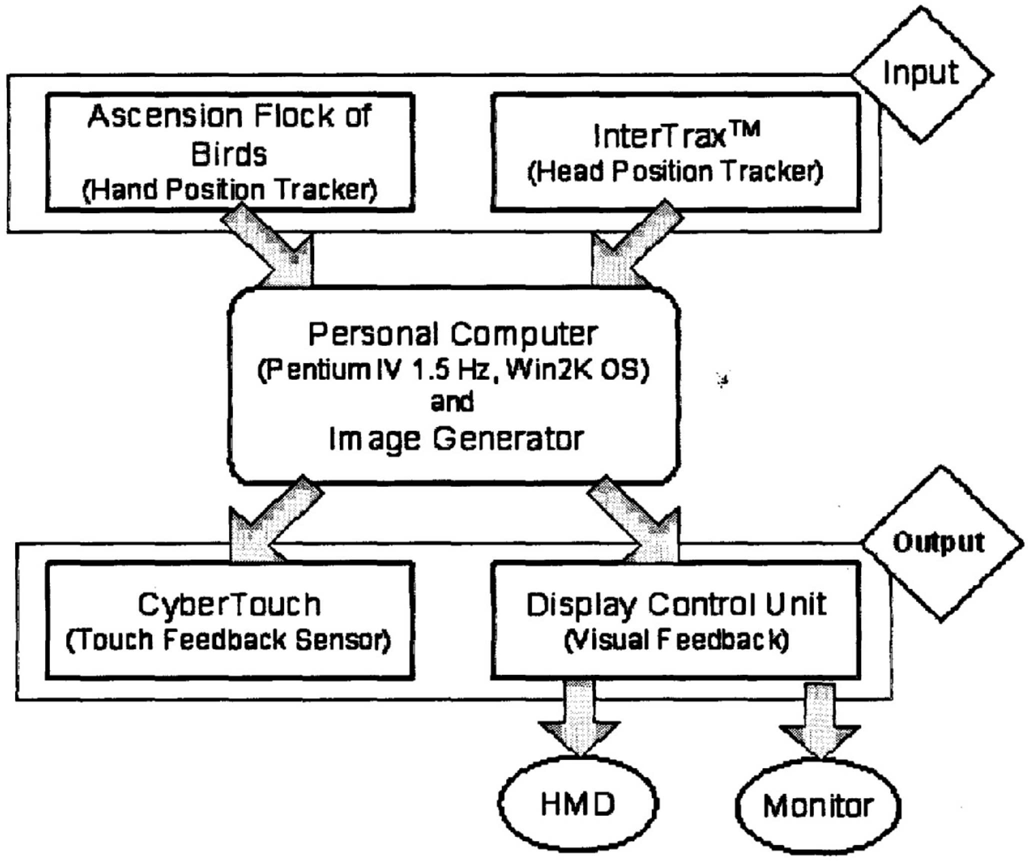


Figure 3.3 System Hardware Architecture

Figure 3.4 PC-based VR Rehabilitation System

3.3.1.2 Hardware Component

(a) Image Generator

One of the most time-consuming tasks in a VR system is the generation of the images. The simulation engine of this system consists of a Pentium IV 1.5 GHz PC with Oxygen GVX 210 graphics accelerator card. The card can support true, quad-buffered stereo up to **1280x1024** resolution, at **118** Hz refresh rate. Other features can be obtained from the vender web site (3Dlabs, Inc., 2002).

(b) Hand Position Tracker

Position tracking is the key element for interaction with a virtual world. One of the major problems for position tracking is latency, or the time taken to measure and pre-process the data before input to the simulation engine. There are a range of different technologies that can be used for trackers including mechanical systems, magnetic systems, optical systems, acoustic (ultrasound) systems, and inertial systems (Stuart, 1996). Magnetic position-tracking technology has been the most widely used tracking technology for VEs.

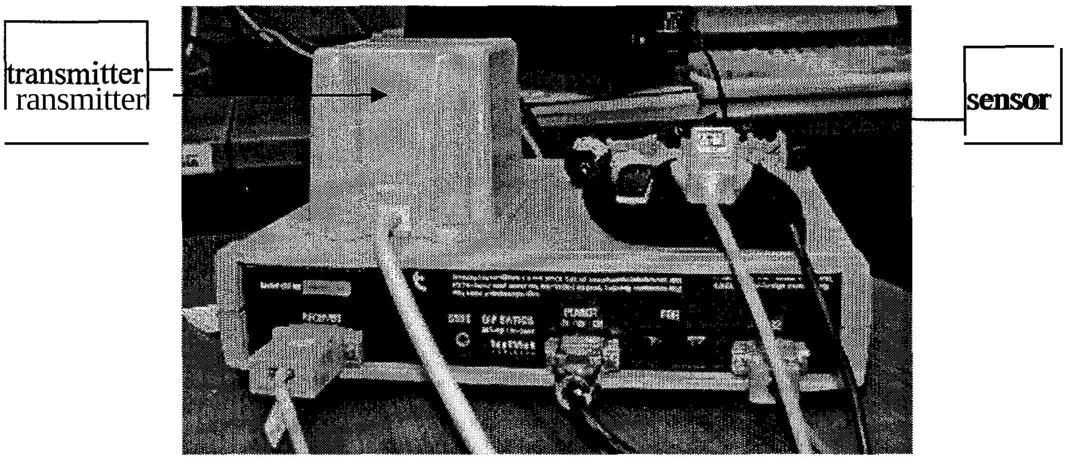


Figure 3.5 Ascension Flock of Birds

Using magnetic position-tracking technology, the Ascension Flock of Birds (FOB)@ (Figure 3.5) is a six degree-of-freedom measuring device that can be configured to simultaneously track the position and orientation of up to thirty sensors by a transmitter (Ascension Technology Corp., Online). It includes a system electronics unit (SEU), a power supply, a transmitter, and sensors. The SEU contains the hardware and software necessary to generate and sense the magnetic fields, compute the position and orientation, and interface with the host computer via an RS-232 port. The transmitter emits the magnetic fields. It also acts as the reference for sensor measurements. The sensor, in this study, is fixed on the wrist of the dataglove and detects the magnetic fields emitted by the transmitter. The sensor is capable of taking

20 to 144 position and orientation measurements per second when it is located within ±1.22 m of the transmitter.

(c) Head Position Tracker

The head position tracker uses InterTrax™, a 3 Degrees of Freedom (3 DOF) tracking system (from Intersense) (Figure 3.6). It can be attached to the head mounted display (HMD) and allows the user to look up, down and around through 360 degrees as he interacts with their environment. Sampled at 256Hz, the sensor signals are continually analyzed by an on-board microprocessor to compute the orientation of the tracker in space. InterTrax™ is not affected by electrical or magnetic interference.

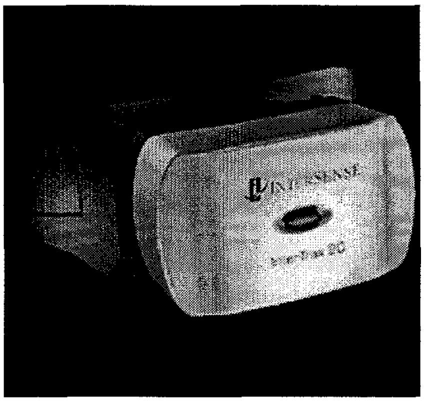
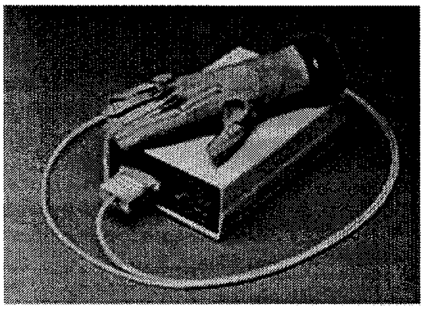


Figure 3.6 InterTrax™ Head Tracker

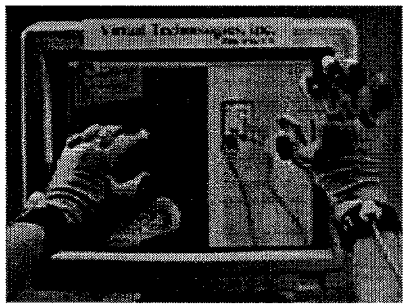
(d) Touch Feedback Sensor

The touch feedback system uses the CyberTouch® (from Immersion Corp.) with an 18-sensor CyberGlove®. The basic CyberGlove system (Figure 3.7 a) consists of an instrumentation unit, a serial cable for connecting to the host computer and the glove.

The glove features two-bend sensors on each finger, four abduction sensors, and sensors for measuring thumb crossover, palm arch, wrist flexion and wrist abduction. In CyberTouch (Figure **3.7** b) small vibrotactile stimulators are attached to each finger and the palm of the CyberGlove. Each stimulator can be individually programmed to vary the strength of the touch sensation. The array of stimulators can generate simple sensations such as pulses or sustained vibration, and they can be used in combination to produce complex tactile feedback patterns. The sensor of FOB is to be mounted on the glove wristband.



(a)



(b)

Figure 3.7 CyberGlove and CyberTouch

(e) Visual Feedback

Immersed visual feedback can be realized with ProView™ XL 50 (Figure **3.8),** an HMD from Kaiser Electro Optics, Inc.. It has an external control box to handle the inputs and outputs for audio, video, and power, with standard VESA-type 15 pin connectors to receive **XGA** (1024 x **768** 60Hz) inputs from graphics engines. Two external monitors may be connected to the RGB outputs (left and right) also through the control box. This enables the therapist to view the same virtual environment experienced by the patient. In the HMD, there is a complete overlap of left and right images for stereo perception. Though its 50° (diagonal) field of view is below user's expectation of a full visual immersion, such reduced field of view has an advantage of helping the patient's to focus attention on the rehabilitation scenario.

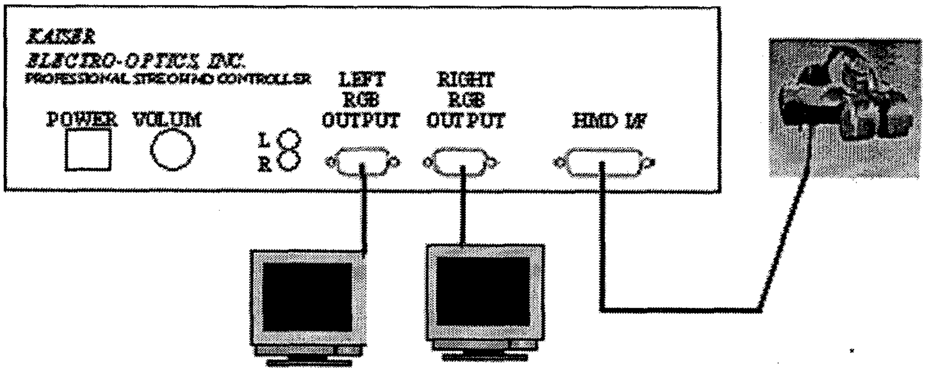


Figure 3.8 HMD and its controller front panel

3.3.2 Software Architecture Design

3.3.2.1 Object-Oriented Method

Object-oriented programming (OOP) is a relatively new method for designing and implementing software systems. OOP recognizes and analyzes the real world in a way that is very close to that of human beings. The major concepts of OOP include objects, classes, encapsulation, class hierarchies, class inheritance, and polymorphism (Rumbaugh et al., 1991). Objects encapsulate procedures to the object itself. These attached procedures, called methods, are invoked through messages sent to the object by the user or by other objects. On receiving a message, an object selects the method indicated by the message, executes it, and responds accordingly. It is the active nature of objects that distinguishes them from other forms of structured representation.

All objects representing individuals, or instances, belong to classes. Classes are further organized into a hierarchy of classes and subclasses. Instances of a class inherit properties from their parent class. OOP allows polymorphism, the ability for a program to work with different objects as interchangeable black boxes. Polymorphism allows the creation of compatible objects that are interchangeable. Modifying and improving a polymorphic program can be simply a matter of plugging in updated objects. Therefore, OOP method can provide the advantages of modularity, modifiability, extensibility, flexibility, maintainability, and reusability. This enables the software to be developed in a flexible and natural way.

OOP focuses on the data to be manipulated rather than on the procedures that carry out the manipulating. The main challenge of object-oriented software design is the decomposition of a software system into classes and subclasses and the definition of the properties of each **of** the basic physical or logical entities in the domain of the actual problem. The architecture framework that defines an object-oriented software system forms the high-level design of the system. It reveals only a set of classes and their definitions and objects. The implementation details of the methods are not part of the high-level design of the system (Wiener and Pinson, 1988).

The high-level design of this system, followed by the section discussing the implementation details of the methods will be described in the following section.

3.3.2.2 Software Architecture

Using object-oriented method, the system software architecture is formed by following the message passed through the whole system. It consists of three major modules, namely Input, Dynamic Central Control (DCC), and Output Packages. Figure **3.9** illustrates the architecture and the major classes in each package. Classes are represented as rectangles with either:class or object:class names. The lines between the classes are links. Each link is labeled with one or more operation names residing on the class the arrow is pointing away from. The arrows indicate the direction of the flow.

The Input Package is mainly composed of *HandPositionTracker* and *HeadPositionTracker* classes. *HandPositionTracker* will track the Flock of Birds sensor on the wrist of the CyberGlove to locate the position of the hand. It will also calculate the position of each finger according to the relative positional relationship between the sensors on fingers **and** the sensor on wrist. Simultaneously, this class will also monitor the values of sensors on the glove to identify the gesture. *HeadPositionTracker* will track the head position input by InterTrax sensor. **As** the hand and head positions change during an interaction with the VE, the tracker classes would send the message of changed positions to DCC Package.

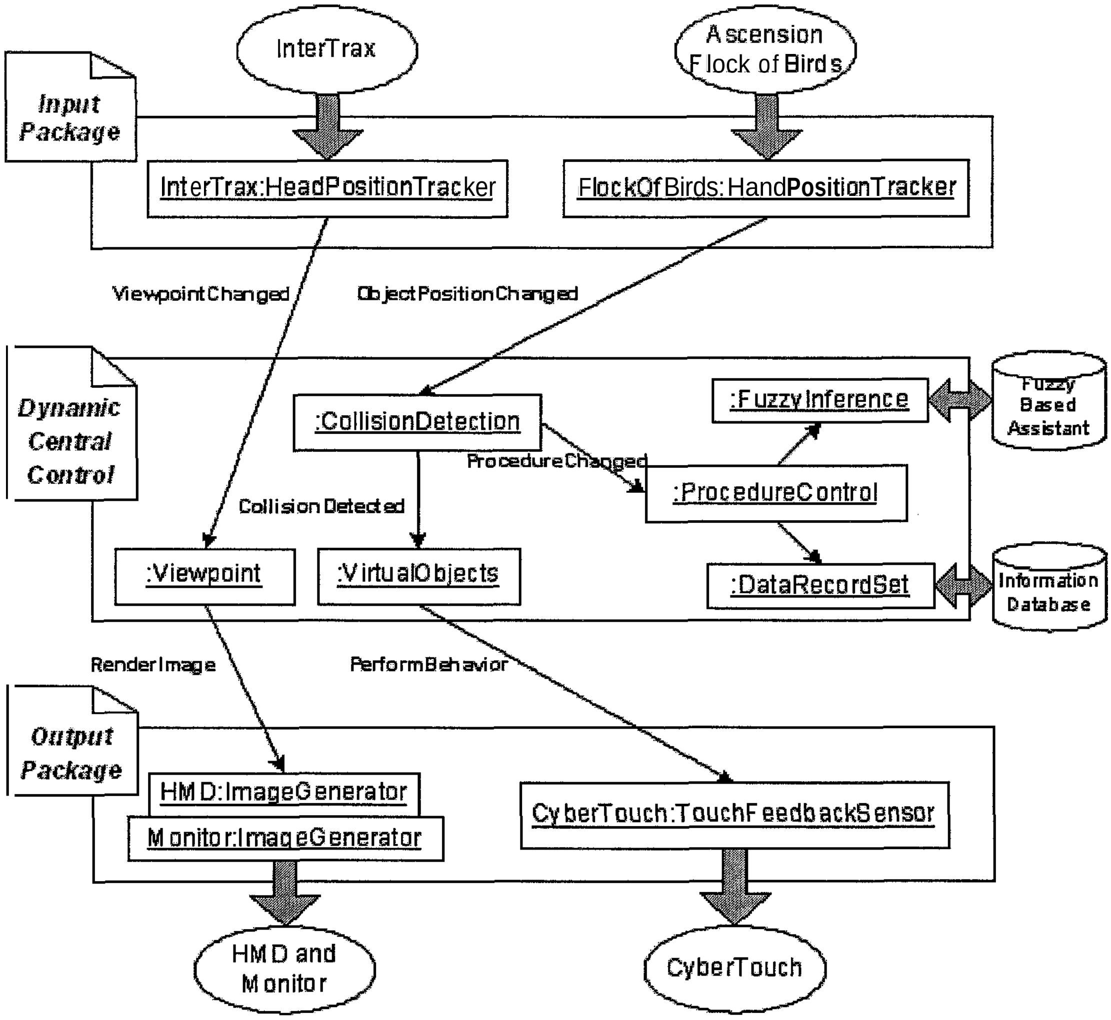


Figure 3.9 System Software Architecture

DCC Package includes a group of classes that control the flow of all system functionality. Viewpoint class is the abstraction standing for the location and direction of the user in the virtual world. From this point all of the objects in a simulation are projected to the screen and rendered. While receiving the message of changed head position, Viewpoint changes its position and orientation and sends the message to the class *ImageGenerator* in Output Package. **As** every task will be decomposed into several subtasks and each subtask is called a procedure, the class *CollisionDetection* will determine which procedure it is and send the *ProcedureChanged* message to the *ProcedureControl* class. Responding to the message, the *ProcedureControl* class would send the training data such as "which-procedure" and "the time spent on this procedure" to the *FuzzyInference* and *DataRecordSet* classes respectively. *DataRecordSet* records and saves those. data into Information Database. *FuzzyInference* invokes the Intelligent Assistant of the system. *FuzzyInference* will be discussed in the Chapter 4.

Another function of the *CollisionDetection* class is to detect if there is a collision between the hand and the virtual objects upon receiving the message of the changed hand position. If there is a collision, the class *VirtualObjects* performs predefined behaviors with respect to the gesture of the user's hand. Meanwhile, it sends the message to the *FeedbackSensor* class in the Output Package.

VirtualObjects is the parent class of all the virtual objects in the virtual kitchen and includes pot, stove, table, and other objects. Its hierarchy is showed in Figure **3.10.** The class *VirtualObjects* lies in the highest level. Virtual objects in the virtual kitchen are also classified as static and dynamic objects. Static objects such as wall and roof cannot be moved, while dynamic objects like pot and stove button can be operated. Virtual objects are represented by *StaticObjects* and *Dynamicobjects* classes respectively that lie in the lower level of the hierarchy. Each class is derived from its parent class and can inherit its parent's properties. In addition, each class can have new data structures and methods that are suitable for particular functions. The functions define the particular motions each dynamic object could have. For example, Figure **3.11** demonstrates the properties in ***Dynamicobjects*** and the ***Put*** classes. The ***Put*** class inherits properties such as Load() and Attach() fiom the ***Dynamicobjects*** class and meanwhile has the particular functions such as FilledWater() and Fall().

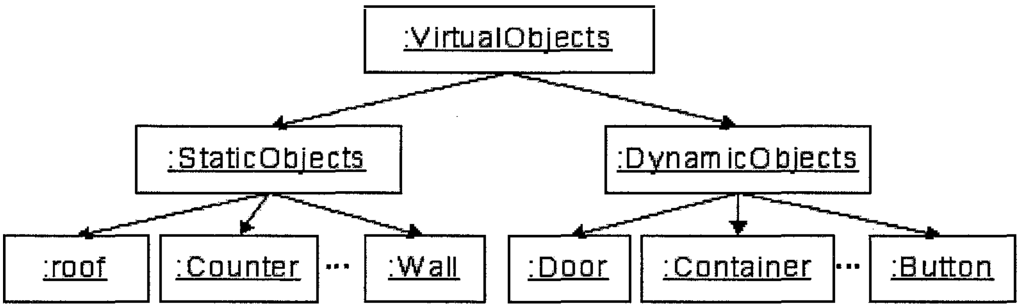


Figure 3.10 Hierarchy of VirtualOjbects Class

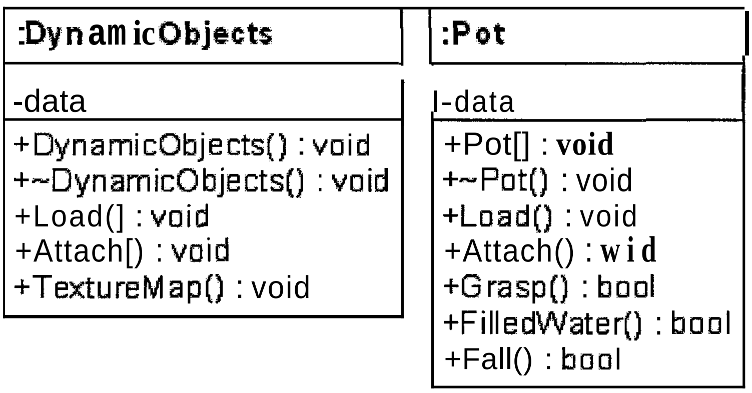


Figure 3.11 Properties of Dynamicobjects and Pot Classes

In the Output package, the object CyberTouch is the instance of the ***TouchFeedbackSenor*** class. After receiving the message from the DDC Package, it will set the values of the corresponding actuators attached on the CyberTouch and produce the appropriate vibration feedback to the user's hand. The objects HMD and Monitor are both the instances of ***ImageGenerator*** class. After receiving the message from the DDC Package, the HMD will display the stereo images to the user. The Monitor will display the view to the person who will monitor the rehabilitation processes.

The tools and methods used to implement the virtual rehabilitation environment will be described in the next section.

3.4 Implementation

The virtual rehabilitation environment constructed and tested for this study is a virtual kitchen simulating the ADL (activities of daily living) room (Figure **3.1)** at the St. Luke's Hospital for the Elderly. One of the designed scenarios, cooking eggs requires the patient to procedurally complete the subtasks as shown in Figure **3.2.** The implementation begins with modelling the environment, followed by the simulation using professional tools.

3.4.1 Development Tool

The fact that virtual reality software is intrinsically difficult to design and implement emphasizes the importance of user interface tools. Currently, systems that support virtual reality software construction can be subdivided into two categories: toolkits and authoring systems. Authoring systems are complete programs with graphical interfaces for creating worlds without restoring to detailed coding. These usually include scripting languages to describe complex actions (e.g. VRML). While simpler to use, current authoring system do not offer all the functionality of toolkits.

Toolkits are extensible libraries of object-oriented functions designed for VR specifications. **A** simulated object is part of a class and inherits its default attributes. This greatly simplifies the task of programming complex worlds. Since the libraries are extensible, it is possible for developers to write application-specificmodules while continue to use the same simulation kernel.

Another important feature shared by VR toolkit is that it is hardware independent. The generic functions are written for use in various hardware platforms. This is achieved by using high-level functions without specifying the hardware they are running on. Low-level translators identify the specific I/O tools at run time. This is especially useful when porting an application from one platform to another.

Toolkits also support some form of networking. This allows parallel or distributed processing as well as the important multi-user interaction. It is therefore possible for a particular teamwork to be carried out on a single application, resulting in an increased productivity.

The commonly used toolkits include MR Toolkit (by Green of the University of Alberta), VRT (by Dimension International Com.), MultiGen-Paradigm (by MultiGen-Paradigm Inc.), and WTK (by Sense **8** Inc.) In this project, the virtual environment was developed with WTK (World Tool Kit).

WorldToolKit (WTK) is a portable, cross-platform software development system for building real-time, integrated 3D applications. Its library has more than 1,000 functions for configuring, interacting with, and controlling real-time simulations. An important aspect of WTK is that it is hardware independent and will run on a range of graphics platform from 50MHz **486** personal computer with graphics accelerators to Silicon Graphics workstations. This means that development can be undertaken on lower cost PC platforms and transplanted later onto specific higher performance target machines.

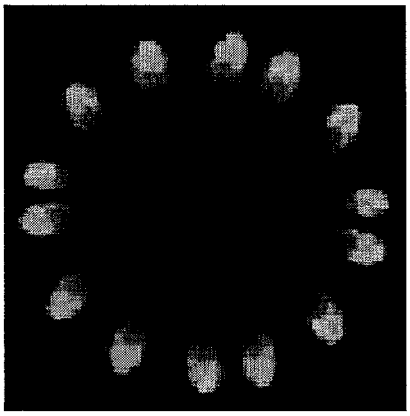
WorldToolKit is structured in an object-oriented manner. Its functions are object-oriented in their naming convention, and are grouped into classes. Applications built with WTK can resemble real worlds, where objects can have real-world properties and behaviours. **As** it is compatible with the C and C++ programming, custom functions can be conveniently added when required. This makes the application flexible and extendable.

3.4.2 Methodology for Modelling the Virtual Objects

The virtual kitchen consists of a collection of geometries and light sources, which can be manipulated by animation and physical simulation procedure. Geometries are three-dimensional (3D) objects that form the building blocks for any real-time simulation. In general, they can be divided into two groups: the static and the dynamic objects. The static features include floors, walls, ceilings, tables, and furniture, and fixtures, while the moving elements may include doors, windows, cupboards, stove button, tap nob, and other movable objects.

Geometric entities can be constructed by two methods. Firstly, built-in functions of WTK may be used to create custom graphical objects and add the texture, colour and lighting properties to the objects. This method is time-consuming with poor fidelity. Alternatively, some third-party tools, such as CAD (computer aided design) program (e.g. AutoCAD, MultiGen Creator, 3D Studio MAX) may be used to model the geometry objects that can be saved in one of the file formats supported by WTK. These objects can be loaded to the environment using **WTnode_load** function provided by the WTK function library. In this project, 3D Studio MAX was used to create the geometries. These are exported into theb*.3ds file format.

There are two important considerations to be addressed in the modelling geometries. The first is on the method of using the texture to increase the complexity and realism of the environment without increasing run-time overhead when transforming them. WTK does not support 3DStudioMAX's Face Mapping and **Box** Mapping of textures. To achieve a more realistic virtual world, the texture files were created from video images and modified with an image editor. Then the texture files were dynamical mapped onto the surfaces of selected geometries during run-time. Figure **3.12** shows samples of flame and wooden textures derived and modified from video images. However, such mapping textures tend to slow the performance and decrease the rendering speed. To minimise this problem, geometries farther away from the user's viewpoint are not mapped with textures during run-time.



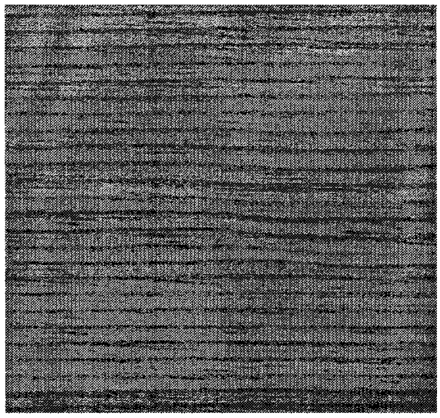


Figure 3.12 Flame Texture (left) and Wooden Texture (right)

The second problem is related to how WTK loads the *.3ds file. If all the geometries in the VE are built into one *.3ds file such that various graphical entities can have the desired spatial relationships, these multiple geometries will be treated by WTK as a single geometry. For example, a pot in the VE would not be moved individually but only together with the entire VE. Therefore, each dynamic geometry need to be save individually into separate files to keep their spatial relationships, even if they are initially built as a single VE. Figure **3.13** shows a pot geometry that has been selected and exported (using **Export Selected** command in the **File** menu) to a single pot.3ds file. During the simulation process, WTK function **WTmovnode_load** will import the file into the VE. Hence the pot will then be treated as a single geometry and can be operated individually.

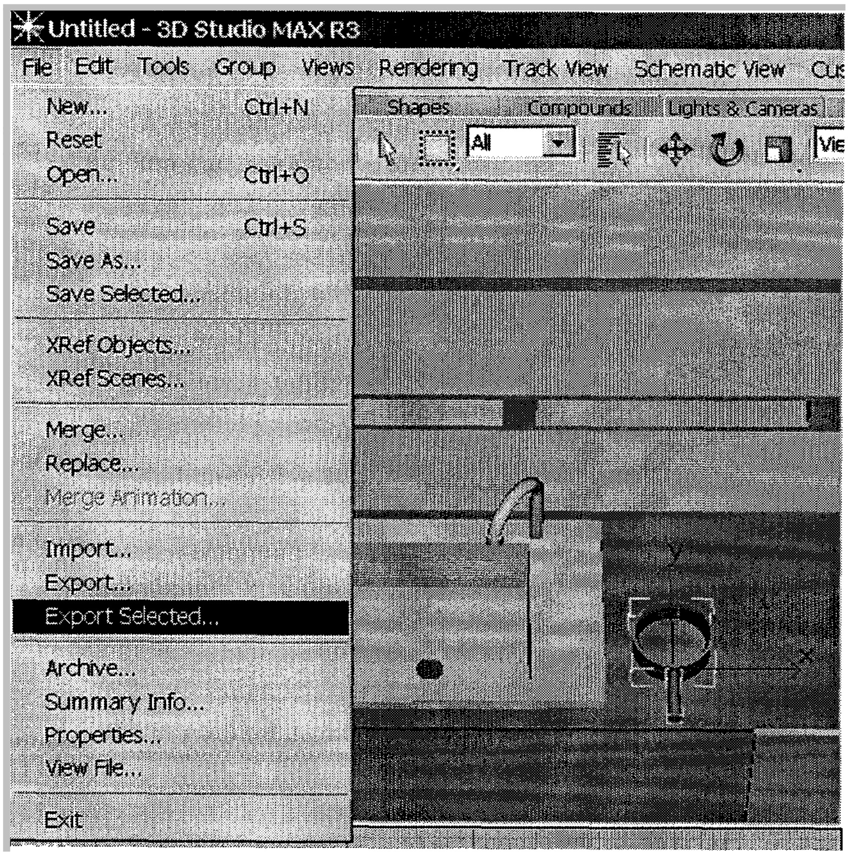


Figure 3.13 Export a single geometry

When modelling the virtual objects, geometry files were first created in 3DStudioMax without the surface details. Textures files are then captured from both the image editor and video images. During run-time, both files are loaded into the virtual world by embedded WTK function. Figure 3.14 shows the methodology for modelling the objects in the virtual rehabilitation environment discussed in this section. The challenge of simulating the virtual rehabilitation environment will be discussed in the next section.

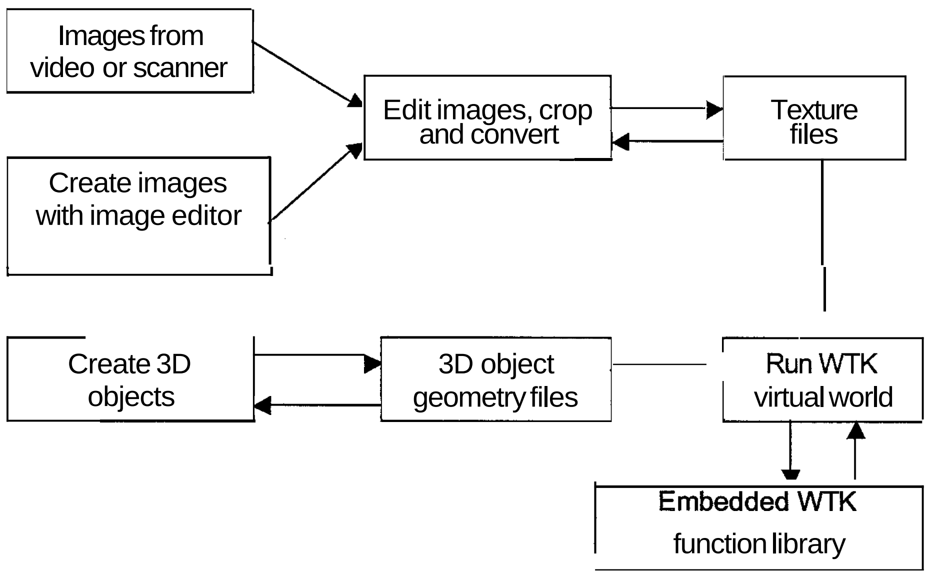


Figure 3.14 Methodology for Modelling the Virtual Objects

3.4.3 Realization of the Virtual Kitchen

Following the completion of modelling the kitchen environment and its objects, the designed classes were programmed and assembled into an entire system. Figure 3.15 shows the flowchart for realizing the environment. Key important processes in this flowchart will be discussed below.

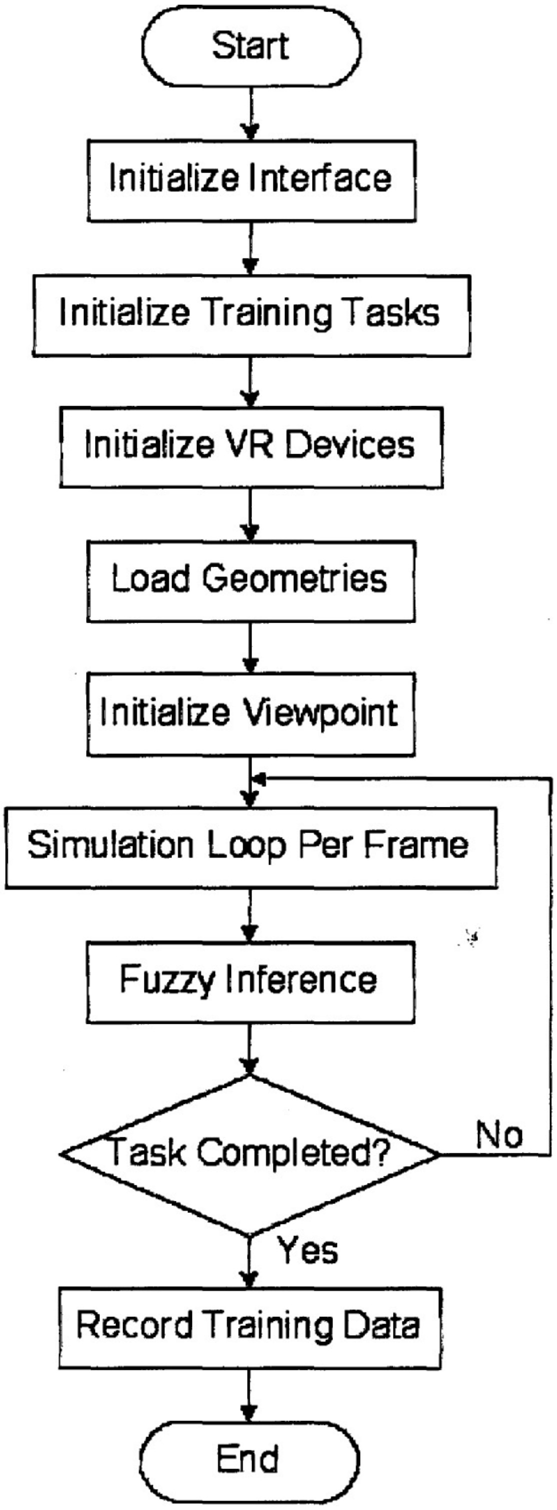


Figure 3.15 Flowchart of Realizing the Virtual Kitchen

3.4.3.1 Initialisation

A set of initialisation procedure prepares and sets up the system for the simulation loop. They include initialisation of training tasks, VR devices, geometries, and viewpoint.

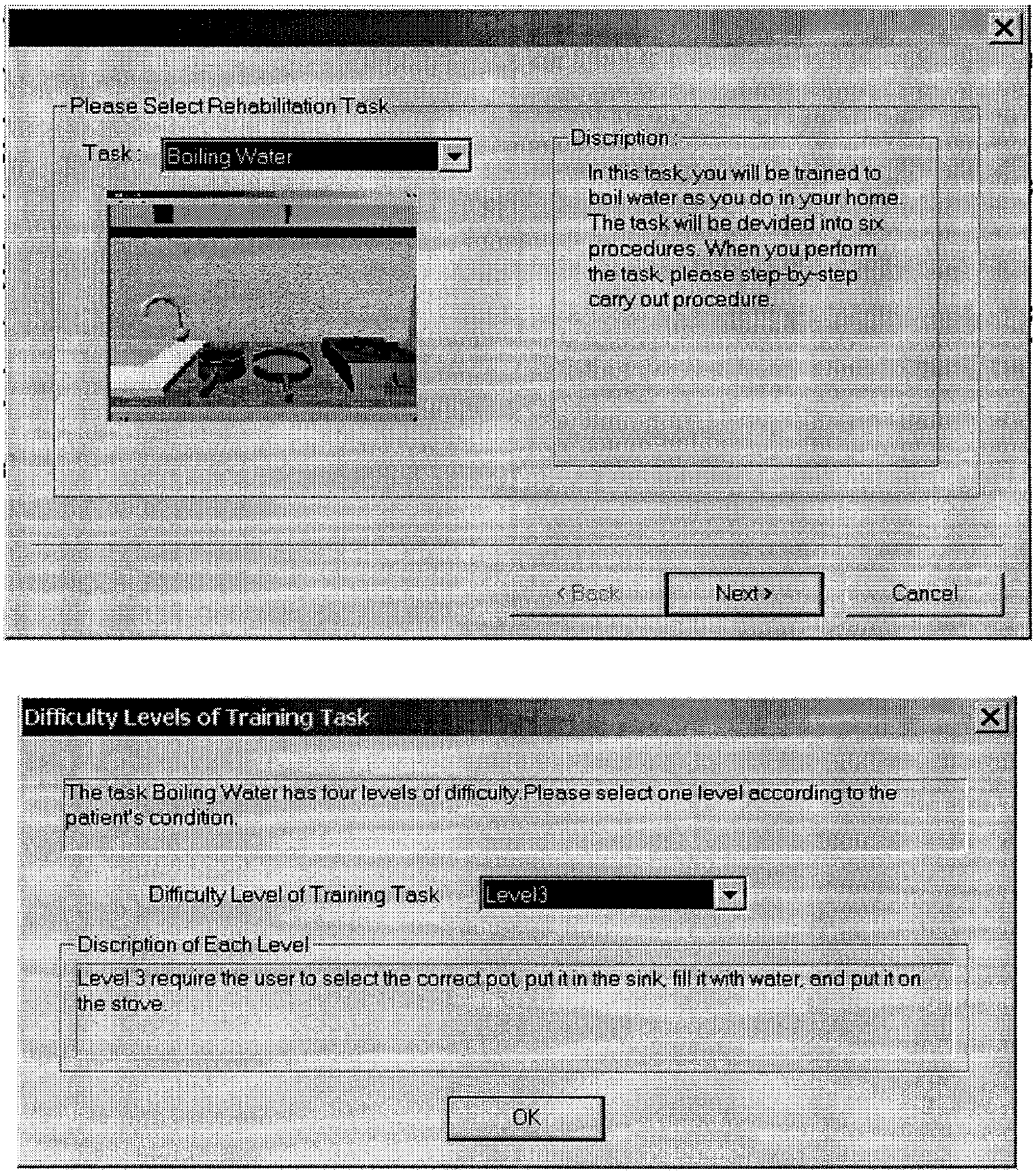


Figure 3.16 Initialisation of Training Task

The initialisation process captures the information related to the training tasks such as task name and task difficulty level. Figure 3.16 shows the interfaces for the task choices for the therapist.

As described in the hardware design, a cluster of VR devices were used to interact with the geometries in the virtual rehabilitation environment. The following special considerations were made when initialising VR devices.

(a) Method for Stereo Viewing

To display a stereoscopic effect, the software must render two images – one as seen from the left eye, and the other as seen from the right eye. There are essentially three different ways for these two images to be displayed:

- Render the full image of both eyes into one single window;
- Divide the display into two along a horizontal axis and render the left eye image in the top part of the display and the right eye image in the bottom part of the display;
- Interleave the left and right eye images as alternate scan lines on a display.

Selection of the appropriate stereo image display method will depend on the suitability of the graphics hardware. The graphics card used in this project has quad-buffers. It has sufficient memory and performance capabilities to render two full views (the left and right images). These views will then be swapped at 120Hz to generate a field sequential view of 60Hz. Figure 3.17 shows that the initialization codes of stereo viewing in the program.

```
//1st window
WTuniverse_new (WTDISPLAY–DEFAULT,
                    WTWINDOW_DEFAULT | WTWINDOW_NOBORDER);
WTwindow *win = WTuniverse_getwindows();
WTwindow_setposition (win, 0,0, 1023,767);
uview = WTuniverse_getviewpoints();
root = WTuniverse_getrootnodes();
// 2nd window for stereo
WTwindow *win2 = WTwindow_new (1024,0,2047,767,
                              WTWINDOW_DEFAULT|WTWINDOW_NOBORDER);
WTwindow_setrootnode (win2, root);
WTwindow_setviewpoint (win2, uview);
WTwindow_seteye (win2, WTEYE_RIGHT);
```

Figure 3.17 Initialization of Stereo Viewing

(b) Initialisation of the CyberTouch and FOB

Initialisation of the CyberTouch and Flock of Birds (FOB) creates the CyberTouch object through linking with the CyberTouch with FOB. It records the initial location and orientation of the CyberTouch in the virtual kitchen, and creates the appropriate relationship for the coordinates between the FOB and the InterTrax head tracker. Figure 3.18 shows the process of the initialisation. The corresponding codes are attached in Appendix A.

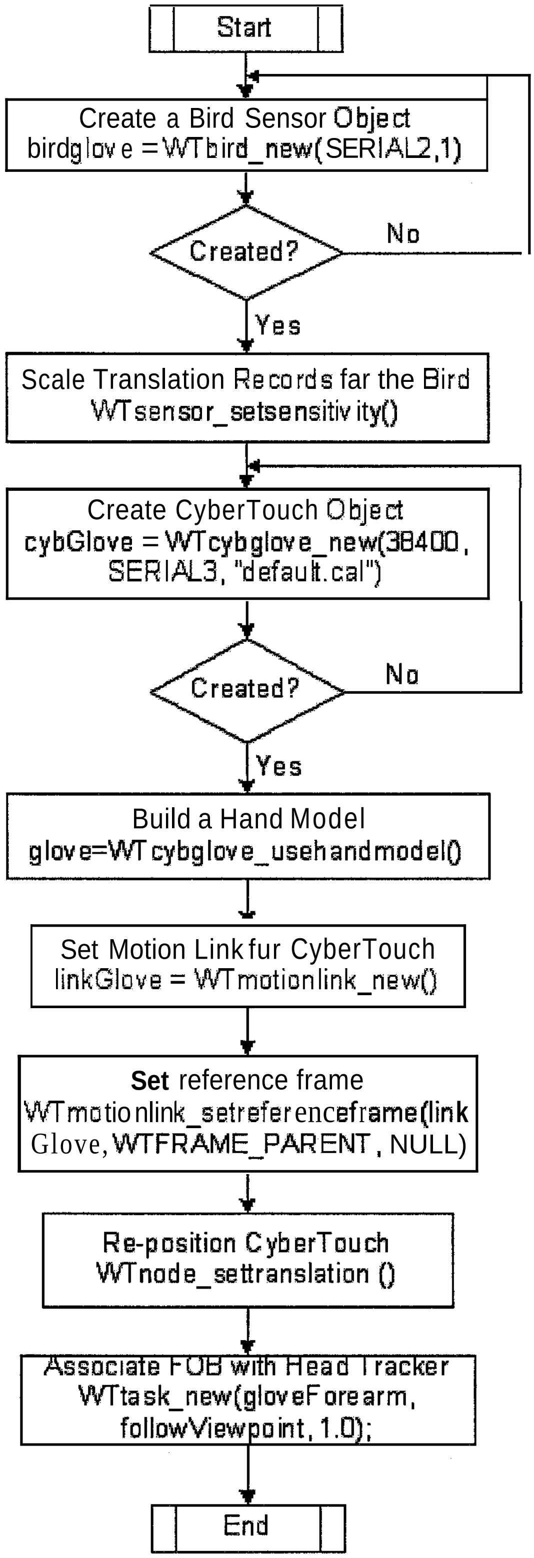


figure 3.18 Initialisation of CyberTouch and FOB

Initialisation of the CyberTouch and FOB begins with the creation of a Bird object on serial **port** *2* running at 9600 baud for the Flock of Birds, by calling **WTbird_new** function. **WTsensor_setsensitivity** defines the maximum magnitude of the translation records for the sensor along each axis.

The next step is to call WTcybglove_new to create a WTcybglove object for the CyberTouch on the serial port 3 running at 38400 baud. Function **WTcybglove_usehandmodel** builds a hand model and returns the forearm node which is the top most node in the hand model structure. The hand model structure is a hierarchy of movable nodes and attachment such as the palm and parts of each finger. For proper control of the hand motion, function **WTmotionlink_new** is called to build a motion link to associate the Bird sensor (source) with the hand (target). The forearm node is the only object in the hand model available for attachment of another sensor to alter the location and orientation of the hand. Input from the CyberTouch determines the location and orientation of all of the finger and wrist objects relative to the forearm. Any attempts to alter the position or orientation of the hand model objects other than the forearm have no effect. In the motion link, the source affects the position and orientation of the target relative to a particular reference frame. **As** the Flock of Birds returns absolute records, the reference frame of the motion link has to be set as **WTFRAME_PARENT,** i.e. to the WTK's world reference frame, in order to obtain the expected behaviour. When a new hand model is created, it is positioned at the universe origin and oriented along the Y-axis. The hand needs to be re-positioned at the front of the viewpoint when the virtual rehabilitation environment is first displayed.

3.4.3.2 Management of the Simulation Loop

The simulation loop is the heart of the virtual kitchen. It manages all the objects including the geometries, sensors, lights, viewpoints, serial ports, and other object types. Each frame of the simulation loop is entered through the function call of **WTuniverse_go1.** Figure **3.19** shows the order of events in a frame of the simulation loop.

In every frame of the simulation loop, three events will be processed: actions, sensors, and behaviours. The loop begins with reading the updated values of the sensors including the hand and head trackers, before it executes the function ProcedureControl::Action(). This function controls the procedure as the user performs each step of the training task. It also captures and temporarily saves procedure-specific information such as the procedure being executed, the target objects in the procedure, time taken by the user to complete the procedure, and the distance between the user's hand and the target objects. With these values, the loop will then update the locations and orientations of the graphical objects and the user's viewpoint. The final event is that the graphical objects perform the predefined behaviours based on the hand gestures when collision happens.

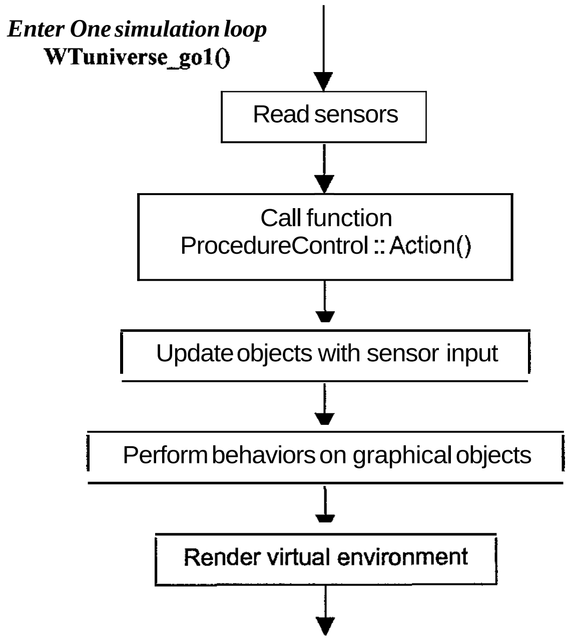


Figure 3.19 Simulation Loop Per Frame

In order to manage simulation loops effectively, several features were considered.

(a) Data Structure of the Objects in the Virtual Kitchen

All the objects in the virtual kitchen are hierarchically organized into a node graph, which helps to describe the relationships between the objects in the environment. Figure 3.20 illustrates an example of the structure of the node graph, consisting of the forearm of the CyberTouch, one of the fingers of the CyberTouch, and the pot in the virtual kitchen.

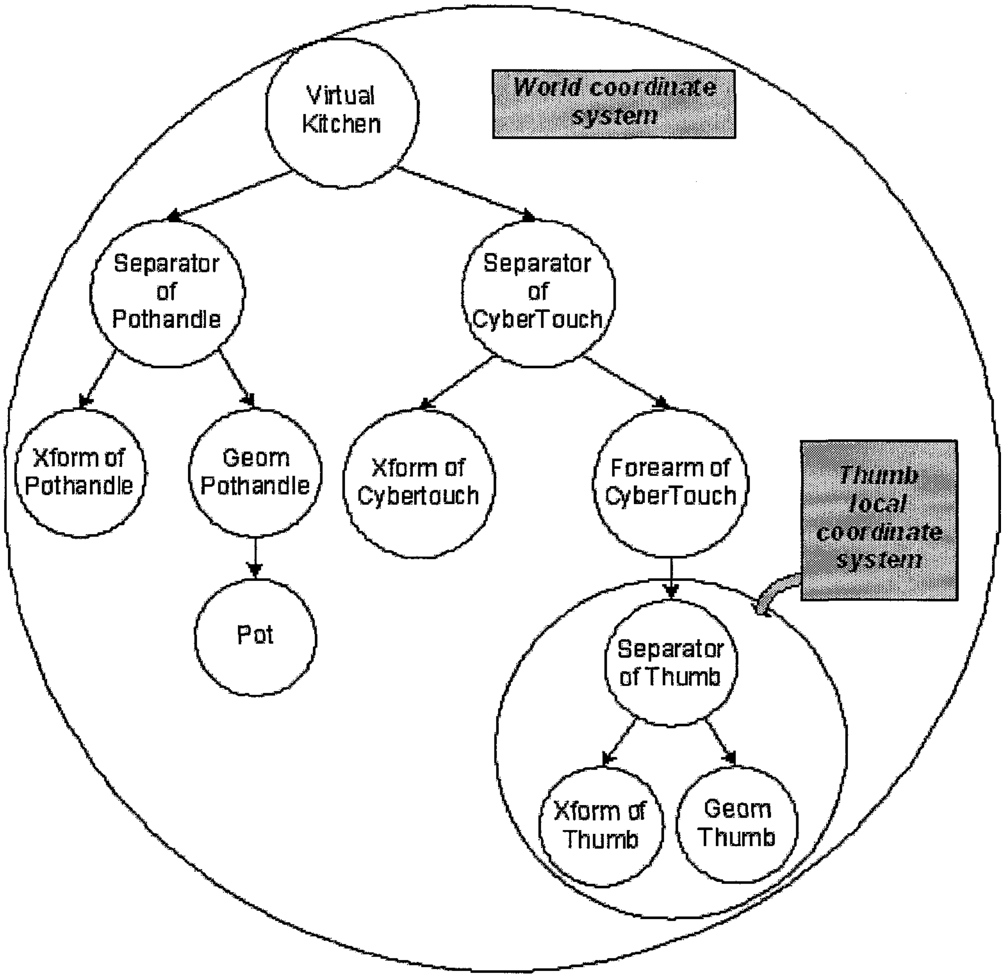


Figure 3.20 Data Structure of the Objects in the Virtual kitchen

In Figure 3.20, node Virtual Kitchen is the ***root*** node, i.e. the entry point into the graph and the point where the application starts to generate the environment. Xform node provides each geometry's position and orientation information. Geom node displays the geometry and material of the object. Separator node prevents state information (e.g. the transformation state) from propagating from one node to its ***sibling*** nodes that have the same ***parent*** node. CyberTouch and pot handle are sibling nodes as they share the same parent node Virtual Kitchen. Node Thumb of CyberTouch is a ***child*** node of its p a r t node Forearm of CyberTouch. The position and orientation of the child nodes have no effect on that of their parent node. On the contrary, the position and orientation of the parent node will have an accumulative effect on that of its child nodes. In Figure 3.20, thumb node can move and rotate in its own local coordinate system, as well as to move and rotate along with the forearm in the world reference frame.

(b) Behaviour Animation

Computer animation has long been used to explore the simulation of various physical systems. Linked structures, fabrics, human motion and natural phenomena can be animated with great accuracy in dynamic simulations. However such dynamic simulations have had to be animated on a stop-frame basis. Therefore creating these simulations in real time is a great challenge in a VR system. In this project, a moderate accuracy level of the object's simulated physical behaviour of the objects is sufficient. The trade-off in the complexity of the simulation helps to reduce the computational burden but does not compromise the rendering quality significantly. It still adds an enhanced sense of reality and gives the patient the more vivid impression and better awareness of the danger he/she faces.

To create a desired animation, a source is connected by a motion link to the target. The source can be a path or a sensor whose changes cause the advent of the animation. The target can be a movable geometry or the viewpoint. Simulation of a pot being grasped is an example of the realization process of such type of animation in this system. When the CyberTouch moves closer to the pot and collides with the pot handle, the gesture of the hand will be read and recognized. If the gesture is the "GRASP" as defined in the program, the pot will be attached to the CyberTouch. The pot will move together with the CyberTouch until the "RELEASE" gesture is recognized. The pot will be detached from the CyberTouch and falls according to the defined "WEIGHT". The states of the pot's transformation are updated and passed by the "data" property declared in the Pot class. The data is a type-defined structure as showed in Figure **3.21.**

```
typedef struct data{
        int go;              // flag, set when moving
        int direction;       // direction, 1 or -1
        int pos;             // position in sequence
        int steps;           // steps in sequence
        WTp3 dir;            // direction (and amount) to move each frame
        int falling;         // flag: falling or not
        float velocity       // speed of falling
        int flat;            // flag: flat or not after being put down
} Data;
```

Figure 3.21 'Data' Property

(c) Collision Detection

Interactive collision detection is a fundamental problem that must be addressed for a realistic VR application. **A** virtual environment filled with virtual objects should induce a feeling of presence to the user. This includes making the images of both the user and the surrounding objects feel solid. For example, an object should not pass through another in a ghost-like manner, and things should move as expected when pushed, pulled or grasped. Such actions require accurate collision detection, if they are to achieve any degree of realism.

However, there may be hundreds, even thousands of objects in the virtual world, so a naive algorithm could take a long time just to check for possible collisions as the user moves. This is not acceptable for virtual environments, where the issues of interactivity impose fundamental constraints on the system. **A** fast and interactive collision detection algorithm is a vital component of a complex virtual environment.

Those collision detection algorithms can be grouped into four approaches: space-time volume interference, swept volume interference, multiple interference detection, and trajectory parameterization. (Jimenez, et al, **1998).** Multiple interference detection approach has been the most widely used under a variety of sampling strategies, reducing the collision detection problem to static interference tests. These basically test the intersections between simple geometric entities, such as spheres, boxes aligned with the coordinate axes, or polygons and segments.

In the system, multiple interference detection approach is used to realize the collision detection. The intersection of two geometries is tested by the bounding boxes aligned with the each geometry local coordinate axes as showed in Figure **3.22.** The major function for testing is **WTnodepath_intersectbox(n1, n2)**.

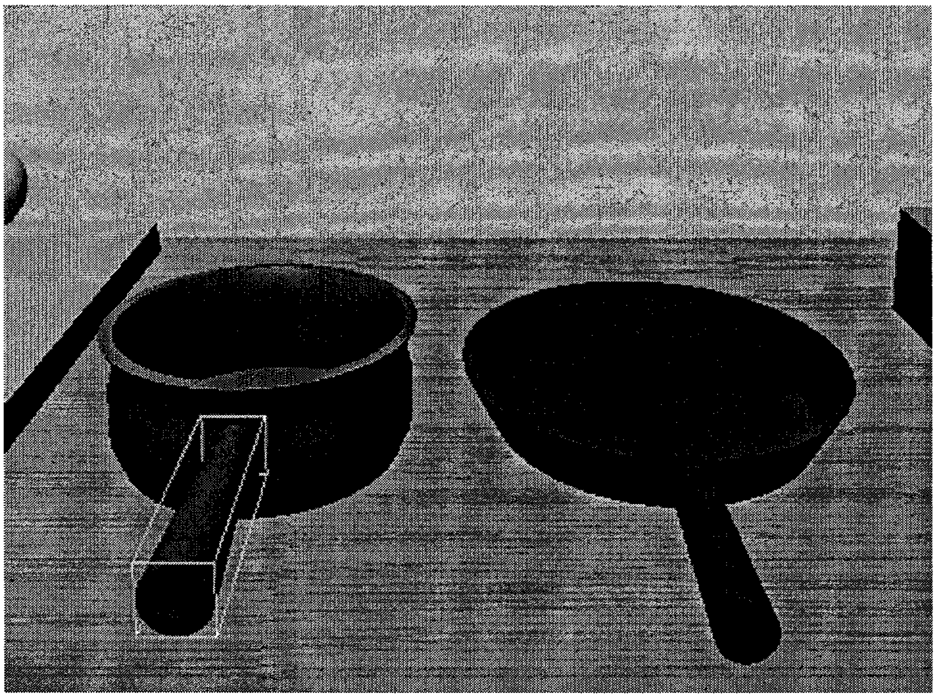


Figure 3.22 Using Bounding Box for Collision Detection

3.5 Summary

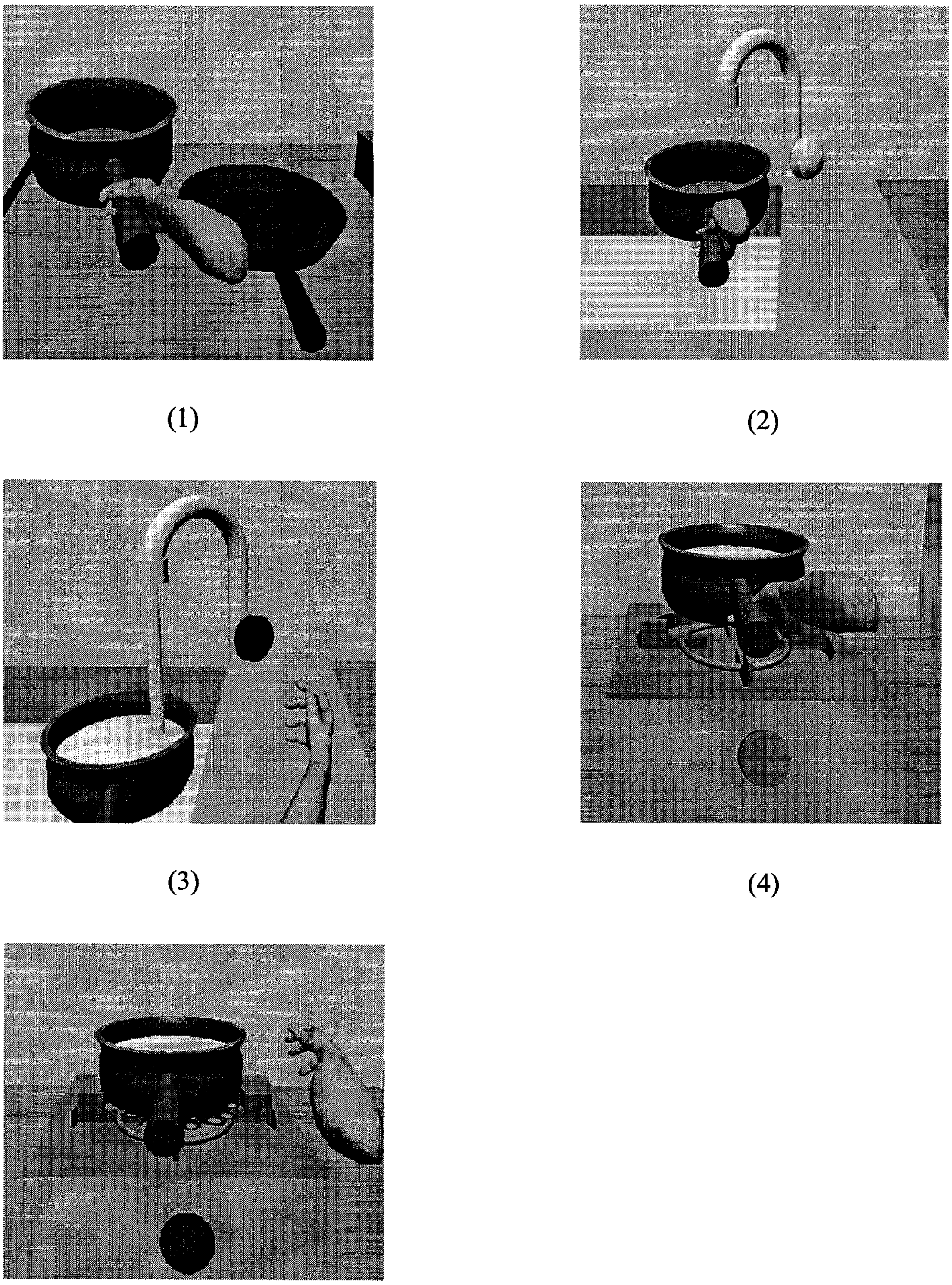
This chapter describes the development of the virtual rehabilitation environment. Elderly with memory deficits caused by dementia retains the preserved procedural learning abilities. **A** functional training environment that exploits preserved learning abilities of the elderly is more suitable for maintaining adequate performance of the activities of daily living (ADL) needed to maximize safe living and functional independence. The requirements and task definition of this system were analyzed based on this point. The system design including the hardware and software architectures was described, followed by the system implementation. During each stage, the important considerations were highlighted and discussed.

The creation of a virtual environment from separate objects is a daunting process. Data structure for organizing different objects in the whole environment, the predefined behaviours of the separate objects, and the logical and physical relationships between the separate objects have to be carefully modelled in the system design stage and refined in the implementation stage. However, the capacity to develop the virtual environment that matches the characteristics of the "real" world absolutely is not technically feasible at the current time.

Figure **3.23** shows some of the implementation results when the user performs the task of cooking eggs in the virtual kitchen. Table **3.2** lists the sequence and captions of the 5 pictures.

Table 3.2 Sequence and Captions of Figure 3.23

Figure No.	Description
(1)	Pick up a pot
(2)	Put the pot into sink
(3)	Fill the pot with water
(4)	Move the pot to the cooker
(5)	Turn on the cooker



(1) (2) (3) (4) (5)

Figure 3.23 Implementation of the Task of Cooking Eggs

CHAPTER 4 DEVELOPMENT OF THE INTELLIGENT ASSISTANT

4.1 Overview

As discussed in Chapter 1, therapists must keep a watchful eye on the patient and are often required to repeat instructions while trying to get the patient to perform an ADL. This increases the burden on a therapist who needs to assist several patients at the same time. In order to reduce the dependence of patients and the burdens on the therapists, the system should possess certain level of intelligence. With the intelligence, the system is able to adapt the training parameters such as stimulus exposure time and level of difficulty to the patient's performance. To endue the system with intelligence, artificial intelligence (AI) technologies would be used to develop an Intelligent Assistant to further enhance the VR system. The Intelligent Assistant should be able to duplicate some of the roles of a therapist.

In the clinical rehabilitation environment, the therapist who assists the patient to perform rehabilitation tasks must have the knowledge and clinical insight in personality, psychological state (i.e., depression, anxiety, psychosis, neurosis, paranoia, etc.), psychological mechanisms (i.e., reaction adjustment and coping behaviours) and human interaction. The therapist would design the rehabilitation process according to the patient's condition and adjust the difficulty level so that the patient can complete the entire task within a reasonable time. To prevent the patient from depression or anxiety, the therapist will give the patient gradually increasing or decreasing instructions. After the patient has succeeded a given task within a reasonable time, the therapist will arrange for him/her to progress to the next stage. The rehabilitation will end when the patient is sufficiently independent in completing the simple tasks of daily life.

The instructions given by the therapists are relatively vague. The vagueness may exist in several fields including "*what*" type of instructions should be given at "*what*" time according to "*what*" kind of evaluations. The three "*what*" can be attributed to two factors. Patients have different physical and psychological conditions. When confronted with the same task, different patients would behave differently. Furthermore, different therapists may give slightly different instructions at different time when assisting the same patient to perform a given task. The instructions and their time of issued are vague. This is partly due to the different experience and knowledge background of each individual therapist. When they assist the patient to perform a task, they give what they think are the proper instructions at that time according to their evaluations. To eliminate this inconsistency, fuzzy logic can be used to establish a system that can effectively handle the vagueness and complexities.

When monitoring a patient performing a rehabilitation task in the clinical environment, the therapist will consider two factors to decide if the patient needs instructions: the behaviours of the patient and the time taken by the patient to complete the task. For example, the patient is asked to find an appropriate receptacle from a set of choices. If the patient grasps the wrong one or the patient cannot decide what to do after a certain period of time, the therapist will remind the patient and show the patient the correct operation. If the patient cannot complete the procedure after repeating it for several times, the therapist will decrease the difficulties of the task by giving more guidance and instruction to the patient or decreasing the number of receptacles. Therefore, the task difficulty, the duration of time and the patient's behaviours are used by the therapists to decide on the proper instructions on helping the patient to complete a rehabilitation task. These parameters can be used as the input parameters for the Intelligent Assistant. The task difficulty can be represented by the task procedure (indexed by k), which can be decomposed into several subtasks according to the level of difficulty. The patient's behaviour can be represented by the time (t) the patient takes to perform this subtask, and the distance (d) between the patient's hand and the objects.

The output parameter will be cue messages that represent the therapist's instructions. In the clinical environment, the therapist usually instructs the patient verbally. However, in a virtual rehabilitation environment, non-verbal instructions can be used. The patient can be hinted to pick up certain objects by changing their brightness or colours. The cue message (*cu*) output from the Intelligent Assistant can include brightness, colour, text or verbal instruction.

Detailed development of the fuzzy-based Intelligent Assistant will be discussed in the next section.

4.2 Knowledge Acquisition

The purpose of knowledge acquisition is to capture the fuzzy rules and build a preliminary fuzzy model. Six therapists were involved in the process of knowledge acquisition.

When a rehabilitation task and the corresponding difficulty level are selected, the Intelligent Assistant should be capable of monitoring the behaviours and guiding the patient to complete the task. The fuzzy rule can be acquired from the therapists through interview and questionnaire. The variables and fuzzy rules are then extracted to build a model of the Intelligent Assistant.

The development of the Intelligent Assistant based solely on the results of the interview and questionnaire would not be sufficient. The memberships of the variables are difficult to decide through interviews and questionnaires. Hence the fuzzy sets cannot be completely obtained. Memberships of the variables are related to the patients' behaviours in the virtual environment (VE). Although the VE is a simulation of the real world, the patients' behaviours may be different from those in the real world. To determine the memberships of the variables, it is not adequate to depend only on the therapist's experience. Therefore, knowledge acquisition requires a combination of acquiring the therapist's experience and capturing the measurements of the patient's performance. The therapists provide the basic linguistic values for building a preliminary fuzzy model. This preliminary model will have to be refined based on the data collected from the patient's performance.

The knowledge acquisition efforts began with interviewing the therapists at the St. Luke's Hospital for the Elderly. The first stage was to identify a class of problems that the system would be expected to solve, including the data that the system would work with, and the criteria the solutions must meet. During the interview, the therapists provided the necessary knowledge of the problem domain through a discussion of their problem-solving methods. The therapists were asked to demonstrate the skills on a selected set of sample problems.

The domain was subsequently defined along with the environment in which the patients exercise the various rehabilitation tasks. These include the type of rehabilitation plans, the treatment strategies, the objects to be used, the procedures for the task, the goals of the task, and the general visual or verbal clues to be given to the patient.

The second stage was also based on interview. The knowledge acquisition was targeted at the task-level. Particular tasks were used to refine the knowledge. There are many strategies in the rehabilitation. Different strategies would use different plans and rules. The tasks are the implementation of the strategies. Different tasks have different goals and structures. Considering the multiplicity of these strategies and tasks, the knowledge was analysed and elicited on the task-level in the second stage.

The previous two stages were used to develop an initial fuzzy model. The main steps of fuzzy modelling can be found in Yager and Filev (1994a) and Driankov, et al (1996). These steps include the selection of the variables, the determination of the linguistic labels into which these variables are partitioned, the formation of the set of linguistic rules that represent the relationships between the system variables, the selection of the appropriate reasoning mechanism for the formalization of fuzzy model, and the evaluation of the model adequacy. The aim of the third stage aims to refine the fuzzy model.

In the third stage, patients and therapists entered into the scenario-based virtual environment together. Sensors measured patients' behaviours. The cues and instructions given by the therapists to the patients were recorded. These data were then used to modify the fuzzy rules and the membership functions. Figure 4.1 illustrates the above knowledge acquisition procedure.

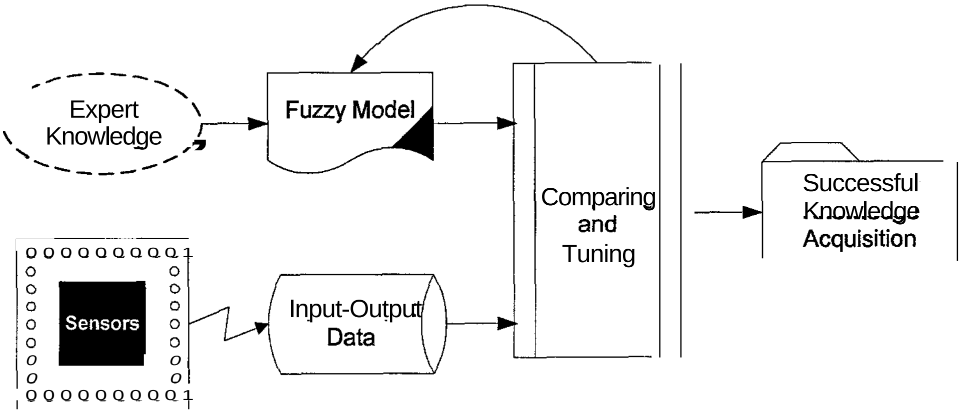


Figure 4.1 Knowledge Acquisition Procedure

In the next section, the boiling water task will be used as an example to demonstrate development of the Intelligent Assistant.

4.3 Implementation

4.3.1 Structure of the Intelligent Assistant

The structure of the Intelligent Assistant is shown in Figure **4.2.** The Intelligent Assistant consists of a fuzzifier, a rule database, an inference engine, and a defuzzifier.

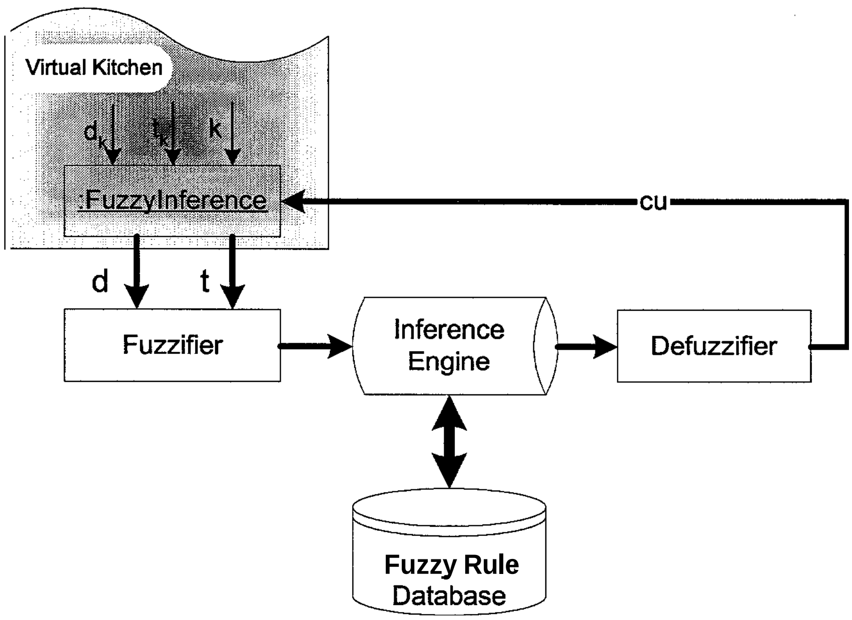


Figure 4.2 Structure of the Intelligent Assistant

The *FuzzyInference* class resides in the Dynamic Central Control package as described in Chapter **3.** It is the communication channel between the virtual rehabilitation environment and the Intelligent Assistant. It is responsible for the exchange of the data between these two parts. The input parameters into the *FuzzyInference* class include subtask (index by k), the distance between the hand and the virtual objects d_k, and the time the patient takes to perform this subtask t_k. Based on Equation 4.1, the *FuzzyInference* class converts the input parameters to time ***d*** and distance ***t*** and send them to the Intelligent Assistant. In Equation 4.1, D_k and T_k are the maximum values related to the different subtask ***k*.**

$$d = \begin{cases} \dfrac{d_k}{D_k} & \text{if } d_k < D_k \\ 1.0 & \text{if } d_k >= D_k \end{cases};$$

$$t = \begin{cases} \dfrac{t_k}{T_k} & \text{if } t_k < T_k \\ 1.0 & \text{if } t_k >= T_k \end{cases}; \qquad (4.1)$$

Where D, T_k ***are the maximum values corresponding to different subtask k.***

The fuzzifier will map crisp inputs time ***(t)*** and distance (*d*) to the fuzzy sets. The rules are IF-THEN statements that describe associations between the fuzzy parameters. Given the required input data, the inference engine matches the premises of the rules in the rule database with the input terms and performs implications. The defuzzifier translates the fuzzy decision into a crisp decision.

The Intelligent Assistant then sends the crisp decision back to the ***FuzzyInference*** class. The crisp decision is a cue ***(cu)*** message, such as increasing, decreasing, or maintaining the cue as determined by the fuzzy reasoning. The cue message is subsequently presented to the patient in the virtual rehabilitation environment. In this way, the Intelligent Assistant helps the therapist by giving consistent cues to the patient.

The four parts of the Intelligent Assistant will be discussed separately in the next sections. In each part, the related fuzzy theory will be introduced first, followed by how this particular part is implemented in the Intelligent Assistant.

4.3.2 Fuzzifier

4.3.2.1 Fuzzy Sets

Introduced by Zadeh (1965), the theory of fuzzy sets describes a subset ***A*** of the universe of discourse *U*, where the transition between full membership and non-membership is gradual rather that abrupt as is the case with classical or crisp set theory. As illustrated in Figure **4.3,** a fuzzy set consists of three components – a horizontal domain axis of monotonically increasing numbers that constitute the population of the fuzzy set; a vertical membership axis between zero and one, indicating the degree of membership in the fuzzy set; and the surface of the fuzzy set that connects an element in the domain with a degree of membership in the set.

The degree of membership is also known as the membership function (Equation 4.2) since it establishes a one-to-one correspondence between **an** element in the domain and a truth value indicating its degree of membership in the set.

$$\mu_A(x) \leftarrow f(x \in A) \qquad (4.2)$$

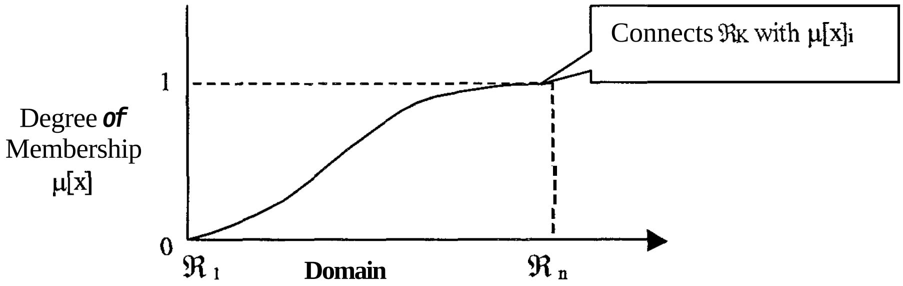


Figure 4.3 The General Structure of a Fuzzy Set

In practical applications of fuzzy set theory, a group of fuzzy sets is defined to represent a set of linguistic or fuzzy terms. These fuzzy terms are possible values that a linguistic variable may take in an expression. A linguistic variable x in a universe of discourse U is defined by

$$T(x) = \{T_x^1, T_x^2, ..., T_x^k\} \tag{4.3}$$

$$M(x) = \{M_x^1, M_x^2, ..., M_x^k\} \tag{4.4}$$

where $T(x)$ is the term set of x; that is, the set of names of linguistic values of x with each value T_x^i being a fuzzy number with a membership function $M_x^i(x)$ defined on U. The number of terms and hence the number of fuzzy sets defined varies according to the specific application. The degree of overlap of adjacent fuzzy sets will also vary depending on the terms and the application.

Fuzzy set operations are defined in terms of the membership functions. Let A and B be two fuzzy sets in U with membership function μ_A and μ_B respectively. The fuzzy set operations of union and intersection, and complement are defined for $x \in U$ by

Union: $$\mu_{A\cup B}(x) = \max[\mu_A(x), \mu_B(x)] \tag{4.5}$$

Intersection: $$\mu_{A\cap B}(x) = \min[\mu_A(x), \mu_B(x)] \tag{4.6}$$

Cartesian Product If $A_1, A_2, \ldots, A_n$ are fuzzy sets in $U_1, U_2, \ldots, U_n$ respectively, the Cartesian product of $A_1, A_2, \ldots, A_n$ is a fuzzy set in the product space $U_1 \times U_2 \times \ldots \times U_n$ with the membership function

$$\mu_{A_1\times\ldots\times A_n}(x_1, x_2, \ldots, x_n) = \min[\mu_{A_1}(x_1), \ldots, \mu_{A_n}(x_n)] \tag{4.7}$$

4.3.2.2 Fuzzy Sets in the Intelligent Assistant

As described in Section 4.1, the task difficulty (k), the time (t) the patient spends in the task, and the distance (d) between the hand and the virtual objects are three main input parameters. Based on the knowledge acquisition, the fuzzy variables are the distance (D), the time (T), and the cue message (CU). Every variable has several fuzzy sets. The linguistic values are:

$$D = \{Close, Near, Far\}$$

$$T = \{Short, Medium, Long\}$$

$$CU = \{Decrease, Decrease\ a\ Little, Maintain, Increase\ a\ Little, Increase\}$$

The next job is to determinate the membership functions of each variable in the Intelligent Assistant. The initial membership functions of the instructions CU are shown in Figure 4.4.

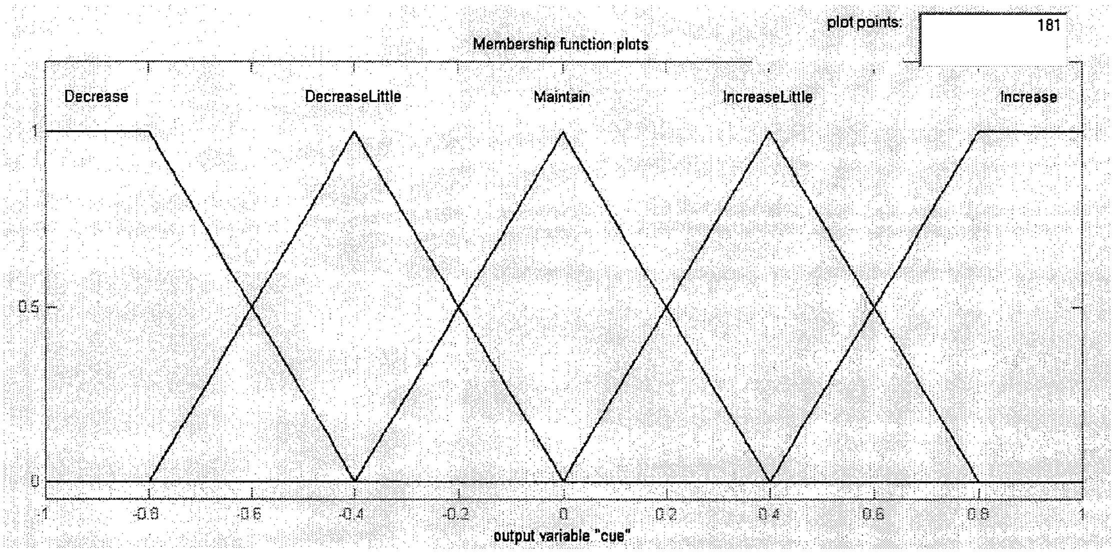


Figure 4.4 Membership Functions of Output Variable "Cue"

The membership functions of the variables ***D*** and Tare shown in Figures 4.5 and 4.6 respectively. In different procedures, the patient will encounter different target objects and spends different time in it. The actual range of the universe of discourse of time *D* and distance Tare different for each procedure. The expected maximum values can be identified using normal healthy subjects. In order not to change the membership functions with different procedures, the universe of discourse of time ***T*** and distance *D* are normalized. It is also anticipated that the virtual rehabilitation environment will be used later to fine-tune the membership functions. Hence the shapes of some of the membership functions could be changed based on the field results. The initial membership functions are developed through surveys on both patients and therapists.

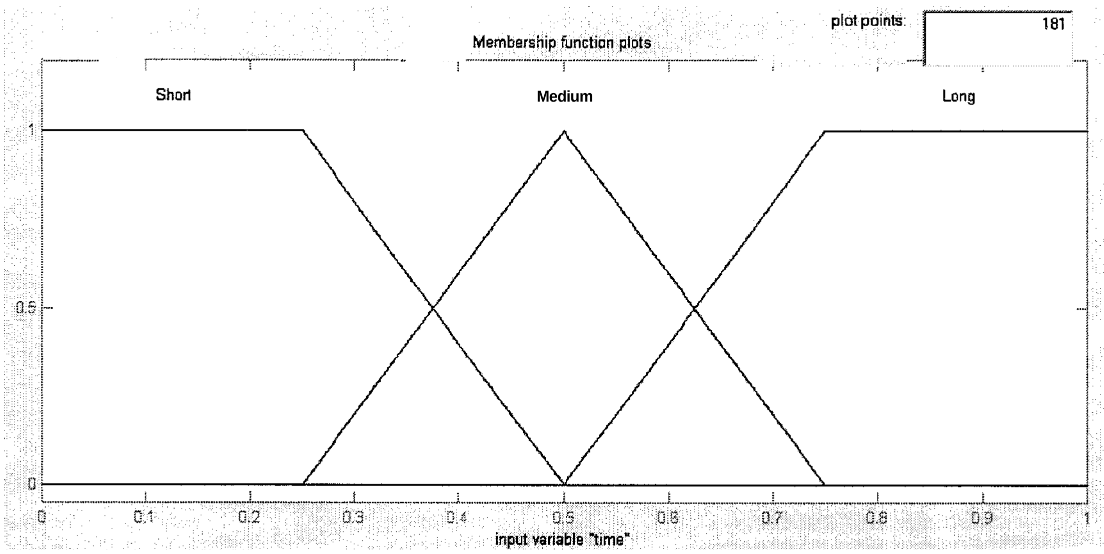


Figure 4.5 Membership Functions of Input Variable "Time"

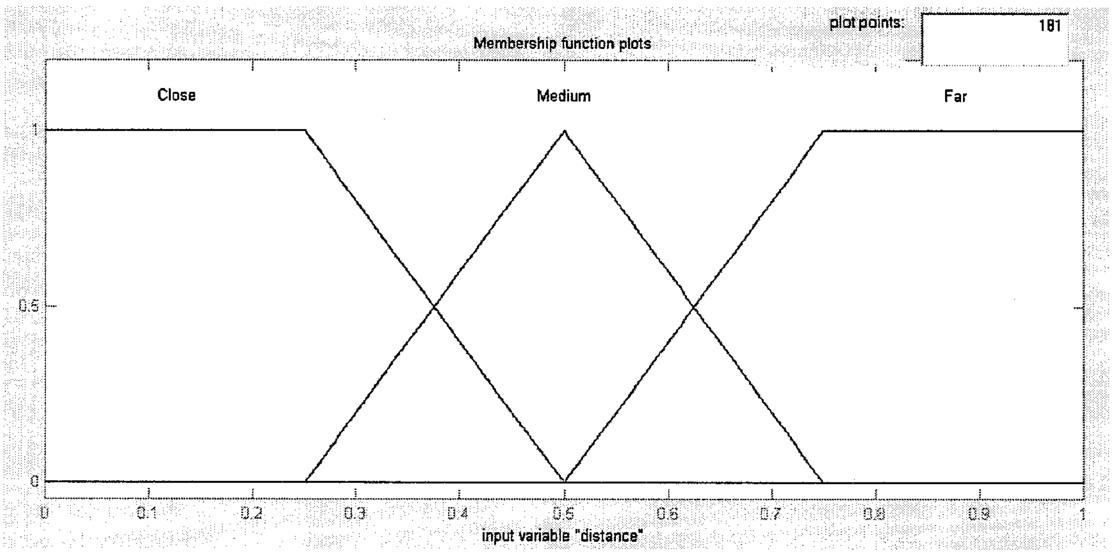


Figure 4.6 Membership Functions of Input Variable "Distance"

After the fuzzifier mags the crisp values to the fuzzy sets, the fuzzy inference engine will start the fuzzy reasoning based on the fuzzy relations.

4.3.3 Inference Engine

4.3.3.1 Fuzzy Relations and Fuzzy Inference

The multi-dimensional fuzzy sets are normally referred to as fuzzy relations. An n-ary fuzzy relation is a fuzzy set in $U_1 \times U_2 \times \ldots \times U_n$ and is expressed as

$$R_{U_1 \times \ldots \times U_n} = \{((x_1, \ldots, x_n), \mu_R(x_1, \ldots, x_n)) | (x_1, \ldots, x_n) \in U_1 \times \ldots \times U_n\} \qquad (4.8)$$

The composition is defined as follows (Zadeh, 1973): let ***A*** be a fuzzy set on ***X***, and ***R*** a fuzzy relation on $X \times Y$. $A \circ R$, the composition of ***A*** and ***R***, is a fuzzy set on ***Y*** and its membership function is expressed as

$$\mu_{A \circ R}(y) = \max_{x \in X} [\mu_A(x) \wedge \mu_R(x, y)] \qquad (4.9)$$

The next example explains the Fuzzy Compositional Rule of Inference. Consider the following rules with two inputs and single input:

Rule 1: IF x is A_1 and y is B_1 THEN z is C_1

Rule 2: IF x is A_2 and y is B_2 THEN z is C_2

where x and y are input variables and z is an output variable.

Assume that the preceding rules have been converted into a fuzzy relation R. For the inputs of fuzzy set A' on X and fuzzy set B' on Y, the output fuzzy set C' on Z can be obtained as

$$C' = (A' and B') \circ R = A' \circ (B' \circ R) = B' \circ (A' \circ R) \quad (4.10)$$

where there are two variables in the premises, and three terms in the fuzzy relation R (relation between x, y, and z). In this case the two-stage composition process for reasoning given in Equation 4.10 can be applied.

Fuzzy inference is the reasoning with fuzzy sets. Like set membership, truth is a matter of degree. Fuzzy inference is implemented through fuzzy rules. **A** fuzzy rule is a conditional of the form

IF X IS A, THEN Y **IS** B,

where A and B are fuzzy sets. The processing or evaluation of **a** rule is commonly referred to as "firing the rule". In using bivalent logic, which was the basis of early artificial intelligence *(AI)* systems, a rule would "fire" if X is A. In this case, the conclusion Y is B is completely true. If X is not A, the rule would not fire and the condition that Y is B would be determined to be completely false. In fuzzy logic, the closer the input matches the IF-part of the rule, the more the THEN-part fires. The degree of truth of the conclusion that Y is B is determined.

4.3.3.2 Fuzzy Inference in the Intelligent Assistant

The rule database contains fuzzy rules that relate distance ***d*** and time t (input parameters) to a series of different cues (*cu*) (output parameter) in order to encourage **and** guide the patient's behaviours, **A** typical rule in the rule database has the following linguistic representation

IF the distance is *far* AND the time is short THEN cues *maintain*

There are totally nine rules are extracted through the knowledge acquisition. These **fuzzy** rules are listed in Table **4.1.**

Table 4.1 Nine Fuzzy Rules

No.	Distance	Time	Cues
1	Far	Short	Maintain
2	Far	Medium	Increase a little
3	Far	Long	Increase
4	Near	Short	Decrease a little
5	Near	Medium	Maintain
6	Near	Long	Increase a little
7	Close	Short	Decrease
8	Close	Medium	Decrease a little
9	Close	Long	Maintain

In the complete knowledge base, the rules can be represented in the following form

$$IF\ D \text{ is } D_i \text{ and } T \text{ is } T_i \text{ THEN } CU \text{ is } CU_i$$

where i is the rule number; D is the vector containing d, the distance between the hand and the target virtual objects in the VE and D_i is one of the fuzzy sets as shown in Figure 4.5; T is the vector containing t, the time the patient spends in the task and T_i is one of the fuzzy sets as shown in Figure 4.6; CU is the vector containing cu, the cue information and CU_i is one of the fuzzy sets shown in Figure 4.4.

These rules are stored in a fuzzy rule database. Each rule in the rule database is associated with fuzzy relations R_i, treated as the intersection of the distance D, time T, and cues CU. The fuzzy relation R_i is defined on $D \times T \times CU$, which is the membership function domain. Its joint possibility distribution is

$$\begin{aligned}\mu_{R_i}(d,t,cu) &= \min[\mu_{D_i}(d), \mu_{T_i}(t), \mu_{CU_i}(cu)] \\ &= \mu_{D_i}(d) \wedge \mu_{T_i}(t) \wedge \mu_{CU_i}(cu)\end{aligned} \qquad (4.11)$$

where $\wedge$ denotes min operation.

Fuzzy relations R_i associated with the individual rules are aggregated using fuzzy union, resulting in the fuzzy relation R. The joint possibility distribution of the fuzzy relation R is

$$\mu_R(d,t,cu) = \bigvee_{i=1}^{9} \mu_{D_i}(d) \wedge \mu_{T_i}(t) \wedge \mu_{CU_i}(cu) \qquad (4.12)$$

Given the measured d and t, their corresponding fuzzy sets are $\mu'_{D_i}(d)$ and $\mu'_{T_i}(t)$. The fuzzy output $\mu_{CU}(cu)$ is

$$\begin{aligned}
\mu_{CU}(cu) &= \mathop{\vee}_{i=1}^{9}[\mu'_{D_i}(d) \wedge \mu'_{T_i}(t) \wedge \mu_R(d,t,cu)] \\
&= \mathop{\vee}_{i=1}^{9}[\mathop{\vee}_{i=1}^{9} \mu'_{D_i}(d) \wedge \mu'_{T_i}(t) \wedge \mu_{R_i}(d,t,cu)] \\
&= \mathop{\vee}_{i=1}^{9}[\mathop{\vee}_{i=1}^{9} \mu'_{D_i}(d) \wedge \mu'_{T_i}(t) \wedge \mu_{D_i}(d) \wedge \mu_{T_i}(t) \wedge \mu_{CU_i}(cu)] \qquad (4.13) \\
&= \mathop{\vee}_{i=1}^{9}\left(\vee_d \left[\mu_{D_i}(d) \wedge \mu'_{D_i}(d)\right]\right) \wedge \left(\vee_t \left[\mu_{T_i}(t) \wedge \mu'_{T_i}(t)\right]\right) \vee \mu_{CU_i}(cu) \\
&= \mathop{\vee}_{i=1}^{9} \tau_i \wedge \mu_{CU_i}(cu)
\end{aligned}$$

where τ_i denotes the degree of firing (DOF) of the i^{th} rule.

The measured d and t are crisp values. The fuzzy sets $\mu'_{D_i}(d)$ and $\mu'_{T_i}(t)$ are fuzzy singletons with membership grade zero everywhere on their universes of discourses, except at the point d and t, at which each membership grade is equal to one. The DOF of the i^{th} rule becomes

$$\tau_i = \mu_{D_i}(d) \wedge \mu_{T_i}(t) \qquad (4.14)$$

Above inference procedure is summarily illustrated in Figure **4.7.** Given the measured d and t, their corresponding fuzzy sets are $\mu'_{D_i}(d)$ and $\mu'_{T_i}(t)$. The fuzzy output $\mu_{CU}(cu)$ can be obtained with Equation 4.13. The $\mu_{CU}(cu)$ will be sent to the defuzzifier where it will be converted to crisp values, which will represent the corresponding output instructions.

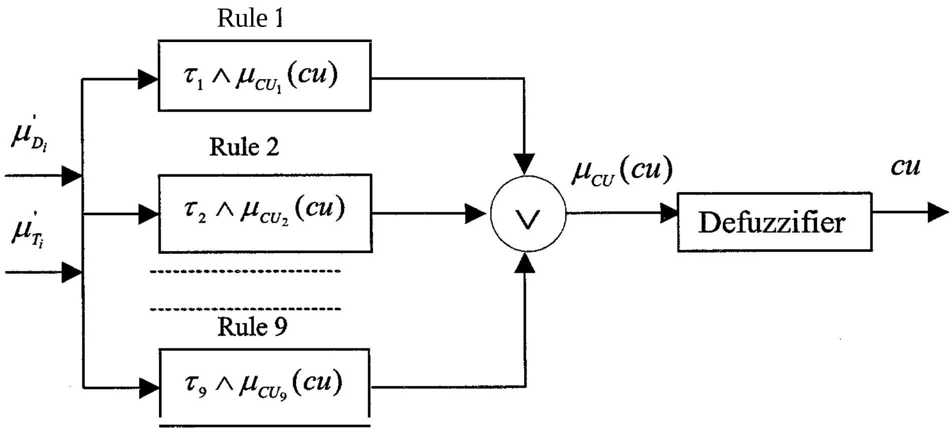


Figure 4.7 Inference Procedure of the Inference Engine

4.3.4 Defuzzifier

The defuzzifier translates the fuzzy decision into a crisp decision. The most common approach to defuzzification is the center of area method (Braae and Rutherford, 1978). Here, the crisp output is

$$\bar{y} = \frac{\sum_j \hat{M}_y^j(w_j)w_j}{\sum_j \hat{M}_y^j(w_j)} \tag{4.15}$$

where w_j be the support value at which the membership function, $\hat{M}_y^j$, reach the maximum value.

Figure **4.8** shows the method of combining two rules.

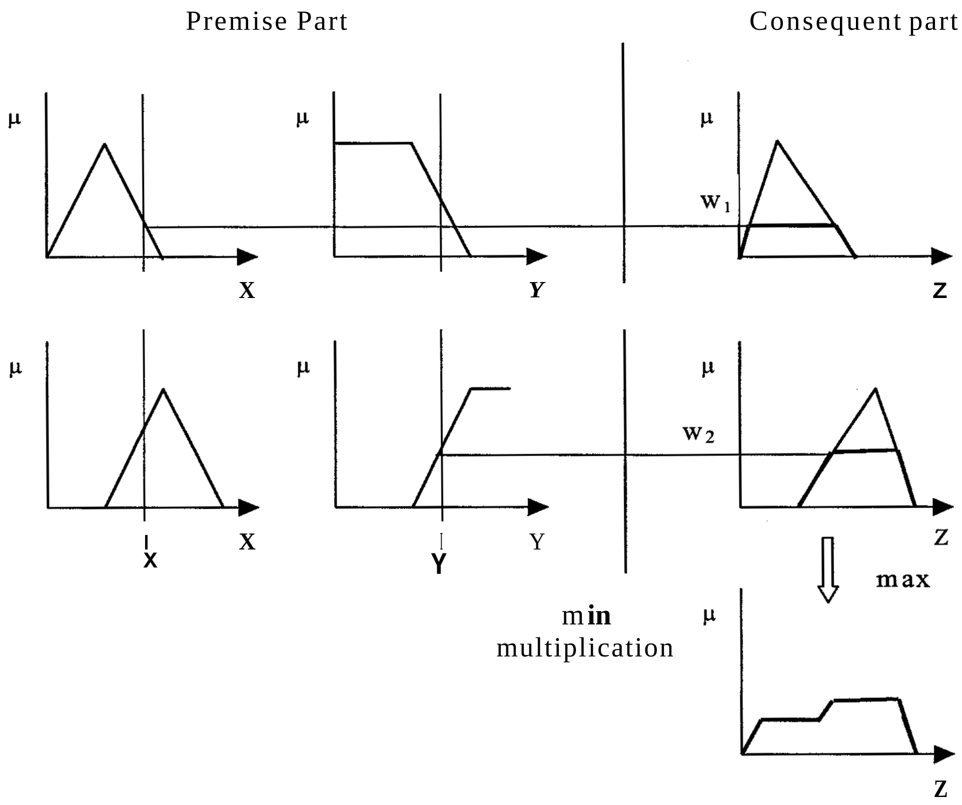


Figure 4.8 Combining Output of Multiple Rules

In the Intelligent Assistant, the defuzzification procedure is used to convert the fuzzy sets $\mu_{CU}(cu)$ into crisp values. The centroid method is used in this application. That is

$$cu = \frac{\sum_{j=1}^{q} \mu_{CU}(cu_j)cu_j}{\sum_{j=1}^{q} \mu_{CU}(cu_j)} \qquad (4.16)$$

wherej is the numbers of values in the domain of **fuzzy** set CU_i **.**

4.3.5 Software Implementation

An OOP approach is used to develop the Intelligent Assistant. The flowchart of the implementation is given in Figure 4.9. The fuzzy rules are formatively stored in a file in advance. When initialized, the rules are extracted from the rule file and encoded into a matrix of fuzzy terms where the dimensions of the matrix correspond to the number of antecedents in the rule. Then the input data are read and built into the structural data, the inference process executed, and the possibility distribution of cue information generated. The cue information is defuzzified into a crisp cue message and sent back to the virtual rehabilitation environment where the message will be translated and presented to the user based on the pre-defined forms. Figure 4.10 shows an example of the cue information.

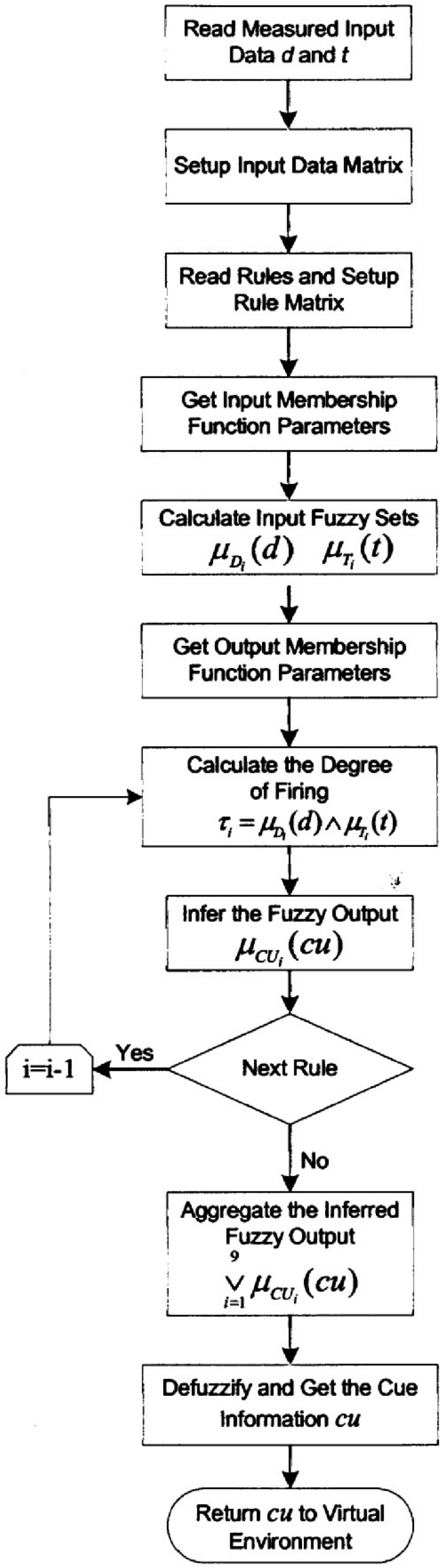


Figure 4.9 Functional Flowchart for the Inference Engine

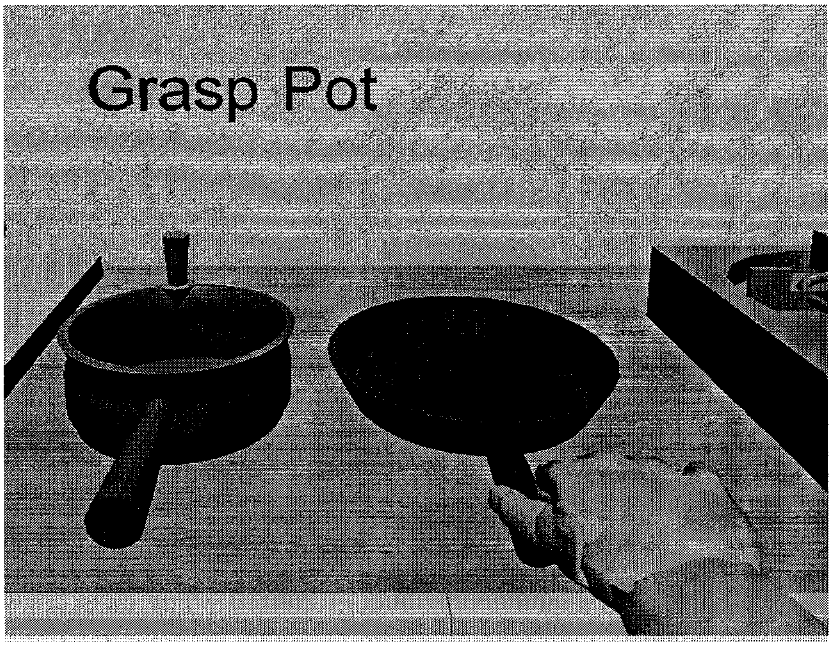


Figure 4.10 an Example of Cue Information

4.4 Summary

The Intelligent Assistant was developed to mimic a therapist. It should provide assistance to the patient who is performing the rehabilitation tasks in the virtual environment. As there exist vagueness in the instructions given by the therapists, fuzzy logic is used to model the approximate and inexact nature of the instructions.

This chapter describes the development of the fuzzy-based Intelligent Assistant. The three-stage knowledge acquisition was discussed. Through knowledge acquisition, the fuzzy rules were extracted from the experience and knowledge of the therapists who are knowledgeable on the rehabilitation of the elderly. The fuzzy rules were stored in the **fuzzy** rule database, which is part of the Intelligent Assistant.

The implementation of the Intelligent Assistant was also described. The structure of the Intelligent Assistant was presented. It consists of four main parts: the fuzzifier, the fuzzy rule database, the inference engine, and the defuzzifier. In each part, the related fuzzy theory was briefly introduced, followed by a discussion on the implementation of each **part.** Fuzzifier maps the crisp input parameters time (*d*) and distance (*t*) to fuzzy sets. Inference engine uses fuzzy sets and fuzzy rules to execute the fuzzy reasoning to get the output fuzzy cue message ***(cu).*** The defuzzifier converts the fuzzy cue message to crisp cue message and sends it back to the virtual rehabilitation environment. The flow chart of the software implementation of these four parts was also described.

A thorough representation of such knowledge is a challenging work because of the complexity of the tasks and the individual human characteristics. The virtual rehabilitation environment will be used on test subjects as an experimental tool to fine-tune the membership function and the rule database.

CHAPTER 5 INTELLIGENT VIRTUAL REHABILITATION SYSTEM

5.1 Introduction

The objective of this project is to develop a new rehabilitation methodology for the elderly with memory problems. The methodology, while based on the conventional rehabilitation concepts, explores the use of the virtual reality (VR) technology and fuzzy logic theory to develop an intelligent virtual rehabilitation approach. To establish this methodology, an intelligent virtual rehabilitation system (IVRS) has been developed. The IVRS consists of two main components: the virtual rehabilitation environment and an Intelligent Assistant. The developments of these two parts were discussed in Chapters 3 and 4. This chapter describes the refinement of the IVRS for the later case study on the old patients. The refinement acts as the initial evaluation. The results are used to evolve the development of the IVRS that will make the two parts work smoothly and naturally, to reduce the cognitive burden on the old patients caused by virtual tools and confusion caused by difference between the virtual and real world, and to verify whether the overall function of the IVRS matches the project's objective.

5.2 Intelligent Virtual Rehabilitation System (IVRS)

The IVRS consists of two main modules: the Virtual Kitchen and the Intelligent Assistant. The Virtual Kitchen provides the training environment for the patient to perform the assigned rehabilitation task, which is decomposed into subtasks based on the difficulty level. The performance of the patient is captured and represented by the parameters such as time and hand position. The data including the current subtask and the parameters are sent to the Intelligent Assistant, which composed of the fuzzifier, fuzzy inference engine, fuzzy rules database, and defuzzyifier. The parameters are processed through the fuzzyfier and fuzzy inference. Combined with the subtask, the outputs from fuzzy inference engine are translated by the defbzzifer into suitable cue messages that are transmitted back to the Virtual Kitchen. The Virtual Kitchen is then adaptively refreshed to provide the appropriate stimulus and instructions to the patient. Figure 5.1 illustrates the relationship and communication of these two components.

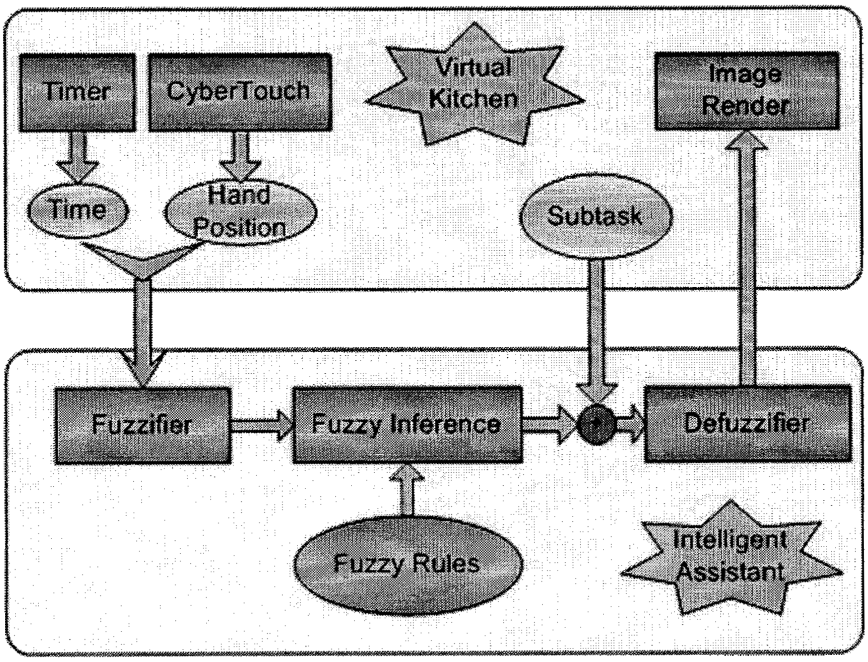


figure 5.1 Communication of Virtual Kitchen and Intelligent Assistant

5.3 Evaluation Methodology of the IVRS

The proposed system can be evaluated using several approaches, which include empirical evaluation, analytic modelling, and techniques such as heuristic evaluation and cognitive complexity analysis (Kieras and Polson, 1985). Currently, empirical evaluation is the most useful and reliable approach for evaluating virtual environments (Stuart, 1996). Techniques used in this evaluation can be videotape analysis, automatic data collection, think-aloud protocol, Likert-like questionnaires, open-ended interviews, and physiological monitoring. Empirical evaluation is one of the methods for assessing human-computer interfaces (HCI).

For the current project, the limitations and incompatibilities between a typical HCI and the IVRS may render the method inapplicable. For the IVRS, it needs to consider a broad variety of issues such as realism of the virtual models, the ease of use of the head-mounted display (HMD) and other VR tools like dataglove. The methodology for the refinement of the **IVRS** was based on part of the framework proposed by Gabbard et. al (1999), supplemented with techniques used in the empirical evaluations of HCIs. It employs a top-down, step-wise refinement space approach. The methodology is illustrated in Figure 5.2.

Heuristic evaluation is a type of analytical evaluation in which persons with related experience assess the system to determine what usability design guidelines it violates and supports. Then, based on these findings, especially the violations, the experienced persons would recommend changes to improve the design. Their recommendations are recorded by the questionnaire. The evaluation will be conducted in two phases. The first phase is the evaluation by the persons with VR experiences. The second phase is the evaluation by the persons working in the rehabilitation area.

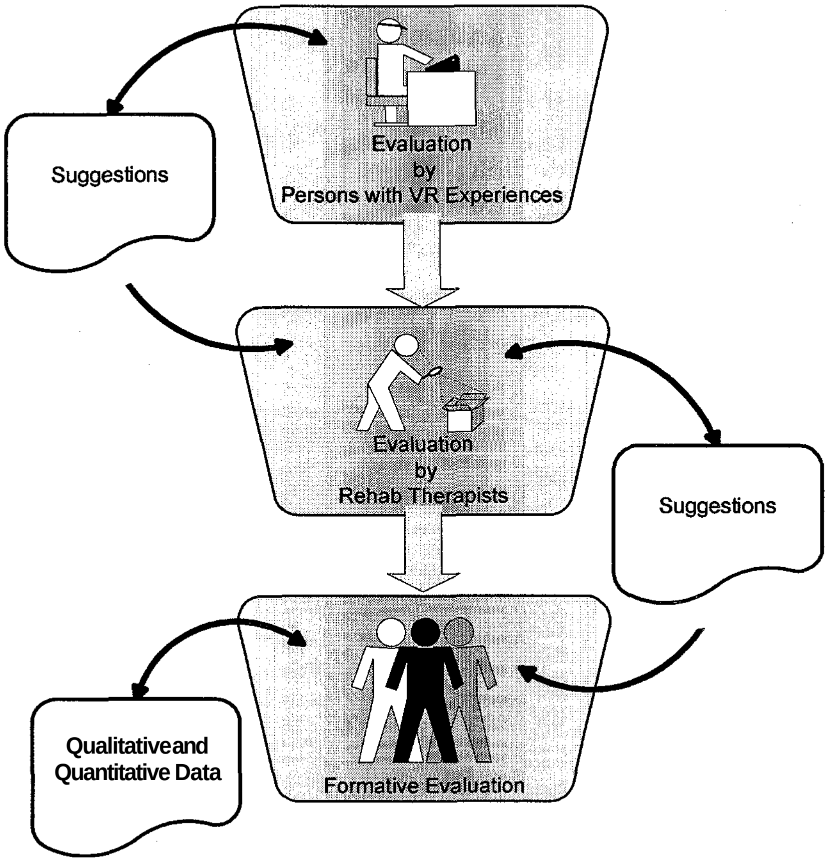


Figure 5.2 Evaluation Methodology of the IVRS

Formative evaluation in the third phase is a type of empirical, observational assessment by the old healthy persons. Both qualitative and quantitative data are collected from the test subjects. Quantitative data include the time it takes and the number of errors committed for a user to perform the task. Quantitative data are automatically collected by the system. Qualitative data documents the events that can affect (either positive or negative) the user's performance or satisfaction. Qualitative data are reflected by the post-experiment questionnaire.

Figure 5.3 illustrates the experimental set up. The experiment was performed on a PC with Pentium IV 1.5 MHz CPU, 512M RAM with the Oxygen GVX 210 graphics accelerator card installed. The major components of the system included CyberTouch for interacting with the VE (virtual environment), ProView™ XL 50 HMD (head-mounted display) for displaying the VE, Flock of Birds for tracking the user's hand position, and InterTrax™ for tracking the user's head position.

Figure 5.3 Experimental Set Up

The experimental task was that of cooking eggs. Table 5.1 shows the nine subtasks for cooking eggs.

Table 5.1 Nine Subtasks of Cooking Eggs

Task No.	Subtasks
1	Find the utensils
2	Choose the correct pot
3	Walk to the sink and put the pot into the sink
4	Fill the pot with suitable amount of water
5	Turn off the tap
6	Walk to the stove and put the pot on the stove
7	Put an egg into the pot
8	Turn on the stove
9	Turn off the stove

5.4 Test 1: Persons with VR Experience

5.4.1 Objective

The first stage test subjects consist of people with experiences in VR hardware and software. The test was designed to evaluate the early prototype of the **IVRS,** including the virtual models in the interface, the effectiveness of input **and** presentation mechanism, the coordination relationship of the components, and the validity of the Intelligent Assistant. The results were used to modify and improve the prototype.

The participants conducted their evaluation in the laboratory individually. The 20 participants, all graduate students from Nanyang Technological University, were first asked to fill in the pre-experiment questionnaire (Appendix B). His/her scores on the pre-experiment questionnaire were used to gauge his/her knowledge and experience of computers and virtual reality (VR) applications.

Table 5.2 Profiles of Test Subjects with VR Experience

Subjects	Age (Years)	Gender	CSL (Points)	SL of VR (points)		
				VR App	HMD	CT
1	26	M	9	6	6	6
2	30	M	9	9	9	0
3	23	M	9	9	9	9
4	29	F	9	9	6	6
5	30	M	9	9	9	2
6	27	F	9	6	6	4
7	29	F	9	9	4	0
8	31	M	9	6	2	0
Mean	28.1		9	7.9	6.4	3.4
SD	2.65		0	1.55	3.30	3.42

CSL -- Computer skill level is summarized from the question 3 and 4 in the pre-experiment questionnaire.

SL of VR – Skill level of virtual reality technology

VR App – Virtual reality application, from the question5 in the pre-experiment questionnaire

HMD – head-mounted display, from the question 6 in the pre-experiment questionnaire

CT – CyberTouch, the data glove used in the system, from the question 7 in the pre-experiment questionnaire

Eight participants were selected based on the questionnaire results. Profiles of the participants are summarized in Table 5.2. All the participants have certain level of experience in exploring or exploiting VR applications. The age of the group ranged from 23 to 31 years, with a mean and standard deviation of 28.1 years and 2.65 years respectively. The mean and standard deviation from scores of the pre-experiment questionnaire were 7.9 and 1.55 respectively. Participants 2, 7, and 8 have no previous experience with the CyberTouch. However, they have experiences with other kinds of dataglove such as 5DT Dataglove (Fifth Dimension Technology). They were considered as participants with relevant VR experiences.

To perform the test, the participant put on the CyberTouch and sat facing the screen. The objective of the proposed system, its interface to the virtual environment (VE), the components and their functions were explained. The Intelligent Assistant and its operation methodology were also introduced. The participant was instructed on the techniques of manipulating the objects in the VE using CyberTouch. The HMD was adjusted to ensure a good fit. The pre-test process took about 10 minutes to complete.

After being familiar with the system, the participant was required to don the HMD and followed the assigned nine subtasks listed in Table 5.1. No verbal instruction was given. The participant was guided by the cue information to work through the task. If the user normally wears corrective glasses to view distant objects, he/she would need to wear them when using the HMD (in accordance with the instruction given by the HMD manufacturer). The test was repeated twice. The task completion time in every test was recorded by the system.

In order to obtain further improvement suggestions from the participants, the participants were allowed to interact with the system without any restrictions after completing the two assigned tests. They can navigate through the environment, grasp and drop the objects, and intact with the buttons. During the test, the participants were asked to perform the test first without the HMD and to repeat the task with the HMD. They were asked to compare their experiences with and without the HMD. If the participant made a mistake such as failing to manipulate an object, the error would be documented.

After completion of the arranged task, each participant would rate the system by answering a questionnaire (Appendix C), which is similar to the Questionnaire for determining User Interface Satisfaction (QUIS) created by Chin, Diehl, and Norman (1988). The score on the questionnaire reflects the participant's opinions on the ease of use, satisfaction with the various tools and features, and specific problems encountered.

5.4.2 Results and Conclusions

Task completion time as performed by people with VR experience is shown in Table 5.3. This will be used as a basis for comparison with the results to be obtained from the healthy old subjects.

Table 5.3 Task Completion Time

Subjects	Test 1 (seconds)	Test 2 (seconds)
1	52	41
2	60	52
3	57	43
4	55	47
5	59	53
6	60	36
7	70	52
8	67	50
Mean	60.2	46.9
SD	6.07	6.03

The subjective test ratings from this group are sumrnarised in the following lists.

- The structure of the prototype is well organized. The user interface is arranged in a logical way. The mapping of the material makes the interface vivid.

- The VE on the HMD gives the users the sense of immersion and depth. Hence, the users would rather manipulate the objects in the VE with the HMD than without the HMD.

- The rendering speed of the images is appropriate. The ratings were justified by the recorded frame-rates (the rate at which the system can render to a window) of 45 fps (frames per second) for monitor display **and** of 35 fps for HMD, both of which is much higher than the acceptable frame-rate of around 20 fps.

- The feedback from the Flock of Birds on the CyberTouch is fast enough to enable the locomotion of the user's real hand to be synchronized with that of the virtual hand. CyberTouch can be easily handled in the VE.

- The cue information works in an intelligent and cooperated way.

Although the suggestion from each individual user tends to focus on different aspects of the system, the main points were found to be similar. They comprised of the following:

- Collision detection between the virtual hand and the virtual objects need to be improved. In certain conditions, the pot would begin to be attached to the hand and move with it even before the user had touched it. This was resolved by reorganizing the data structure of the pot and its handle, and by modifying the scheme of the collision detection algorithm. **As** described previously in Chapter **3** the algorithm for collision detection uses a bound box around the object. The precision of this frequently used technique may deteriorate if the box size is larger than the object. This was improved by having a smaller pot handle hidden within the original one, i.e. using a pot handle of the same shape but with smaller size in the same position of the pot handle.

- The verbal cue information needs to be improved. The verbal cue information will be generated by the system if the user is unable to proceed with the required procedure. The verbal cue information was found to have repeated too frequently, and this frustrated some users. The problem was resolved by adding an interval of two seconds between successive verbal cue information.

- The ability to roll during the navigation could be removed. The head tracker has three degrees of the movement: pitch, yaw, and roll. The ability of roll caused some users wearing the HMD to have a lost of balance perception during navigation. The ability to roll was subsequently removed.

The test results from the first stage have been used to improve the early prototype of the **IVRS.** The improved prototype was used in the next stage of the test, namely the evaluation by the therapists working in the rehabilitation area.

5.5 Test 2: Therapists

5.5.1 Objective

The test was designed for the therapists to evaluate the two sub-objectives put forward in Chapter 1. With their knowledge and experiences in the cognitive rehabilitation area, the therapists can provide valuable insights on:

a) The usability issues of VR technology for the rehabilitation of the dementia elderly.

As discussed in Section 1.1, functional rehabilitation methods are more beneficial for the AD patients. VR technology has advantages in the development of a functional environment than the conventional computerized rehabilitation. However, there are specific factors to be considered when applying VR technology for the rehabilitation of the dementia elderly. For example, to avoid distracting patients, traditional interaction tools in human-computer interface such as pressing of keys or clicking of mouse have been replaced with novel interaction techniques using data glove and position trackers. However, it is important that these new interaction techniques should not impose extra cognitive burdens on the patients. As the potential user (i.e. those with AD) will not be able to provide meaningful feedback on the system, the evaluation of the new interaction will have to be perfonned by the therapists. Therapists will provide, based on their professional insights, the potential issues of these interaction technologies on the dementia patients. They can evaluate the interface, input and presentation mechanism. They can suggest appropriate ways to reinforce the positive effects and to reduce the negative effects of the VR technology in cognitive rehabilitation.

b) The Intelligent Assistant

As detailed in Chapter 4, **fuzzy** logic was explored to realise the Intelligent Assistant. Fuzzy rules were extracted to represent the knowledge and experience of the therapists working in the rehabilitation area. This test will try to validate the **fuzzy** rules so as to improve the Intelligent Assistant.

The procedure in this test was the same as those described in the section 5.4.2.

The test subjects are five occupational therapists from the St. Luke's Hospital of the Elderly. Similar to the participants in the previous evaluation, they also completed the pre-experiment questionnaire. Their age ranged from 23 to 34 years, with **a** mean of 27.4 years and a standard deviation of 4.5 years. They had worked as occupation therapists fi-om 2 to 14 years, with **a** mean of 5.8 years and a standard deviation of 5.5 years. Although they use computer in their daily work, they have limited knowledge on VR technologies. The mean and standard deviation fiom scores of the pre-experiment questionnaire on VR technology experience were **2.8** and 1.79 for VR application respectively. The zero score in Table 5.4 means that the participant has never used the HMD or the CyberTouch before. This includes the other types of HMD or dataglove.

Table 5.4 Profile of Rehab Experts

Subjects	Age	Gender	Working Years	CSL (points)	SL of VR (points)		
					VR App	HMD	CT
1	36	M	14	9	6	4	4
2	30	M	7	9	2	0	0
3	23	F	2	9	2	0	0
4	25	F	2	9	2	0	0
5	25	F	3	9	2	0	0
Mean	27.4		5.8	9	2.8	0.8	0.8
SD	4.5		5.5	0	1.79	1.79	1.79

CSL -- Computer **skill** level is summarized from the question **3 and 4** in the pre-experiment questionnaire.

SL **of** VR – Skill level **of** virtual reality technology

VR App – Virtual reality application, from the question5 in the pre-experiment questionnaire

HMD – head-mounted display, from the question ***6*** in the pre-experiment questionnaire

CT – CyberTouch, the data glove used in the system, from the question **7** in the pre-experiment questionnaire

5.5.2 Results and Discussions

The results of post-experiment questionnaire (Appendix D) are shown in Table 5.5. The rating was on a seven-level scale with 1 meaning "very negative feeling", 4 meaning "neutral", and 7 meaning " very positive feeling". The last two rows are the values of mean and standard deviation for the corresponding questions. The analysis of the feedback includes several aspects such as overall reaction to the system, display, input, learning, and professional evaluations on the system.

Table 5.5 Test Results of Rehabilitation Experts

Subjects	Questions																	
	Overall Reaction to the IVRS				Display			Input		Learning				Professional Ratings				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	5	5	7	3	5	4	5	5	4	5	6	5	4	4	4	5	5	5
2	5	5	6	3	7	5	7	7	5	6	7	6	6	5	5	5	5	5
3	5	5	6	6	6	4	6	6	4	6	6	6	5	5	4	5	5	5
4	5	5	5	3	4	4	4	6	5	6	6	5	4	6	4	4	3	4
5	5	5	6	3	6	5	6	6	5	5	5	5	5	6	6	6	6	6
Mean	5	5	6	3.6	5.6	4.4	5.6	6	4.6	5.6	6	5.4	4.8	5.2	4.6	5	4.8	*5*
SD	0	0	0.71	1.34	1.14	0.55	1.14	0.71	0.55	0.55	0.71	0.55	0.84	0.84	0.89	0.71	1.10	0.71

5.5.2.1 Overall Reaction to IVRS

Questions 1 to 4 were used to test the overall reaction of the test subjects to the rehabilitation in the Virtual Kitchen. They are shown in Table *5.6.* The ratings of these 4 questions are shown in Table *5.5.*

Table 5.6 Questions 1 to 4

1. The virtual environment (VE) is:

1	**2**	3	4	5	6	7
Very artificial	Artificial	Somewhat artificial	Neutral	Somewhat realistic	Realistic	Very realistic

2. My affection after operating the VE is:

1	2	3	4	5	**6**	7
Very frustrating	Frustrating	Somewhat frustrating	Neutral	Somewhat satisfying	Satisfying	Very satisfying

3. Training in the functional VE is:

1	**2**	3	4	5	6	7
Very dull	Dull	Somewhat dull	Neutral	Somewhat stimulating	Stimulating	Very stimulating

4. The procedure for completing the tasks is:

1	**2**	3	4	5	***6***	7
Very rigid	Rigid	Somewhat rigid	Neutral	Somewhat flexible	Flexible	Very flexible

All 5 therapists considered the virtual kitchen to be "somewhat realistic" [Mean=5, SD=0], and their affection after operating the VE to be "somewhat satisfying" [Mean=5, SD=0], and training in the VE to be "stimulating" [Mean=6, SD=0.71]. They would like to see better realism in the Virtual Kitchen, although they considered the realism of the present interface to be feasible for rehabilitation. However, they thought the procedure for completing the task should be enriched [Mean=3.6, SD=1.34] and recommended adding more gaming factors into each procedure and increasing the difficulty level of the task. For example, besides the pot and the pan, the patients should be confronted with more utensils such as kettle, bowls, and cups when they begin to select one of them for cooking egg.

5.5.2.2 Feedback on Presentation Mechanism

Table 5.7 Questions 5 to 7

5. VE on HMD (head-mounted display) is better than on monitor:						
1 Strongly disagree	2 Disagree	3 Somewhat disagree	4 Neutral	5 Somewhat agree	6 Agree	7 Strongly agree
6. Easy to interact with VE is easier with HMD and head tracker:						
1 Strongly disagree	2 Disagree	3 Somewhat disagree	4 Neutral	5 Somewhat agree	6 Agree	7 Strongly agree
7. My reaction to using on HMD is:						
1 Very sick	2 Sick	3 Somewhat sick	4 Neutral	5 Somewhat comfortable	6 Comfortable	7 Very comfortable

To increase immersion of virtual rehabilitation environment and reduce the distraction of the outside world, the HMD is used in the IVRS. Questions 5 to 7 (Table5.7) reflected the subjective ratings on the effectiveness of presenting the virtual environment on the HMD compared with not using the HMD. The ratings on Question 5 show that most of participants preferred to don the HMD to interact with the virtual environment (VE) [Mean = 5.6, SD = 1.141. The mean and standard deviation of the ratings on Question 7 related to the side effect of the HMD is 5.6 and

1.14 respectively. This means that most of the participants feel comfortable with the HMD. The main negative suggestion on the HMD is the bulky weight of the HMD, not the sickness usually caused by the delays of rendering image.

However, ratings on Question 6 are lower [Mean = 4.4, SD = 0.551 mainly due to the bad performance of the position tracker. A small angle of the head rotation would cause a sudden transformation of the user's viewpoint in the virtual environment. The therapists think it would be very difficult for patients to control the position tracker. Instead of the position tracker, arrow keys on the keyboard were used to transform the user's viewpoint. The therapists thought the arrow key was the better tool than the current position tracker to transform the user's viewpoint in the virtual environment.

5.5.2.3 Feedback on Input Mechanism

Table 5.8 Questions 8 to 9

8. Using CyberTouch to handle objects in the VE is more natural than using mouse:						
1	2	3	4	5	**6**	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree
9. Learning to operate the CyberTouch is:						
1	2	3	4	5	6	7
Very difficulty	Difficulty	Somewhat difficulty	Neutral	Somewhat easy	Easy	very easy

To provide patients the natural contact means to perform the rehabilitation tasks, the CyberTouch was used in the IVRS. Question 8 concerns the comparison of mouse with the CyberTouch. The mean value of the ratings showed that the therapists preferred to use CyberTouch to handle the objects in the VE [Mean=6, SD=0.71]. Question 9 concerns the ease of learning to use the CyberTouch. They felt that learning to operate the CyberTouch was not quite difficult [Mean=4.6, SD=0.55].

5.5.2.4 Feedback on Learning

As the learning abilities of old people with dementia are reduced, the system should have the capability to facilitate learning and usage. Fuzzy rules were used to represent the knowledge and experience of the therapists. The fuzzy assistant was designed to simulate the therapists to provide assistance to the patient performing a rehabilitation task. The following questions aim to discover the subjective ratings on the fuzzy assistant.

Questions 10 to 13 in Table 5.9 reflect the evaluation of the therapists on the overall function of the fuzzy assistant. The therapists agreed that the Intelligent Assistant would simplify the rehabilitation tasks (Question 10 [Mean=5.6, SD=0.55]), help patients to perform the tasks (Question 11 [Mean=6, SD=0.71]), and make the learning of operation in the virtual environment easy (Question 12 [Mean=5.4, SD=0.55]). However, their ratings on the intelligence and cooperation of the system (Question 13) were not very high [Mean=4.8, SD=0.84]. This may be due to the explanations they listed for questions 19 and 20.

Table 5.9 Questions 10 to 13

10. Intelligent Assistant simplifies the task						
1 Strongly disagree	2 Disagree	3 Somewhat disagree	4 Neutral	5 Somewhat agree	6 Agree	7 Strongly agree
11. Straight-forward to perform the given tasks:						
1 Strongly disagree	2 Disagree	3 Somewhat disagree	4 Neutral	5 Somewhat agree	6 Agree	7 Strongly agree
12. Learning to use the system is						
1 very difficult	2 Difficult	3 Somewhat difficult	4 Neutral	5 Somewhat easy	6 Easy	7 very easy
13. The system is intelligent and cooperative with users:						
1 Strongly disagree	2 Disagree	3 Somewhat disagree	4 Neutral	5 Somewhat agree	6 Agree	7 Strongly agree

Table 5.10 Questions 19 to 20

19. Should the formats and contents of the Intelligent Assistant be improved? If, please explain briefly? ____
20. Is the timing of the cue information suitable? If not, how to adjust it? ____

Questions 19 and 20 in Table 5.10 reflect the evaluation of the therapists on the input and output of the fuzzy assistant. The inputs to Intelligent Assistant are the time and distance captured while the patient performed the task. The Intelligent Assistant outputs cue information to help the patient to perform the task easily. Their suggestions on the Intelligent Assistant in Questions 19 and 20 included:

- Enrich the contents of the cue information by decomposing the current cue information into more detailed procedures. For example, ask the patient what he/she wants to do next before directly telling him/her how to do.
- Enriching the means of displaying the cue infomation such as adding flashing light to highlight the objects to attract the patient's attention.
- Reducing the interval repetition of the verbal cues. Excessive repetition of the verbal cues could have negative side effect as it could lead to frustration.
- The timing of the cue information should be further adjusted for the normal old people.

5.5.2.5 Professional Evaluations

Questions 14 to 18 in Table 5.11 were designed to collect the profession opinions of the therapists regarding the potential impacts of this new rehabilitation approach on the patients and themselves.

Table 5.11 Questions 14 to 18

14. Training of activities daily living (ADL) in the virtual environment (VE) is useful for the rehabilitation of the patients with memory deficits:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Your suggestion:

____

15. Patients can perform this VR-based training easily:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Your suggestion on the training task:

____

16. VR-based training can reduce our workload:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Please explain briefly:

____

17. The performance trained in this VE can be transferred to the real world:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Write down your opinion:

____

18. VR-based training can better motivate the patients in rehabilitation task:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Please explain briefly:

____

After experiencing the IVRS, the therapists gave their ratings on each question based on their knowledge and experiences in the rehabilitation area. The feedbacks are summarized as follows:

- Training of activities daily living (ADL) in the virtual environment (VE) is useful for the rehabilitation of the patients with memory deficits [Mean=5.2, SD=0.84]. The degree of usefulness would depend on many factors such as the patients' learning abilities and their adaptability to the new challenge.

- In the therapist's view, the patients would be able to perform the VR-based training. However, they may need to put in more cognitive efforts when performing this VR-based training [Mean=4.6, SD=0.89].

- The therapist agreed that this VR-based training could reduce their workload [Mean=5, SD=0.71]. Though the VR technology may need them to spend time in instructing the patients, they thought that the virtual rehabilitation system could capture a lot of information precisely. That could help them save a lot of time and workload.

- The therapists somewhat agreed that the performance learned in this VE could be transferred to the real world [Mean=4.8, SD=1.10]. However, they also suggested that the transfer fi-om the VE to the real world needed to be further verified using patient subjects.

- The therapists considered VR-based training could better motivate the patients in rehabilitation task [Mean=5, SD=0.71].

5.6 Summary of the First Two Phases of Tests

The IVRS has been improved in the aspects of collision detection, speech information, and position tracking based on the suggestions of the subjects with VR experience. The detailed improvements have been described in Section 5.4.2.

In the second phase of the test, the experienced therapists focused on the suitability issues of the virtual environment for rehabilitation purposes. During the test, subjective ratings and comments were gathered on both the negative and positive aspects of the overall and component functions of the IVRS. They gave positive ratings on the training in the VE and the usage of the HMD and CyberTouch in the rehabilitation task. The ratings and comments on the training in VE indicate that the proposed methodology of developing a functional virtual environment combined with the traditional rehabilitation method is at the appropriate level. They gave negative ratings on the usage of the head position tracker due to its unpredictable behaviour. Instead of using the head position tracker, the therapists thought it would be more appropriate for patients to use the arrow keys in the keyboard to control the user's viewpoint.

The therapists also tested the overall function of the Intelligent Assistant. Although they were asked to evaluate the input and output of the Intelligent Assistant, the therapists did not comment too much on the timeliness of the cue message. They suggested using old healthy persons to do test and record their task completion time to adjust the Intelligent Assistant before testing the proposed system on the patients. The therapists focused their attention on the appropriateness of the cue messages in the rehabilitation. Their ratings indicate that the Intelligent Assistant could assist the patients to complete the rehabilitation task. The therapists also suggested richer contents and better presentation methods of the cue message. The improved cue messages are listed in Table 5.12. They will be used in the next phase of the test.

Table 5.12 Cue Message From Intelligent Assistant

Type No.	Input	output	Cues (Defuzzified Output)
1	Time is short and distance is far away; Time is medium and distance is medium; Time is long and distance is close;	Maintain	Word instruction Image indication
2	Time is short and distance is medium; Time is medium and distance is close;	Decrease a little	Image indication
3	Time is short and distance is close;	Decrease	Speech encouragement
4	Time is medium and distance is Far away; Time is long and distance is medium;	Increase a little	Image instruction Image indication
5	Time is long and distance is far away;	Increase	Image instruction Image indication Speech instruction

In the following test, the old healthy people will be the subjects. The quantitative and qualitative data will be recorded and used to improve and verify the system.

5.7 Test 3: Healthy Old Persons

5.7.1 Objective

As a result of memory deficit, elderly dementia patient with memory deficits may encounter more limiting factors when being trained in the virtual environment. One of the limiting factors could be the lack of computer knowledge and experience. This factor may cause the patient to be afraid of the new approach and may refuse to use it. Therefore, this factor should be investigated before this new approach could be tested on the patient. This experiment was designed to evaluate the usability of the virtual rehabilitation approach for normal elderly with limited computer knowledge and experience. By measuring the effectiveness, efficiency, and satisfaction of the normal elderly using the IVRS, it can determine if the normal elderly can satisfactorily tolerate the virtual rehabilitation approach.

Ten healthy persons above 55 years old without visual or short-term memory deficiencies were selected from the cleaners at Nanyang Technological University. Their age ranges from 55 to 65 years, with the mean and standard deviation of 59 years and 2.5 years respectively. None of them has any previous experience in computer or VR application.

Before the start of the tests, visual conditions of the participants including visual acuity (using Snellen Eye Chart) and colour vision (using colour plates from Ishihara, (1997)) were checked. This is to eliminate those with visual deficiency. In addition, examples of words having the same font size as those displayed in the IVRS were displayed on a screen to check for any negative effects of long-eyesightedness in the subjects. Their short-term memory was evaluated through their ability to recall information. The participant's knowledge and experience of computers and virtual reality were ascertained through pre-experiment questionnaire (Appendix B).

The participants were then asked to don the CyberTouch and sit facing the screen. Various components of the **IVRS** such as the **HMD,** CyberTouch, and Flock of Birds were introduced. The participants were instructed on the technique of manipulating the objects with the CyberTouch and Flock of Birds. The **HMD** was also adjusted to ensure a good fit.

After they had become familiar with the experiment settings, the participants was informed that 5 more tests would be carried out, and would be recorded in terms of both time and accuracy. The participant was also informed that both time and accuracy were equally important, and that he/she should carry out the task as they would in real life. During the tests, no verbal instruction was given. The participant had to complete the task with the cue guidance. The time taken by each participant to complete a procedure was automatically recorded into the database. However, if the participant was unable to complete the entire procedure, the result would be excluded.

After each test, the participants were asked to recall some events they experienced during the test. The contents are listed in the Appendix F. The answers were recorded. The participants were not informed of the memory test prior to the beginning of the test. The post-experiment questionnaire (Appendix E) was administered after completion of the task.

5.7.2 Results

Task completion time, number of errors, and number of correct memory recall answers were recorded and analysed. All the participants gave the correct answers on the memory recall questions. The summarized results of total error numbers and the task completion time are shown in Tables 5.13 and 5.14 respectively, with their mean and standard deviation values given in the last two rows. Table 5.15 shows the results of post-experiment questionnaire. In Table **5.13,** examples of the operational errors included:

- Participant was unable to hold an object to the correct location after picking it up.
- Participant could not pick an object up however hard he/she tried.
- Participant could not position the objects correctly such as putting the pot outside the frame of the stove.

Table 5.13 Number of Errors

Subjects	Number of Errors in Every Test				
	Test 1	Test 2	Test 3	Test 4	Test 5
1	6	6	4	2	3
2	8	7	5	4	4
3	5	5	3	2	2
4	4	5	4	3	2
5	6	6	5	3	3
6	6	5	3	3	2
7	7	6	4	3	3
8	5	5	4	2	2
9	6	6	3	2	3
10	7	6	5	4	3
Mean	6	5.7	4	2.8	2.7
SD	1.15	0.67	0.82	0.79	0.67

Table 5.14 Task Completion Time

Subjects	Task Completion Time for Every Test (seconds)				
	Test 1	Test 2	Test 3	Test 4	Test 5
1	179	200	159	122	100
2	230	198	143	138	101
3	127	151	110	92	97
4	111.46	118	108	101	100
5	186	190	191	145	140
6	198	195	163	120	117
7	251	200	189	185	130
8	134	135	110	91	95
9	156	174	133	118	111
10	199	188	157	111	114
Mean	177.4	175.0	146.6	123.2	110.6
SD	45.10	29.72	30.99	27.56	15.22

Table 5.15 Subjective Ratings of Post Experiment Questionnaire

Subject	Question									
	1	2	3	4	5	6	7	8	9	10
1	5	5	5	5	4	4	6	5	4	5
2	5	6	6	7	5	6	7	7	5	6
3	5	6	6	6	6	5	6	6	4	6
4	5	5	5	4	5	4	6	6	5	6
5	5	5	6	6	6	5	6	6	5	5
6	5	5	6	5	5	6	7	5	4	5
7	5	6	6	7	7	5	7	7	5	6
8	5	6	6	6	6	5	6	6	4	6
9	5	6	5	4	4	5	6	6	5	6
10	5	5	6	6	6	6	6	6	5	5
Mean	5.0	5.5	5.7	5.6	5.4	5.1	6.3	6.0	4.6	5.6
SD	0	0.53	0.48	1.07	0.97	0.74	0.48	0.67	0.52	0.52

5.7.3 Discussions

(a) Task Completion Time

Table 5.14 shows that all the old subjects could complete the five tests. The longest task completion time is **251** seconds taken by subject 7 in the first test. The shortest time is 91 seconds taken by subject 8 in the fourth test. The mean value shows a decreased trend of the completion time a test subject took to complete the task with each additional test run. It decreases from 177 seconds in the first test to 110 seconds in the fifth test. Figure 5.4 graphically illustrates this trend.

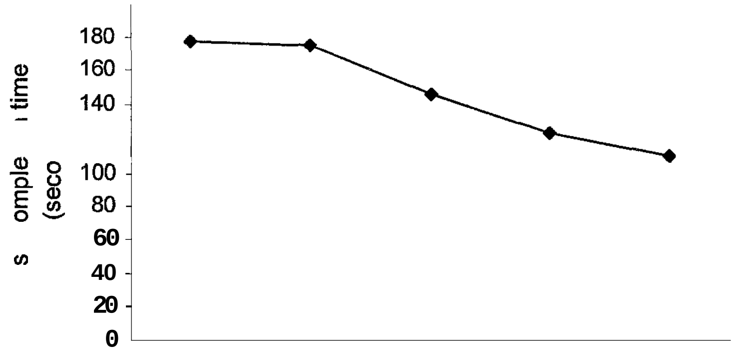


Figure 5.4 Mean Values of Task Completion Time of Old Subjects

Table 5.16 shows mean values and the t-analysis results of the task completion time for the first and the final tests. Although the mean completion time for the first two tests did not show obvious improvements, the t analysis result indicates a significant improvement in the task completion time during the entire training process [t = 4.52, p<0.005]. The facts that all the subjects could finish the task within **3** minutes with significant improvement in subsequent tests suggested that the method developed for building the virtual rehabilitation environment is at an appropriate level for the normal old persons.

Table 5.16 T-analysis Value of Task Completion Time

First Session		Final Session		t-analysis (seconds)	Sig. Level
Mean (seconds)	SD (seconds)	Mean (seconds)	SD (seconds)		
177.4	45.10	110.6	15.22	4.52	$p < 0.005$

Table 5.17 Task Completion Time of Younger and Older Subjects

Younger subjects		Older subjects	
Mean (seconds)	SD (seconds)	Mean (seconds)	SD (seconds)
46.9	6.03	175.0	29.72

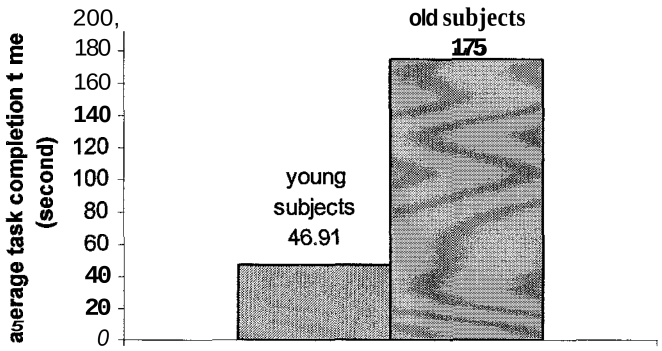


Figure 5.5 Comparison of Task Completion Time of Younger and Older Subjects

However, when compared with the younger subjects, the older subjects spent much longer time in the task. Table 5.17 shows the mean values of task completion time for the younger (Table 5.2) and older subjects were 46.9 and 175 seconds respectively. Figure 5.5 illustrated the time difference graphically. The difference in knowledge and experience of computer and VE ofthe two subject groups may contribute strongly to the gap of task completion time. The younger subjects, having knowledge and experience of computer and VE, may be more "at home" with VE set-ups and behaviour faster in the cyberspace. By contrast, the old subjects, having little knowledge and experience of computer and VE, may need more time to move and control themselves in the VE. The lower mobility and slower reflexes of the older subjects can also intensify such difference.

(b) Number of Errors

Table **5.13** shows the number of errors of the old subjects made during the five tests. The mean values decrease fiom ***6*** to 2.7 occurrences. This is illustrated graphically in Figure 5.6, where the trend of decreasing errors with each additional test taken can be seen clearly.

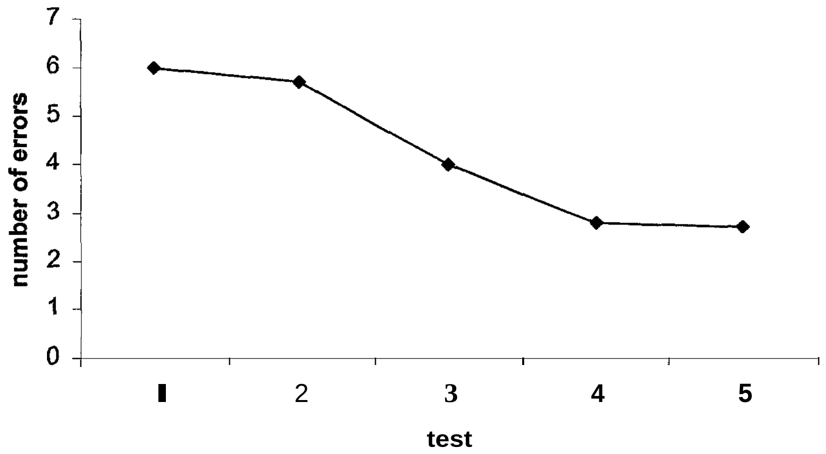


figure 5.6 Mean Values of Number of Errors

Table 5.18 shows the mean values of the number of errors and t analysis results of the first and final test. The t analysis shows significant improvement [$t = 4.11$, $p<0.005$] of the subjects during the whole training process. This result indicates the potential effectiveness of training in the IVRS.

Table 5.18 T-analysis Value of Errors

First Session		Final Session		t-analysis	**Sig.** Level
Mean	SD	Mean	SD		
6	1.15	2.7	0.67	**4.1**1	P < 0.005

(c) User satisfaction

Subjective evaluation data from the subjects was also positive (Table 5.15). In the follow-up questionnaires, all the subjects expressed strong interest in the virtual system. Although they did not have any previous experience with computer, they commented that the virtual environment gave them a real and straightforward feeling when interacting with the computer. They also agreed that it was more natural and easier to use the CyberTouch than keyboard or mouse. The also agreed that the cue message could help them to complete the task.

During the pre-training on the CyberTouch, the subjects saw their task actions in the VE through the screen. During the five tests, they wore the HMD **to** complete the designed task in the VE. After the tests, no subject expressed sickness, although they complained about the weight of the HMD. On contrast, they said the images in the HMD were brighter and more vivid than those were on the screen.

5.8 Summary

The new memory rehabilitation methodology for the dementia elderly was evaluated with three phases of tests. The first two phases of test results were collected by follow-up questionnaires. The first-phase test focused on the IVRS, which is the platform of realizing the new methodology. The subjects were graduate students with experience in operating or designing virtual environments. Their feedbacks were mainly on improvements to the hardware and software system.

The second phase of the test was done by the occupational therapists with experience in the rehabilitation area. Based on their knowledge and experience, the therapists evaluated the suitability of the virtual environment suitable for old patients. They also evaluated the overall function of the Intelligent Assistant. The therapists had positive comments on the objective, early design, and effectiveness of the new rehabilitation approach. They also suggested on a richer environment to attract the attention of the patients. Help information for improving the intelligence of the **IVRS** was also suggested.

According to suggestions from the first two phases of tests, the IVRS was improved for the third test. In the third phase, the subjects were ten old persons without any knowledge and experience in computer. Their test results were reflected though the statistics of the task completion time and number of errors they made during the tests. Although they spent more time in the task than the students with VR experience, their performance improved in terms of shorter task completion time and fewer errors with repetition of the tests. They also gave positive subjective evaluation on the system effectiveness. The results showed that the old subjects could tolerate the VR application. The results also showed the efficiency and effectiveness of the training in **IVRS**.

The three phases of tests have showed positive results of this new rehabilitation approach. The **IVRS** was also improved based on the suggestions from first two phases of tests. In Chapter **6** the test will be moved to the clinic environment. The subjects of the case study will be patients with memory deficits due to dementia.

CHAPTER 6 A CASE STUDY

6.1 Introduction

As discussed in Chapter 5, the initial test of the Intelligent Virtual Rehabilitation System **(IVRS)** has been conducted in three phases. In the first phase, test results were collected fi-om the subjects with experience in using and developing VE applications. This was mainly used for the improvement in the development of the virtual kitchen and the functional rehabilitation environment of the IVRS. In the second phase, test results were collected fi-om therapists working in the rehabilitation area. With their clinical knowledge and experience, the therapists provided positive feedback on the virtual rehabilitation approach, including suggestions to improve the design and performance of the Intelligent Assistant within the **IVRS.** In the third phase, test results were collected fi-om normal old persons who have few knowledge and experience with computers. The results revealed that the normal old people could accept the challenge of the VR application and could familiarise with it quickly. They were able to complete the virtual cooking task in the virtual kitchen with the assistance of the Intelligent Assistant. They also were able to gradually pick up speed and made fewer errors in completing the task after a few cycle of training in the IVRS. These positive results encouraged this further study on the dementia patients.

This chapter presents a case study on the assessment of whether the virtual rehabilitation approach could in practice be applied to the rehabilitation of dementia patients. The objective of this case study is to find out answers for the following critical questions:

(a) Can dementia patients benefit from training in the virtual rehabilitation environment?

Dementia patients should encounter more issues with the VR applications than normal old persons because they may face problems when performing complex tasks such as using the telephone or planning a meal. Operating the VR tool may also impose further burdens on their cognitive or physical functions. This leads to an important question: "Can dementia patients overcome the obstacle of VR application for routine rehabilitation training?" This project develops a methodology for building an appropriate virtual rehabilitation environment in which the dementia patients could be trained to perform the rehabilitation tasks. This case study is to determine the effectiveness of the methodology.

(b) Can the Intelligent Assistant assist the patient effectively to complete rehabilitation tasks?

The new methodology will provide an intelligent rehabilitation approach for dementia patients. This will reduce the dependency of patients on the therapists during the rehabilitation period and relief the burdens of the therapists who are likely to take care of several patients at the same time. In the IVRS, the Intelligent Assistant is based on fuzzy logic theory. The fuzzy rules were acquired from the knowledge and experience of the therapists. To evaluate the Intelligent Assistant, the therapists will be invited to observe the patients when they perform the virtual rehabilitation task. The therapists will evaluate the contents of the instructions, as well as when, where, and how the instructions were given. The record will be used to evaluate the Intelligent Assistant.

(c) Does the new memory rehabilitation methodology have an advantage over the conventional approach?

A common problem encountered in the conventional approach is the transfer and generalization of the trained skill from the rehabilitation environment to the real world. The patient may not be able to use the knowledge or abilities he learned from the clinical laboratory in his living environment. This case study is to find out whether the virtual memory rehabilitation can solve this problem and whether the ability the patient achieved from the training in the VE could be transferred to the real world.

Currently there is no established methodology for evaluating the application of virtual rehabilitation on old patients. Based on the above objectives, a methodology has been developed to evaluate the proposed virtual rehabilitation approach.

6.2 Method

6.2.1 Selection Protocol of Test Subjects

A patient will be selected to do the test in the **IVRS.** The selection protocol for admission to the **IVRS** is described in Figure 6.1. Some items seen in Figure 6.1 are explained as follows.

- Patients with *severe memory deficits* are not allowed to do the test. Memory deficit can be tested based on the AMT (Abbreviated Mental Test) scores (see Appendix G). Derived by Hodkinson **(1972),** the AMT score is commonly used to quickly test the cognitive function in elderly patients. Scores of less than 7 indicate likely cognitive impairment.

- Patients with *severe physical disability,* for example those who cannot control their hands effectively, are excluded for obvious reason that they will not be able to operate the objects in the test. The patient should be able to discern vibration in his hand, as it is a feedback mode of the CyberTouch. The CyberTouch will give the user vibration feeling when the user touches any object in the virtual environment.

- Patients who are not motivated or refused to do the test in the **IVRS** due to various reasons or cannot concentrate on their tasks for at least **30** minutes are to be excluded.

- *Apprehension of task requirements* is to train the patient to be familiar with virtual devices and the virtual environment. After the training, the patient should be able to perceive the coupling of the hand movement in the real world with the virtual hand in the IVRS. The patient should be able to pick up and carry the objects in the IVRS. The patient should be able to operate virtual devices such as switching on **and** off the virtual cooker.

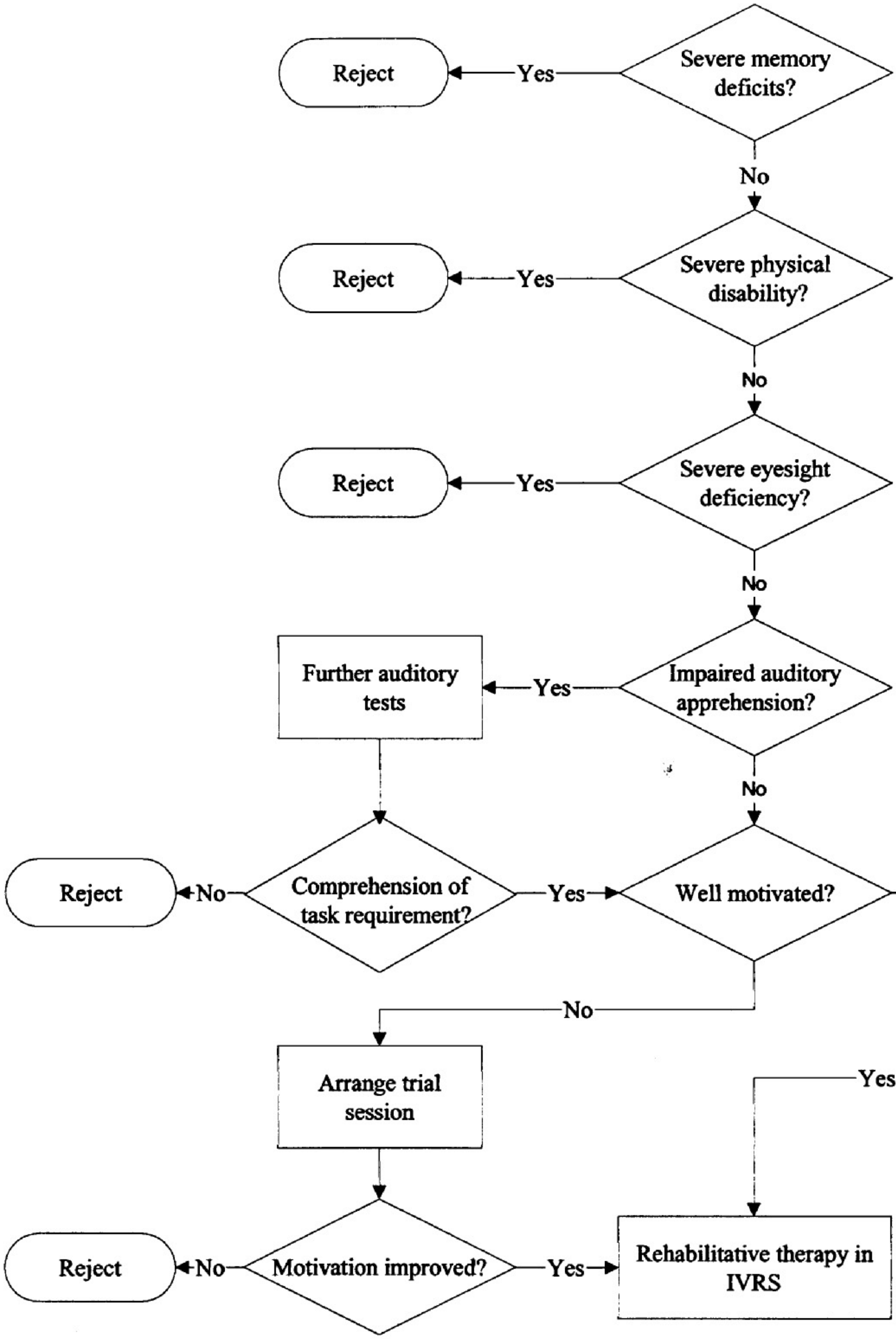


Figure 6.1 Selection Protocol for Admission to IVRS

6.2.2 Test Subjects

After the patients themselves and their families had agreed, two female subjects who satisfied the above requirements were invited to participate in this study. These two subjects, aging at 78 and 81 years old respectively, both suffered from left hemisphere strokes about a year ago. Both of them were right hand dominant and required the assistance of a walker. Hereafter, the first patient will be identified as Patient **A,** and the second as Patient B. Patient **A** had ataxia and required assistance in using her hemi paretic right hand. Patient B functioned well with her right hand. Both of them had an AMT score of 4, indicating cognitive impairments.

Table 6.1 Nine Subtasks of Cooking Hard-Boiled Eggs

Task No.	Subtasks
1	Find the utensils
2	Choose the correct pot
3	Walk to the sink and put the pot into the sink
4	Fill the pot with suitable amount of water
5	Tum off the tap
6	Walk to the stove and put the pot on the stove
7	Put an egg into the pot
8	Tum on the stove
9	Turn off the stove

6.2.3 Materials

The designed test task was cooking hard-boiled eggs. This task can be further divided into nine simple operational subtasks that can be used by the occupational therapist for assessment as shown in Table 6.1.

The patients performed the test in two types **of** environments: the real kitchen and the virtual kitchen. **As** described in Chapter **3,** the virtual kitchen was constructed based on the real unit at the Hospital. The only difference between real kitchen and its virtual replica is that the locations of the sink and the stove were interchanged. This was done purposely **to** test whether the training in the virtual world would affect the subject's performance in the real kitchen. The test equipment of the virtual kitchen (Figure 6.2) is listed in Table 6.2. These have been described in Chapter 5.

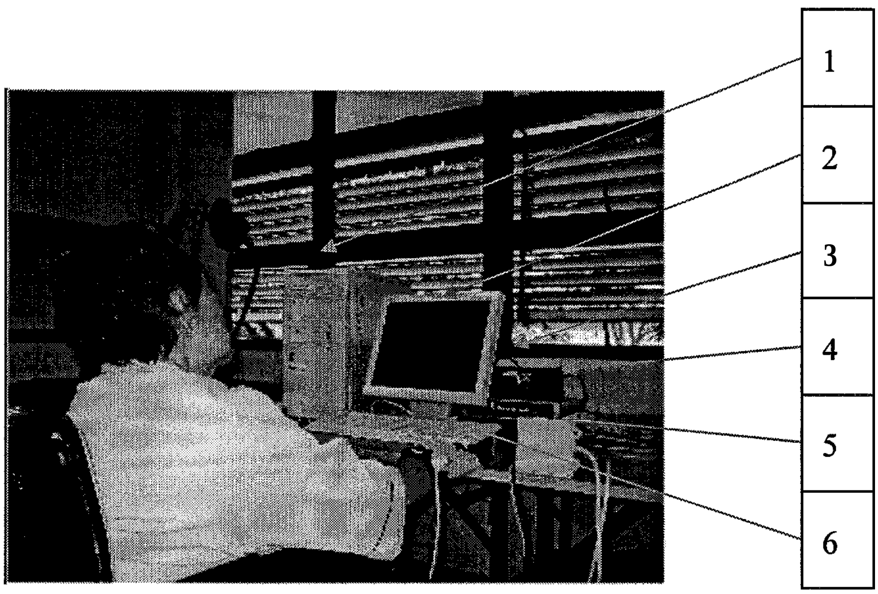


Figure 6.2 Test Settings

(Note: The boxed number corresponds to the device number of Table 6.2)

Table **6.2** Device Lists **of** Test Settings

Device No.	Device Name
1	Personal computer with Pentium IV 1.5GHz CPU
2	15" LCD monitor
3	CyberTouch controller
4	Position tracker: Ascension Flock of Birds
5	Transmitter
6	CyberTouch glove and Sensor of the position tracker

6.2.4 Procedure

Patient **A** first did the test in the real kitchen environment, accompanied by a clinical therapist and the experimenter. The assigned task is cooking an egg. She was required to complete the task for five times. The patient was asked to observe the experimenter to cook an egg. At the same time, the therapist would give instructions on each subtask to the patient. After which, the patient began to do the test by herself. If the patient made a mistake or could not decide what to do, the therapist would correct her or give her instructions until the patient completed all the subtasks. The experimenter recorded the patient's operational behaviours in each of the nine subtasks. The data includes the time the patient spent of each subtask, and the mistakes made. These data were later used for comparison with those captured in the virtual kitchen.

On the following day, Patient A received her training session in the virtual kitchen. The patient first watched the experimenter operating the task. Then she was instructed on how to perform it. Errorless performance training was used as much as possible to take account of' the suggestion by Baddeley and Wilson's (1994) that patients with amnesia rely on implicit memory to acquire new information but that implicit memory does not have the same potential as explicit memory to correct for errors. The patient was corrected as soon as she began to make a wrong performance. To facilitate her correct performance, and to allow the patient to learn the operations in a gradually increasing succession of stages, the fuzzy-based Intelligent Assistant would give out the instructions based on the time the patient spent and the distance between her hands and the virtual objects.

Patient B began the test in the virtual kitchen first, then in the real kitchen. However, some changes were made to her test procedure. The steps before the patient place the pot on the cooker were unchanged. After putting the pot on the cooker, Patient A who began the test in the real unit was instructed to put the egg into the pot first and turn on the cooker. Patient B had to turn on the cooker first before putting the egg into the pot. Another difference was that the positions of the sink and the cooker in the real environment were switched in the virtual environment. In the real kitchen, the sink is located on the right side and the cooker on the left. In the virtual kitchen, the sink was on the left while the cooker was on the right.

Similar to the procedure used in the test of the NRS for normal old persons (as described previously in Section 5.6.1), each of the patients was trained ten times to use CyberTouch to pick up, hold, and drop the things in the virtual kitchen before they began the test.

Thereafter, each patient was given training sessions for a period of two days, each session lasting approximately 40 minutes. Ten minutes later after each session, the patients were asked three questions as shown in Appendix F. Due to the limitation of the test period, short-term memory was the mainly target.

6.3 Results

Tables 6.3 and 6.4 show the recorded time spent and number **of** errors made in each of the test.

Table 6.3 Time Spent in Each Test

Patient	Test 1 (seconds)		Test 2 (seconds)		Test 3 (seconds)		Test 4 (seconds)		Test 5 (seconds)	
	VE	RE	VE	RE	VE	RE	VE	RE	VE	RE
A	431	240	389	260	331	283	267	256	281	241
B	373	175	332	166	243	149	237	155	176	153

Note: VE – virtual environment; RE – real environment.

Table 6.4 Number of Errors Made in Each Test

Patient	Test 1		Test 2		Test 3		Test 4		Test 5	
	VE	RE	VE	RE	VE	RE	VE	RE	VE	RE
A	11	3	6	3	4	3	3	4	3	3
B	8	2	5	2	5	2	3	2	3	2

Note: VE – virtual environment; RE – real environment.

In Table 6.3, it can be seen that both patients spent longer time in the virtual rehabilitation task than in the real task. This is because they needed extra time to be accustomed to moving around in the virtual environment. They also took longer time to place the objects at the destinations. This may be due to their adaptation to the depth perception of objects within the virtual environment.

In Table 6.4, no error was recorded for not knowing how to do a subtask. Some examples of the erroneous steps taken by test subjects include:

- Patient was unable to hold an object and bring it to its correct destination.
- Patient picked up an unsuitable utensil such as a pan to fill up with water.
- Patient misplaced the objects, e.g. putting the pot outside the frame of the stove.

In the virtual environment, controlling the CyberTouch and placing the objects increased the error rates for the tests in the virtual environment. In the real environment, both patients could not hold the pot even if there were no water in the pot. Patient **A** could not even grasp the egg because of her hemi paretic right hand. In the first test in the real kitchen, Patient A attempted to use **a** pan to fill up with water and was corrected by the therapist.

Table 6.5 records if the patient answered the questions listed in Appendix F correctly.

Table 6.5 Patient's Answers To Questions in Appendix F

Patient	First Day			Second Day		
	Q1	Q2	Q3	Q1	Q2	43
A	YES	YES	NO	YES	YES	YES
B	YES	YES	YES	YES	YES	YES

6.4 Discussion

To simplify the explanation and analysis of those results, three questions proposed in Section 6.1 are answered fiom the following four concerns.

(a) Is this an appropriate methodology for developing a virtual functional environment?

Table 6.3 shows that both patients could finish the task within some 7 minutes in the virtual kitchen. With the increase **of** each additional test, the task completion time (Table 6.3) and the number of errors (Table 6.4) decreased. This trend shows the improvements of the patients with the progress of the tests.

Table 6.6 lists the task completion time two patients spent for each of the tests. Extracted fiom Table 5.5, the average completion time normal old subjects spent for each test is listed in the third row. Figure 6.3 graphically illustrates the task completion time in Table 6.6.

Table 6.6 Task Completion Time Patients and Normal Old Subjects Spent for Five Tests

	Test 1 (seconds)	Test 2 (seconds)	Test 3 (seconds)	Test 4 (seconds)	Test 5 (seconds)
Patient **A**	431	389	331	267	281
Patient B	373	332	243	237	176
Normal Old Persons	177	175	147	123	110

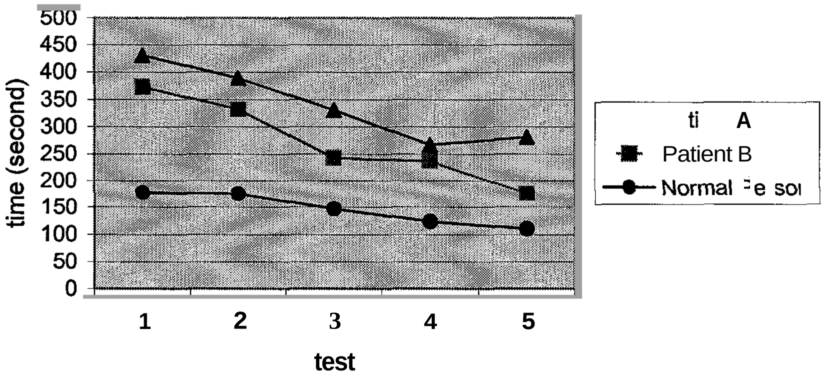


Figure 6.3 Comparisons between Patients and Normal Old Subjects

When compared with normal old subjects, the patients took longer and made more mistakes in each of the tests. The patients moved their hands more slowly than normal old subjects. They spent longer time to move around in the virtual environment and to follow the cue message. However, their learning curves show a similar trend. The trend is that the task completion time and the number of errors decreased with increasing cycle of tests. This suggests that the usability level of the IVRS is at the appropriate level, not only for the normal elderly, but also for the two patients.

Figure 6.3 also shows that the patients have the steeper curves than normal old subjects. This may be due to the extra time the patients took to understand the cue message of the Intelligent Assistant. Sometimes the patients even wait for the therapist to tell the meaning of the words since patients were illiterate. Hence this part of time obviously affected the whole task completion time. With each additional test, the patients were more familiar with them and follow the cue message faster. This part of time was decreased gradually. For normal old patients, they did not depend on the cue message too much. Most of them could understand the cue message since the first test. Therefore the task completion time was mainly decided by the time taken to move around in the virtual environment and complete subtasks one by one. This part of time would not decrease sharply within five turns of test.

In Figure 6.3, both Patient A and B had a convex point in their curves. This was due to the extra time the patients casually spent in a subtask in this test.

The patients were able to gradually learn to control the VR devices such as the CyberTouch. Using the CyberTouch to contact with the virtual objects gave the patients a somewhat natural sensation. They learned to use it in an easy and natural way. Therefore the patients were not distracted by the mode of controlling the VR devices, and could concentrate on the rehabilitation task. When they touched or hold a virtual object, the patients would sense the vibration produced by the CyberTouch. The patients were excited by this game factor that gave them the impetus to complete the task.

The therapists noticed that although the patients had no idea what the devices in front of them were, they were not afraid of using them. They did not understand why they could touch objects presented on the computer screen. But they could answer correctly that they had cooked some eggs when the therapist asked them what they did.

The results indicate that the designed functional virtual rehabilitation can provide the patients with home-like feelings. The proposed method for developing the virtual rehabilitation environment is appropriate and effective.

(b) Is the Intelligent Assistant useful?

Considering the decreased capability of activity, the average task completion time of the normal old subjects was doubled as the baseline of the time set, which is one of the inputs into the Intelligent Assistant. Five therapists were invited to observe the test. The profiles of these five therapists have already been presented in Table 5.3. When a cue appeared during the test, the therapists would rate the input and output of the Intelligent Assistant. The inputs and outputs of the Intelligent Assistant are classified into five types depending on the outputs, as shown in Table 5.12. Table 6.7 shows the questionnaire for collecting the ratings of the therapists.

The ratings and the suggestions on each type of the output are summarized in Table **6.8** and Table **6.9** respectively.

Table 6.7 Questions for Evaluation of Intelligent Assistant

18. The system is intelligent and cooperative with users:

1	2	3	4	5
Strongly disagree	Disagree	Neutral	Agree	Strongly agree

19. There are five types of cues (please see Table 5.12). Do you think the timing of these types of the cues is suitable?

1	2	3	4	5
Not at all	Unsuitable	Neutral	Suitable	Precisely

Give the suggestion on how to improve the formats and contents of the cues.

____

20. Do you agree that the Intelligent Assistant can play the role of the therapists?

1	2	3	4	5
Strongly disagree	Disagree	Neutral	Agree	Strongly agree

Please state the reasons of your ratings.

Table 6.8 Therapists' Ratings On Intelligent Assistant

Subject	Patient A							Patient B						
	Q1	Q2					Q3	Q1	Q2					Q3
1	3	3	4	4	4	3	3	4	3	4	4	4	4	4
2	4	3	4	5	4	3	4	4	4	4	5	4	4	4
3	4	4	4	5	4	4	4	4	4	4	5	4	4	4
4	3	3	4	4	4	3	3	4	3	4	4	4	4	4
5	3	3	4	4	4	3	3	3	3	4	4	4	3	4
Mean	3.4	3.2	4	4.4	4	3.2	3.4	3.8	3.4	4	4.4	4	3.8	4
SD	0.55	0.45	0	0.55	0	0.45	0.55	0.45	0.55	0	0.55	0	0.45	0

(Note: Question numbers Q1 to Q3 refer to that of Table 6.7)

Table 6.9 Evaluation of Intelligent Assistant by Therapists

Type No.	Evaluation of Therapists
1	▪ Instruction and indication are generally timely and suitable. ▪ Difficult for illiterate patients to follow the words.
2	▪ Indications appeared timely. ▪ Good to use flashing objects to attract patients ▪ Animation of clapping hands or smiling face to encourage patients directly.
3	▪ Speeches of encouragement were timely and effective.
4	▪ Appropriate to provide more cues to remind the patients at this time. ▪ Should present more effective cues. ▪ Better to change Image for Instruction to Speech for Instruction.
5	▪ Correct to provide more cues at this time. ▪ Not necessary to present Image for Indication as it may distract patients with too much information. ▪ Speech for Instruction has the best effect. ▪ Therapist should provide assistance such as performing the task together with the patient.

(Note: Type No. refers to that shown in Table 5.12)

The therapists were generally satisfied with the overall function of the Intelligent Assistant. Table 6.8 and Table **6.9** showed that the Intelligent Assistant was capable of providing timely assistance to the patients. Depending on the time the patient spent for each of subtasks and the position of the patient's hand, the Intelligent Assistant generated the appropriate cues such as word, image, sound, and speech to simulate an experienced therapist guiding the patient to complete the task.

However, it was found that the patients could not comprehend the words due to their illiteracy. This is a reason for the lower rating for Type 1 output. By contrast the flashing simple images attracted the patients better. Speech output had the best effect and encouraged the patients to interact with the virtual world more directly and naturally.

The psychological states of the two patients differed considerably. Patient A was more prone to be depressed than Patient B. Patient A needed more speech instructions. The Intelligent Assistant was unable to capture the mood of the patients. For Patient A's case the therapist had to talk with her more frequently to know her feelings and even to perform the task with her together. Therefore Intelligent Assistant is more suitable to the patients with stable psychological states.

(c) How did the beneficial effects of training the patients in a virtual environment compare with training them in the real environment?

During the test, the patients made a number of mistakes such as dropping the eggs onto the table or repeated attempts to grasp an object in the virtual environment. In the real environment, the patients were unable to hold the pot with water. Patient A could not grasp the eggs because of her hemi paretic right hand. It could be seen that the patients made more errors in the virtual environment than in the real environment. However, they laughed instead of feeling embarrassed or discouraged when they made a wrong move in the virtual rehabilitation environment. They felt satisfied with their performance. After they had completed a test, they were willing to carry on the next test when the therapist asked for their agreement. In the real environment, Patient **A** repeatedly requested for toilet breaks during the test in the real environment. The therapist regarded that she might feel unconfident and nervous because of the failure of grasping the egg. The patients felt relaxed and were readily willing to take part in the rehabilitation process. Obviously, the effectiveness of training in the virtual environment was better than that of in the real environment.

In the real kitchen, the therapist had to look after the patients very carefully to keep them away from dangers. The virtual rehabilitation released the burden of the therapist. In the virtual environment, the therapist would not worry about the safety of the patients such as being hurt by the fire. If the patient was 'hurt' by the fire in the virtual environment, the occurrence could be recorded and the scenario could be repeated to train the patient in avoiding this danger. This would avoid the potentially heavy cost for the consequences caused by any wrong actions. The Intelligent Assistant provided the patients with timely and useful information. The therapist only needed to assist the patients occasionally when he observed the patients did not know how to follow the information. Therefore, the therapist could concentrate on watching the performances of the patients and providing more accurate assessment.

It would therefore appear that for the two patients, the beneficial effects of training in the virtual environment exceeded the beneficial effects of training in the real environment.

(d) Will the skill trained in the virtual environment transfer to the real environment?

As described in Section 6.2.3, the procedure for completing the task was arranged a little differently for the two patients. In the first day, Patient A carried out the tests in the real environment, with frequent requests for toilet breaks. After the tests, she could not answer Question 3 (see Table 6.5). In the second day, she was moved to the virtual environment. Just after she had put the pot onto the cooker, the test was paused. The therapist asked her if she remembered putting the eggs into the pot first or turning on the cooker first in the real environment training. She said she could not remember that procedure. And her performance was not affected by the interchanged positions of the sink and the cooker. She answered all the questions correctly.

Patient B showed other interesting results. She completed all the tests in the virtual environment in the first day and could answer all the questions correctly (Table 6.5). In the second day, she was moved to the real kitchen. When she held the pot and moved to the sink, she first moved to the left side as trained in the virtual environment. After she had put the pot on the cooker, the therapist asked her if she remembered putting the eggs into the pot first or turning on the cooker first in the virtual environment. She remembered and performed the exact procedure. It suggests that what patient B trained in the virtual environment was transferred to the real environment.

Other factors may have influenced these results. First, it could be due to the nature or intensity of the VR training. For a procedure of the task, the patients may have repeated more times in the virtual environment because they needed to overcome the mistakes before progressing to the next procedure. In spite of this, they were in good mood and not depressed. Secondly, the patients were not distracted from the task in the virtual environment. And game factors such as vibration from the data glove, flash information, and encouraging words provided by the Intelligent Assistant motivated the patients to keep focus on the task.

6.5 Summary

The case study was conducted in the clinic environment. The purpose of the study is to determine whether the new memory rehabilitation methodology is applicable for the dementia patients and whether the new approach has advantages over the conventional approach. Two moderate dementia patients who met the test criteria were selected for the study. They were required to cook hard-boiled eggs in real and virtual kitchens according to their designed procedure.

Analysis of the test results shows that the new methodology of virtual functional environment is effective. The Intelligent Assistant can generally play the role of the therapists to provide timely and useful information to the patients. The patients also gain more benefits in the virtual environment than they did in the real environment, and the skill trained in the virtual environment was transferred to the real environment.

Due to the limitation of the test period and restricted supply of suitable subjects, only the short-term memory was targeted during the test. The patients showed they could remember the numbers of eggs and the places of the pot and kettle after being trained in the virtual environment. However, it has not showed obvious evidence of the improved behaviour or performance in the real environment. To determine if the new memory rehabilitation methodology is effective in improving the general behaviour or performance of the patients, further studies will be needed.

CHAPTER 7 CONCLUSION AND FUTURE WORK

7.1 Conclusion

The potential for improving the quality of life of dementia patients also depends on the correct application of methodologies and technological aids. The application of VR technology in rehabilitation has significant advantages over the conventional rehabilitation methods. **A** number of researchers have reported positively on the VR applications for the memory rehabilitation. However, the VR applications for the dementia patients are few and in their earliest stage. **A** number of problems need to be studied and clarified. An important question is whether the weight of VR application is too great to be overcome by dementia patients. The other problem existed in the clinic environment is the over burden on a therapist who takes care of the rehabilitation of several patients at the same time. To reduce the therapist's burden requires that a VR application should have certain intelligence to mimic a therapist to assist patients.

To study and solve the above problems, this project has developed a new memory rehabilitation methodology for the dementia elderly. The methodology explores the conventional memory rehabilitation theory and approaches, the advanced virtual reality (VR) technology, and fuzzy logic theory to develop an intelligent approach. To study the proposed methodology, the intelligent virtual rehabilitation system (IVRS) has been developed. The following research work has been achieved.

(a) A methodology for building a virtual rehabilitation environment suitable for the dementia patients has been developed.

Currently there is no developed methodology for building virtual environments for the elderly. Additional considerations need to be taken for dementia patients and other "non-typical" users. This project has developed a new methodology for building an appropriate virtual rehabilitation environment for the dementia patients. The protocol is established by considering the characteristics of memory deficits as a result **of** dementia, the medical protocol obtained from the investigations in the hospital, and the characteristics of VR techniques. The approach is developed by exploiting preserved procedural memory, building a functional virtual environment, applying rehabilitation tasks associated with the patient's daily living activities, enhancing natural interactions between user and virtual environment, and enriching game factors to give user the impetus to continuously engaged in the rehabilitation exercise.

Subjective test results fi-om the therapists provide positive ratings on the suitability issues of VR technology for the rehabilitation of the dementia elderly. Statistical test results fi-om the healthy old people and the patients present a similar trend during the test. The trend is that the task completion time and operation errors are decreased with the progress of the test. This trend indicates that the training in the virtual environment is efficient and effective. The suitability of the virtual environment for the normal old people and dementia patients is at appropriate level. Those qualitative and quantitative results showed that the developed methodology is effective.

(b) A new application of fuzzy logic in the Intelligent Assistant has been developed.

As described in Section 2.4.4, errorless learning resulted in superior performances of the dementia patients in memory rehabilitation. Current techniques usually use pre-programmed prompts or cues to provide errorless learning environment. They cannot dynamically modify the cues or prompts in response to the patient's Performances. However, the incorporation of intelligence within the virtual rehabilitation is a novel approach. This approach is capable of dynamically and intelligently adjust the rehabilitation processes depending on the patient's performances. It mimics a therapist to assist the patient's performances quickly and effectively.

In clinical practice, the therapist's instructions for assisting patient's performances possess certain uncertainties. Movements of the patients also have certain uncertainties. Therefore fuzzy logic theory is investigated to build the Intelligent Assistant. This is a new application of fuzzy logic in the Intelligent Assistant as it takes into consideration the vagueness and uncertainties of the conditions and treatments. This project captured the therapist's knowledge and experience to establish fuzzy rules and present them in the virtual rehabilitation environment. It also established a representation scheme for the fuzzy-based assistant including inputs and output variables and the fuzzy inference engine based on the fuzzy relationship between the inputs and output, The potential of this approach has been only investigated from therapists' feedback. The therapists evaluated the Intelligent Assistant through two phases of test. In the first phase, they focused on the representation of cue information output from the Intelligent Assistant. They gave suggestions on enriching the cue information. In the second phase, they observed the patients to complete the rehabilitation task and evaluated the Intelligent Assistant in all aspects. The evaluation results show that the overall function of the Intelligent Assistant is satisfied. It dynamically generates the appropriate cues such as word, image, sound, and speech to simulate a therapist guiding the user to complete the task depending on the time the user takes and the position of the user's hand. It also keeps learning tasks simple and provides correct responses before the individual has a chance to make an error.

(c) Virtual rehabilitation is a better approach than conventional rehabilitation.

Comparing the patients' performances of training in the real world and virtual environment, it is obvious that the patients showed better results in the virtual environment than in the real world. Although they may make more errors in the virtual environment than the real environment, the patients did not feel embarrassed or discouraged. Instead, they were confident and happy with their performance. The good mood is beneficial for the patients to concentrate on the rehabilitation task and enforce their objects and spatial memory such as the numbers of the eggs and the places of the pot and kettle. Moreover, they were shielded from potential real dangers in the virtual kitchen, such as burnt by fire or scaled by the hot water. The therapists could concentrate more on the assessment of the patient's rehabilitation so as to improve its effectiveness. Hence the patients gain more benefits in the virtual environment than they did in the real environment.

The test results from patients also show that skill trained in the virtual environment is transferred to the real environment. Virtual rehabilitation shows the potential to overcome the transfer problem, which is a common problem encountered in conventional methods.

7.2 Future Work

Future work are recommended in the following aspects, based on the limitations existed in the current project.

- **Improve the virtual rehabilitation environment.**

Many of the negative comments from the therapists can be traced to hardware deficiencies and software bugs. For example, the arrow keys were used instead of the position tracker to move the user's viewpoint. This was due to the difficulties encountered in controlling the tracker. There is also an intermittent software bug that causes the virtual object to stick excessively long to the user's hand.

- **Improve the Intelligent Assistant.**

The effectiveness of the fuzzy-based intelligent assistant has yet to be further investigated from more detailed clinical trials. Task completion time, one of the inputs of the Intelligent Assistant, can be improved. In the case study, the average task completion time of the normal old subjects was doubled as the baseline of the time set into the fuzzifier. If more patients could be involved a long-term test, the baseline of the time set could be statistically calculated from a collection of data.

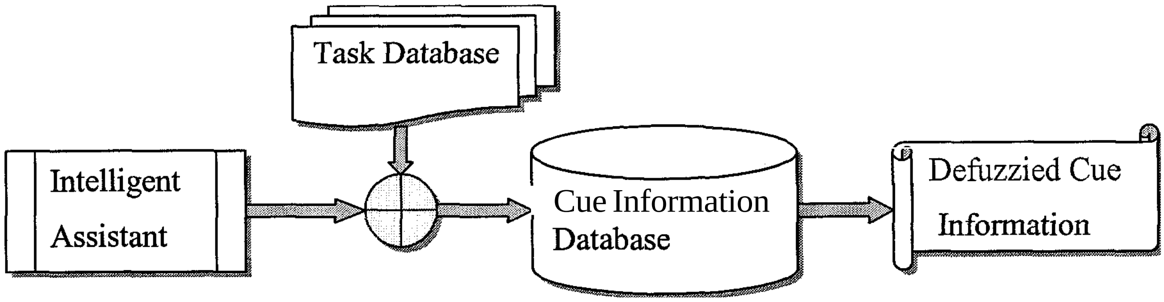


Figure 7.1 Intelligent Assistant Structure

The contents of cue information, defuzzified from the Intelligent Assistant, are dependent on rehabilitation tasks. The contents may need to be changed based on the different scenarios of training tasks. For example, when the task is cooking eggs, the cue information may need to tell user to put an egg into a pot. If cooking noodles, it may need to tell user to put noodle into a pot. This limitation can be improved by building a task database and a cue information database to associate the defuzzified cue information with the corresponding training task. The structure of the database may be constructed as shown in Figure 7.1. Before the cue information is defuzzified, task data such as contents of subtasks and fuzzy decision could be mapped to the cue information database and get the related contents of cue information. So that contents of cue information could be dynamically changed with the corresponding training task.

- **Conduct long-term test on more dementia patients.**

Only two patients participated in the case study due to the short supply of suitable patients. Therefore the case study can only be regarded as exploratory research. Although the case study presented the evidence to prove the effectiveness of the proposed methodology, it is necessary to involve more patients in the test. This would allow better statistical data to be collected for the proposed methodology. One of future work could be the study on the effectiveness of the new memory rehabilitation methodology in improving the general behaviour or performance of the patients. Currently, only short-term memory has been investigated in the case study due to the limitation of the patient's rehabilitation period in the Hospital. It has not shown good evidence of improved behaviour or performance in the real environment. Therefore a long-term test that involves more test subjects should be carried out.

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APPENDIX A INITIALISATION OF CYBERTOUCH AND FLOCK OF BIRDS

```
//intialize the sensor attached to the glove's wrist
WTp3 posGlove;
AfxMessageBox ("Initializing Bird sensor and CyberGlove...");
birdglove = WTbird_new(SERIAL2,1);
if(birdglove)
{
    float radius = WTnode_getradius(root);
    WTsensor_setsensitivity(birdglove, 0.1f*radius);
}
//initializeRighthand CyberGlove
cybGlove = WTcybglove_new(38400, SERIAL3, "default.cal");
//create graphical hand model
if(cybGlove)
{
    glove=WTcybglove_usehandmodel(cybGlove,"hires_hand.vnf", 1.0f,root);
    gloveForearm=WTcybglove_getforearm(cybGlove);
    //set motion link for glove
    linkGlove = WTmotionlink_new(birdglove, glove, WTSOURCE_SENSOR,
                                                WTTARGET_MOVABLE);
    // set reference frame
    WTmotionlink_setreferenceframe(linkGlove,WTFRAME_PARENT, NULL);
    WTq orientGlove = {-0.7071f, 0.0f, 0.0f, 0.7071f};
    WTnode_setorientation(glove, orientGlove);
    WTviewpoint_getposition(uview, posGlove);
    posGlove[X]+=15.0f;posGlove[Y]+=25.0f;posGlove[Z]+=30.0f;
    WTnode_settranslation(glove, posGlove);
    WTtask_new(gloveForearm, followViewpoint, 1.0);
    WTtask_new(gloveForearm, collisionCookEgg, 2.0);
}
```

APPENDIX B PRE-EXPERIMENT QUESTIONNAIRE

(Scores in parentheses were not shown to subjects)

1. Age __________
2. Gender Male/Female
3. (2 points/year, 9 points maximum) How many years have you been using a computer (0 for never use computer before)? __________
4. (9 points) How often do you use computer (anything on computer)?
   - (9 points) everyday
   - (6 points) several times a week
   - (2 points) seldom
   - (0 points) almost never
5. (9 points) How much do you know of the virtual reality (VR) application?
   - (9 points) develop a VR application
   - (6 points) use a VR application
   - (2 points) see a VR application but never use it
   - (0 points) never see a VR application
6. (2 points/time, 9 points maximum) How many times have you been using the head-mounted display (HMD) (0 for never use HMD before)? __________
7. (2 points/time, 9 points maximum) How many times have you been using the dataglove (0 for never use dataglove before)? __________

APPENDIX C POST-EXPERIMENT QUESTIONNAIRE

(For Subjects with VR Experience)

Overall Reaction to the System

1. The virtual environment (VE) is:

1	2	3	4	5	6	7
Very artificial	Artificial	Somewhat artificial	Neutral	Somewhat realistic	Realistic	Very realistic

2. My affection after operating the VE is:

1	2	3	4	5	6	7
Very frustrating	Frustrating	Somewhat frustrating	Neutral	Somewhat satisfying	Satisfying	Very satisfying

3. Training in the VE is:

1	2	3	4	5	6	7
Very dull	Dull	Somewhat dull	Neutral	Somewhat stimulating	Stimulating	very stimulating

4. The procedures for completing the tasks are:

1	2	3	4	5	6	7
Very rigid	Rigid	Somewhat rigid	Neutral	Somewhat flexible	Flexible	Very flexible

5. System Speed is:

1	2	3	4	5	6	7
Very slow	Slow	Somewhat slow	Neutral	Somewhat fast	Fast	Very fast

Display

6. VE on HMD (head-mounted display) is better than on monitor:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

7. To interact with VE is easier with HMD and head tracker:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

8. My reaction to using on HMD is:

1	2	3	4	5	6	7
Very sick	ick	Somewhat sick	Neutral	Somewhat comfortable	Comfortable	Very comfortable

Please use several words to describe your feeling about HMD.

Input

9. Using CyberTouch to handle objects in the VE is more natural than using mouse:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

10. Learning to operate the CyberTouch is:

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy

Learning

11. Straight-forward to perform the given tasks

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

12. Cue information simplifies the task

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

13. Learning to use the system is

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy

14. The system is very intelligent and cooperative with users:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

APPENDIX D POST-EXPERIMENT QUESTIONNAIRE

(For Subjects with Rehabilitation Experience)

Overall Reaction to the System

1. The virtual environment (VE) is:

1	2	3	4	5	6	7
Very artificial	Artificial	Somewhat artificial	Neutral	Somewhat realistic	Realistic	Very realistic

2. My affection after operating the VE is:

1	2	3	4	5	6	7
Very frustrating	Frustrating	Somewhat frustrating	Neutral	Somewhat satisfying	Satisfying	Very satisfying

3. Training in the VE is:

1	2	3	4	5	6	7
Very dull	Dull	Somewhat dull	Neutral	Somewhat stimulating	Stimulating	very stimulating

4. The procedure for completing the tasks is:

1	2	3	4	5	6	7
Very rigid	Rigid	Somewhat rigid	Neutral	Somewhat flexible	Flexible	Very flexible

Display

5. VE on HMD (head-mounted display) is better than on monitor:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

6. Wearing on HMD make it easer to interact with VE:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

7. My reaction to using on HMD is:

1	2	3	4	5	6	7
Very sick	sick	Somewhat sick	Neutral	Somewhat comfortable	Comfortable	Very comfortable

Please use several words to describe your feeling about HMD.

____

Input

8. Using CyberTouch to handle objects in the VE is more natural than using mouse:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

9. Learning to operate the CyberTouch is:

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	very easy

Learning

10. Straight-forward to perform the given tasks

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

11. Cue information simplifies the task

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

12. Learning to use the system is

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	very easy

13. The system is very intelligent and cooperative with users:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Please scale the following questions according to your knowledge and experience

14. Training of activities daily living (ADL) in the virtual environment (VE) is useful for the rehabilitation of the patients with memory deficits:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Your suggestion:

____

15. Patients can perform this VR-based training easily:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Your suggestion on the training task:

____

16. VR-based training can reduce our workload:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Please explain briefly:

____

17. The performance trained in this VE can be transferred to the real world:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

Write down your opinion:

____

18. VR-based training can better motivate the patients in rehabilitation task:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

19. Should the formats and contents of the intelligent assistant be improved? If, please explain briefly?

____

20. Are the timing of the cue information suitable? If not, how to adjust it?

____

APPENDIX E POST-EXPERIMENT QUESTIONNAIRE

(For Normal Old Subjects)

Overall Reaction to the System

1. The virtual environment (VE) is:

1	2	3	4	5	6	7
Very artificial	Artificial	Somewhat artificial	Neutral	Somewhat realistic	Realistic	Very realistic

2. My affection after operating the VE is:

1	2	3	4	5	6	7
Very fi-ustrating	Frustrating	Somewhat fi-ustrating	Neutral	Somewhat satisfying	Satisfying	Very satisfying

3. Training in the VE is:

1	2	3	4	5	6	7
Very dull	Dull	Somewhat dull	Neutral	Somewhat stimulating	Stimulating	Very stimulating

Display

4. Wearing on HMD make it easer to interact with VE:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

5. My reaction to using on HMD is:

1	2	3	4	5	6	7
Very sick	sick	Somewhat sick	Neutral	Somewhat comfortable	Comfortable	Very comfortable

Input

6. Using CyberTouch to handle objects in the VE is more natural than using mouse:

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

7. Learning to operate the CyberTouch is:

1	2	3	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	very easy

Learning

8. Straight-forward to perform the given tasks

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

9. Cue information simplifies the task

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

10. Learning to use the system is

1	2	a	4	5	6	7
Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy

APPENDIX F QUESTIONS FOR SHORT-TERM MEMORY

1. What was the **task** you have just completed?

❑ Cooking eggs

❑ Boiling water

❑ Cooking noodles

2. Where were the eggs?

❑ In the pan

❑ Outside the pan

3. How many eggs were on the counter?

❑ 3

0 4

0 5

APPENDIX G AMT SCORE

1. Age	0	1
2. Time (to nearest hour)	0	1
3. Address (for recall at end of test) Say to client: I am going to say an address. Say: 42 West St. can you say that address please? I am going to ask you to repeat it for me in a few minutes.	0	1
4. Year	0	1
5. Name of your home address	0	1
6. Recognition of two persons.	'0	1
7. Date of birth	0	1
8. Year of First World War	0	1
9. Name of present Prime Minister	0	1
10. Count backwards 20-1	0	1
TOTAL SCORE		

Scoring

Each correctly answered question scores 1 point.

Interpretation

Scores of less than 7 indicates likely cognitive impairment

Application

(Re Q **6)** If 2 people are not available then picture cards illustrating commonly identifiable individuals such as police officer and nurse in uniform or a member of the clergy or sportsperson or other commonly recognizable position may be used.

LIST OF ACRONYMS

3 DOF	3 Degrees of Freedom
AD	Alzheimer's Disease
ADL	Activities of Daily Living
AI	Artificial Intelligence
AMT	Abbreviated Mental Test
DOF	Degree of Firing
FOB	Flock of Birds
HCI	Human-computer Interface
HMD	Head-mounted Display
IVRS	Intelligent Virtual Rehabilitation System
OOP	Objected-oriented Programming
SGI	Silicon Graphics Inc.
TBI	Traumatic Brain Injury
VR	Virtual Reality
VE	Virtual Environment
WTM	World Tool Kit