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A Virtual Reality Training System for Helping Disabled Children to Acquire Skills in Activities of Daily Living

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Abstract. Deficiency of hand function presents difficulty to disabled people in various activities of daily living. While rehabilitation training in occupational therapy is helpful for them to cope with their deficiency, the paper presents a virtual realty based system in attempt to provide an alternative approach to complement the conventional methods. The system simulates tasks of daily living in virtual environments and produces real-time interactive graphics and forces to enable trainees to practise the skills in cyberspace. Currently, three tasks are simulated, namely, door opening, water pouring and meat cutting. Visual, audio and haptic cues are produced as guidance in response to user's actions. The performance of the users is recorded automatically on the fly with quantifiable metrics to enable objective analysis of the learning progress. Findings from initial trials with disabled children show that they found it very interesting to use the system and could adapt to the virtual training environment for practicing the tasks. Further study will be conducted to improve system usability and to evaluate the training effectiveness.

Keywords: Virtual reality, activities of daily living, haptic device, force feedback, occupational therapy.

1 Introduction

Deficiencies in hand dexterity present challenges to disabled children in performing various activities of daily living (ADLs). The impairment does not only affect their self-care abilities but could also lead to low self-esteem and other psychological impacts. Special schools for the physically disabled have been providing special education and rehabilitation services to the students. In ADL training, occupational therapists strive to improve the students' self-care abilities and maximize their level of independence.

Conventional ADL training is conducted in real or physically simulated environments through various training modalities [1], including behavioural approach for skill acquisition, neuro-developmental approach, conductive education, constrain-induced movement therapy and biofeedback. However, the training is associated with potential issues concerning safety, logistics, efficiency and cost. Besides, the approaches are not readily customizable for people with different levels of disability, where therapists are required to focus on meeting specific training needs rather than teaching technical strategies [2].

In this regard, we propose to use virtual reality (VR) technology and haptic user interface to complement conventional ADL training, so as to improve the teaching and learning of self-care skills. By leveraging these technologies, ADL training can be conducted in computer-simulated environments which can offer various advantages [3], e.g. flexible and realistic settings in virtual environment, customizability, quantitative assessment, safe training on risk-prone skills and repetitive training.

2 Related Work

The burgeoning VR technologies has found many practical applications in rehabilitation [4, 5]. The applications include hand rehabilitation after stroke [6, 7] and brain lesions [8], manual dexterity assessment [9, 10] and hand-eye coordination training [11], where haptic devices are used to enable users to make use of the sense of touch in the therapy. While providing feedback forces in real time, the haptic devices also make possible real-time quantitative measurement of position and orientation during rehabilitative training [7, 9, 12], thus allowing objective performance evaluation of kinematic and dynamic motor abilities [9, 13].

Nevertheless, VR training systems specifically developed for ADL are relatively scarce, particularly with the use of haptic technology. An early work on VR ADL training is the Virtual Life Skills project, which developed a virtual city involving a house, cafe and transport system [14, 15]. Therapists used the system to teach children with learning difficulty the use of public toilet, for example. An immersive virtual kitchen was also proposed for people with traumatic brain injury (TBI) to learn meal preparation tasks [16]. VR training system simulating a real supermarket was developed to allow patients with TBI to practise the shopping tasks [3], such as exploring the virtual supermarket and picking up goods. However, these applications focused on the training of cognitive abilities. Users only made use of non-intuitive input devices like joystick or mouse as user interface, making it impractical to train the actual manual skills involved. A more recent work employed touch-screen monitor to create a virtual environment simulating the operation of an automated teller machine to train and assess persons with brain injury [17]. Furthermore, with haptic devices, computer-generated force feedback is introduced to provide interactive haptic guidance in handwriting training for children with cerebral palsy [18-21].

3 The Virtual Training System

3.1 System Framework

Given the variety of tasks in ADL training, the design of the proposed VR system adopts a modular design approach where individual training tasks are simulated and developed as separate software modules that can be "plugged" into the system to "play" the specific training task. The hardware components of this system include a computer with keyboard and mouse, an LCD monitor, speakers and most importantly a pair of haptic devices. The software components include a simulation engine, a model database and a user performance database. The system framework is shown schematically in Fig. 1.

With the haptic devices, user can manoeuvre virtual objects with the pen-like stylus while feeling the computer-generated feedback forces in real time through the handle. Furthermore, the pen-like handle is detachable and can be replaced by customized handles mimicking real objects involved in ADLs, e.g. key, jar or knife.

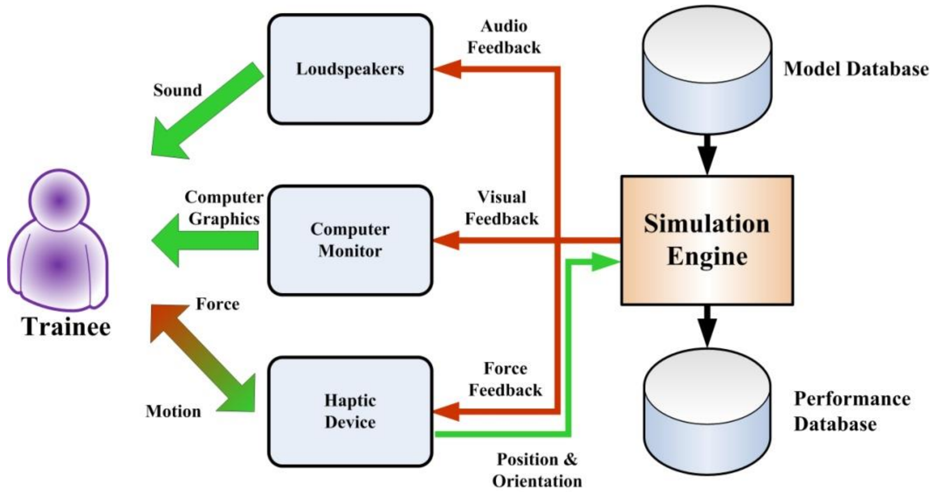

Fig. 1. The system framework.

The *simulation engine* models the interactions between the virtual objects according to the user's input through the haptic device. Based on the input, the engine computes and generates real-time responses in the form of visual, audio and force feedback that are presented to the user via computer monitor, loudspeaker, and the haptic device respectively. In the prototype system, three task modules are developed for the training, namely, Task 1: door opening, Task 2: water pouring, and Task 3: meat cutting. Tasks 1 and 2 involve one-hand operation, while Task 3 requires bimanual coordination.

3.2 User Interface

The proposed system has been implemented with a desktop computer with Intel Core 2 Duo E8500 3.17GHz CPU, 4 GB RAM, and Nvidia GeForce GTX650 display card. The haptic devices employed are the Phantom® Omni® manufactured by the SensAble Technologies Incorporated. The device has 6 degrees-of-freedom input (position and orientation) and 3 degrees-of-freedom output (feedback force). 3D printing technology is adopted to fabricate a key (for Task 1), a jar (for Task 2), a piece of luncheon meat and the handle of a knife (for Task 3), as shown in Fig. 2. These 3D-printed "handles" are attachable to the haptic devices, by which the user can interactively manoeuvre the corresponding virtual objects being rendered visually on the computer monitor.

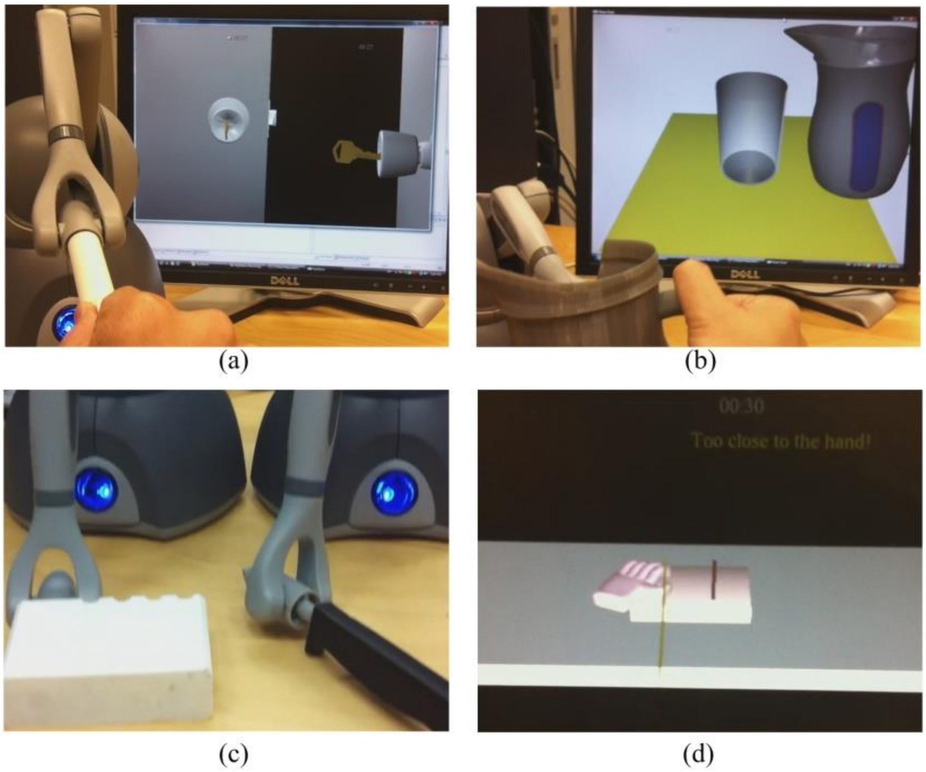

Fig. 2. Haptic-enabled VR simulation of three training tasks: (a) inserting a key into the key hole; (b) pouring water into a glass; (c) 3D-printed "handles" for the meat-cutting tasks, with the white block on the left as the "meat" and the black handle on the right as the knife; (d) visual prompt (top right on the screen) is invoked when the knife (yellow) is too close to the left hand, while a cut should be made along the guideline (red).

3.3 Training Task Simulation

For Task 1, front view and side view of the scene are provided to assist user to determine the relative position of the keyhole and the key in order to facilitate key insertion. Collision detection and response are performed so that user can feel the resistive forces (as haptic cues) when the key is in contact with the door or the door knob. The task is completed after the key is inserted into the key hole and the user turns the key by 90 degrees. Sound clips are also played when the turning of the inserted key is made. The task completion time and the number of collisions are recorded for performance evaluation.

For Task 2, the user holds the handle of the 3D-printed jar to control the position and orientation of the jar and to fill the glass with water. Different audio cues are played when water is poured into the glass and mistakenly spilled on the table surface respectively. The particle system technique commonly used in computer graphics is employed to simulate the pouring water. As real-time interactive fluid simulation is computationally intensive, graphical processing unit (GPU) is used to accelerate the computation [22]. This approach also enables the measurement of the amount water poured into the glass and spilled on the table surface, which serves as a performance indicator in addition to the task completion time.

Task 3 requires bimanual operations and is thus relatively more complicated to perform. To reduce the difficulty, the task is divided into 3 stages where a user is required to complete one stage before progressing into the next. In the first stage, the left hand is used to put the piece of virtual meat on the table surface. The user also needs to press it against the table with a certain amount of force; otherwise visual and audio prompts will be invoked. In the second stage, the user needs to use the right hand to move the edge of the virtual knife over the region where a cut is to be made (highlighted with a red guideline). Visual and audio prompts are invoked when the knife is too close to the left hand (see Fig. 2(d)). In the last stage, the knife is constrained to be moved only along the guideline indicated in the second stage. To complete the task, the user needs move (slide) the virtual knife back and forth horizontally along the straight line for three times (i.e., making a cut at the virtual meat). If the system detects that the extent of knife movement is too small, the cut is not counted and a visual prompt will be displayed accordingly. The number of prompts invoked and the task completion times are recorded as performance indicators. For all the three tasks, the position, trajectory and velocity of haptic device stylus, as well as the contact forces are recorded for performance analysis.

4 Trials

Preliminary trials had been conducted to collect user feedback on the prototype system. Students and occupational therapists of a special school were invited to participate in the trials (see Fig. 3). While some effort was required for the disabled students to adapt to the virtual environments and to develop an association between the input interface (the 3D-printed handles) and the objects in the virtual environment, they found it very interesting to use the VR system to learn ADL skills. The computer-game-like setting is a motivation to the students. Observations from the trials also suggest that the system is suitable for students of mild to moderate disability.

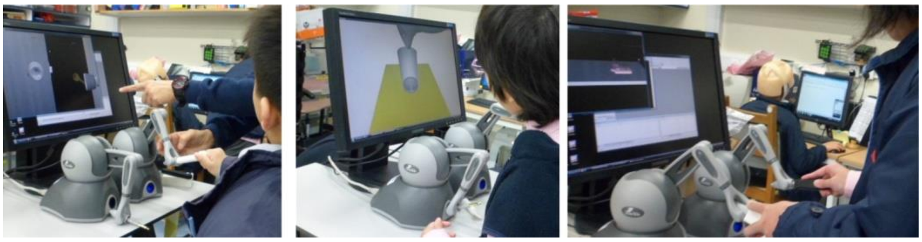

Fig. 3. Preliminary field trials of the virtual ADL training system

5 Discussion

Initial feedback and comments on the proposed VR ADL training system from the occupational therapists and the students are quite positive. While the bimanual operations in Task 3 is relatively difficult, the children were found to be able to adapt to the virtual environments developed for simulating the single-handed tasks Task 1 and Task 2. The children demonstrated the ability to correct their hand movement based on the visual feedback displayed on the screen and the force feedback they perceived via the haptic device, thereby successfully inserting the virtual key into the key hole and pouring water into the virtual glass.

A comprehensive study is being planned to investigate the feasibility of the proposed training system. The purpose of the study is to (1) evaluate the training effectiveness of the system, particularly the effectiveness of the transfer of the skills learned from the virtual world into reality, (2) determine the usability of the system, (3) identify the user groups that can be most benefited from the system, and (4) identify practical issues and rooms for further enhancement in order to make it practical for use as a routine training exercise. A pre-post test design will be adopted where subjects with various degrees of impairment are invited to practise with the VR system repeatedly. Their virtual learning performance will be measured and recorded to analyse the training progress. Before and after the virtual training, the subjects are also required to perform the three ADL in real environments, where their performance will be video-taped and assessed by occupational therapists. The results will be used to determine the training effectiveness of the proposed system.

6 Conclusion

The project is an example of interdisciplinary effort to meet special education needs, demonstrating the synergy of occupation therapy and information technology to benefit disabled children. Through innovative use of VR technology and haptic user interface, a safe, flexible and cost-effective environment is created for disabled children to practise various ADLs. The goal of the project is to produce a practical

VR ADL training system to complement conventional training methods. There are few training systems of this kind. It is anticipated that the proposed system can improve the learning curve of self-care skills and raise the children's self-confidence. In addition, as the system can be used for therapy and assessment, it has the potential to reduce the workload of occupational therapists and special teachers through the automation and convenience offered.

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