Virtual Training Environment Providing Force Feedback for Motoric Improvement of Upper Extremity

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Abstract: We suggest a motor rehabilitation support system for upper extremity with force feedback. A client throws a ball underhanded using a force feedback device, and then the client can receive rehabilitation for an arm’s motion sensing feel of weight. Throwing motion is difficult, so we built training environment that the client can select challenge level that is suitable to his/her ability. Furthermore, the system can indicate movement of arm. We evaluated basic functions of our system. Participants of experiments could throw well by watching an indicator of moving the upper extremity and receiving force feedback.

1. Introduction

According to the survey of Health, Labor and Welfare Ministry in Japan, about 900 thousands people have the impairment in upper extremity \cite{1}. Many equipments and systems have been developed for the effective rehabilitation training for challenged people.

In this study, we propose a motor training support system for upper extremity. Particularly a client can act in the virtual training environment with force feedback. We try to develop a system based on common rehabilitation which a client can train in liminary space.

Some rehabilitation support systems using virtual reality (VR) technology have been studied \cite{2, 3}. Humans have to combine many kinds of motions when they perform or exercise because most actions in daily living consist of a number of movements. Therefore rehabilitation training which clients simultaneously perform a number of movements in the target motion should be undergone as tasks. However it is difficult to perform a task action for people with nerve diseases. In this case, it is effective that divided movements from the target motion combine gradually. In this training method, they can simultaneously perform a number of movements and accomplish the target action. Based on this thinking, developing a system using VR technologies which can change training environments easily is aimed. The training environment enables the client to gradually enlarge the kinds of movements, finally the system enables him/her to perform the target motion.

Furthermore, clients can acquire the target motion through the repeated training which utilizes sensory information received by them, so this training is very effective for acquiring the action containing a number of coordinated motions. Then a force feedback device is introduced to the training support system, and presenting visual and force feedback is attempted. It is expected that the client easily immerses him/herself in the three dimensional virtual training environment by using visual and force interfaces. Therefore the system facilitates the training.

2. Target Motion and Rehabilitation Method

2.1 Target motion and needed exercise of upper extremity

A client moves an upper extremity based on the action of throwing a ball in the training using our system. The client throws a ball underhanded like softball pitchers. This action consists of a number of upper extremity motion mainly based on flexion and extension of shoulder joints and cubital joints.

2.2 Rehabilitation method for upper extremity

Matsumoto has said that the rehabilitation for upper extremity should aim at 1) alleviation of contracture at joints, 2) increasing muscle strength and 3) formation of transmission pathway in motor center \cite{4}. In other words, her method takes steps that at first abnormal movements are reduced, next muscle force is enhanced to properly move, and at last ideal motions are made by repeating target motions by the client himself/herself.

In many cases, the training through the step 1) to 3) is practiced, so Matsumoto’s method is thought of as common rehabilitation training. Her method also focuses to tangible tasks in daily life in many training cases, so it seems to strongly intend application to actual life. In this study, a training menu based on step-by-step system is adopted and we incorporate it in the training using our system.

3. Rehabilitation Support System with Force Feedback

3.1 System overview

System configuration is showed in Figure 1, appearance is showed in Figure 2 and the screen shot is showed in Figure 3. The system consists of the input and output interface, the virtual training environment, the training evaluation module and the intelligent tutoring module (ITS module). We mainly focus on the virtual training environment.

3.1.1 Input and output interface

The input and output interface includes a force feedback device, a mouse device and a part of presenting message. Input by a mouse device is an interface to configure the virtual training environment. Output by the part of presenting message indicates result of the training. A force feedback device is an interface to the virtual training environment. PHANToM Desktop \cite{5} (made by SensAble Technologies, Inc.) is introduced as a force feedback in this system. Introduction of the device aims at reflecting three
dimensional movement of upper extremity to the system and enhancing feel of immersion and training effectiveness.

As VR-based systems using PHANToM, a surgical simulation system [6] and a simulation system of modeling ceramics [7] are built. The aim of these systems is similar to the idea of motion training from a point of skill acquisition, so it is appropriate to use the device as an interface for training of bodily motion through experience.

A client acts target motion holding the force feedback device, and an object is moved based on the client’s motion in the virtual training environment. The device gets data of reaction force following the model of resistance force of projection during the act by the client and generates appropriate force. The client can perceive force feedback from the device.

3. 1. 2 Virtual training environment

The virtual training environment includes training environment building module, PHANToM controller, the control module of VR environment and the part of configuration of training level. The training environment building module can change mass of a ball and training level.

The control module of VR environment consists of the initial speed model, motion model of the object, the model of resistance force of projection and indicator of the position data of PHANToM’s stylus. All models are currently defined only one structure each. Though, changing these models enable to build an unlimited and complex training environment.

3. 2 The step-by-step training system

The training motion by throwing a ball in this system has four levels each a kind of motion and task. In Step 1 (Figure 4) and 2 (Figure 5), a client rolls a ball simplified throwing motion. In Step 3 (Figure 6) and 4 (Figure 7), a client acts ordinarily “throwing” underhanded. The different between “rolling” and “throwing” action is only the direction of flexion and extension of shoulder joints and the measure of flexion and extension of cubital joints. So, these are fundamentally the same throwing action. Additionally, the training tasks are provided for each Step: rolling farther forward in Step 1, rolling/throwing to set direction in Step 2 or 3, throwing to set direction and distance in Step 4. These tasks are based on the common training method as described in preceding chapter, that are 1) alleviation of contracture at joints, 2) increasing muscle strength and 3) formation of transmission pathway in motor center. The relationship between the step-by-step training system in this system and the rehabilitation method for upper extremity purported by Matsumoto [4] is explained in Figure 8.
The effectivity of an interface greatly influences the capability of the overall system. So in this paper, we discuss the effectivity of presenting visual and force feedback as the first step of the evaluation of the overall system.

4. Evaluation of Feedback Function

Evaluation of basic functions of our system is described. The effectivity of an interface greatly influences the capability of the overall system. So in this paper, we discuss the effectivity of presenting visual and force feedback as the first step of the evaluation of the overall system.

4.1 Evaluation I: Effectivity of indication of upper extremity motion

4.1.1 Procedure

Participants were eight university students who were 21 to 27 years old and had no disabilities. In this experiment, two environments of Step 4 which participants threw to set direction and distance were used. One indicated a pointer showing the position of the stylus, the other didn’t indicate. The mass of a ball was set 150 g in both conditions. The stop positions of a ball in all trials were recorded based on the target and its surrounding which was separated into 21 areas. The task performance was evaluated by a number of successes which is meant by stopping a ball at the center row of a target.

4.1.2 Results and discussion

Figure 10 shows a number of successful throwing by each participant in conditions of no-indicating a pointer and indicating a pointer. From p1 to p8 in Figure 10 mean participants of this experiment. Average of the number of successes was 11.5 (SD=3.34) in a condition of no-indicating, 15.1 (SD=3.27) in a condition of indicating. T-test was conducted between the number of successes in two conditions, then the result showed that the number of successes in the condition of indicating was larger (t(14)=2.19, p<.05). Six participants could throw in the central row of the target when a pointer was indicated, and two participants could throw there when a pointer wasn’t indicated. There were small participants and the task performance varied between individuals in this experiment, however, we thought that presentation of a pointer indicating the position of PHANToM’s stylus can assist moving upper extremity forward straight.

4.2 Evaluation II: Effect of influencing throwing action by the volume of reaction force

4.2.1 Procedure

Participants were eight university students who were 21 to
27 years old and had no disabilities. In this experiment, the environment of Step 4 was used. Before experiments, participants rehearsed to adjust to manipulate the system. In trials, participants threw a ball 20 times changing ball’s mass. A conductor instructed participants to throw to the red zone of target in the center. The stop positions of a ball in all trials were recorded based on color-separated areas on the target. Then the task performance was evaluated by the number of throwing onto the target.

4.2.2 Results and Discussion

Figure 11 shows results of participants every mass of a ball, 0 g, 100 g and 300 g. From p1 to p8 in Figure 11 mean participants of this experiment. Averages of success of the task were 6.5 (SD=3.82) in the condition of 0 g, 9.5 (SD=3.89) in the condition of 100 g and 10.9 (SD=1.73) in the condition of 300 g. T-test was conducted between the number of successes in the condition of 0 g and 300 g, then a significant difference was confirmed (t(14)=2.95, p<.05). A significant difference by t-test between in the condition of 0 g and 100 g wasn’t confirmed (t(14)=1.56, n.s.), however, the number of successes when the mass was 100 g had a tendency to be larger than when the mass was 0 g. Hence, we think that the system with force feedback, that is when the mass is 100 g or 300 g in this experiment, enables the client to throw easily.

5. Conclusion and Future Works

A motor rehabilitation environment using VR technologies for upper extremity by throwing a ball with force feedback was proposed and the effectivity of its force feedback function was considered in this study. A client can train the movement of upper extremity while he/she perceives feel of weight using the system. Throwing action is rather difficult for physically challenged people because it needs many kinds of upper extremity movement. So, we divided the action into four motions and built an environment which enabled challenged people to select a training step of his/her choice. Additionally, the motion of upper extremity was indicated to assist accomplishing target motion. In assessments of the feedback functions, we found that the client can act throwing very well by watching a pointer. And we also found that the client can throw very well easily by feeling sense of force feedback. Therefore we found that these feedback functions are effective for throwing tasks in the system.

Future works are measuring muscle function during the use of the system and making actually disabled people to use the system. We will bear out the effectiveness of our system for motor rehabilitation for upper extremity.

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References