Virtual Motor Learning Environment with Function of Presenting Force Feedback for Speedy Motion

Atsushi Kanbe, Yukihiro Matsubara
Graduate School of Information Sciences, Hiroshima City University, JAPAN
kanbe@lake.its.hiroshima-cu.ac.jp

Abstract: A motor learning support system for speedy motion of an upper extremity is proposed. A learner throws a ball underhanded using a force feedback device, and then the learner can perform the motion feeling ball's weight. Throwing motion is speedy and complicate, so we built a training environment that the learner can select challenge level that is suitable to learner's ability. Furthermore, the system can indicate movement of arm. We evaluated visual and force feedback functions of our system. Participants of experiments could throw well by watching an indicator of moving the upper extremity and feeling force feedback.

Keywords: Motor learning, Virtual environment, Force feedback, Speedy motion of upper extremity

Introduction

Human has high levels of motor skills. However, a lot of training is needed to accurately perform complicate and/or speedy motions.

To perform actions properly, human repeats acting a target motion after he/she has an image of the motion. Then, human finds difference between an image of the target motion and the trial, i.e. error. In next trial, human attempts to modify the motion based on the error. Hence, it is expected that making a learner understand errors leads to encouraging learning.

In previous studies, a 3D-display motor learning system for the observation of motion[1] and a movement instruction system using virtual environment[2] have been proposed. The system of [1] using VRML enables learner to watch the objective motion changing a viewpoint freely, and the system of [2] can superimpose a model motion on a learner's motion and observe.

Meanwhile, human often performs holding an object in his/her hand. On this occasion, human is forced to receive the gravity of the object or centrifugal force related object's movement when human performs something to act such as holding or moving. If human have to accurately perform with weight on his/her hand, it is important to learn not only the visual accuracy of movements but also the accuracy of dynamic load in the movements. Furthermore the feed-forward control which human programs needed movements for the target motion is needed to perform speedy motion, so feedback information sensed by human's body directly is also important. It is expected that the training with force feedback for development of speedy motion enables to effectively instruct in the development of motor scheme.

In this study, feedback from a virtual training environment is improved by presenting force as well as visual information. This leads to enhance the development of sensorial part of motor scheme and support the acquirement of accurate motion in motor learning.

A learner starts training from an easy motion included basic movements in our system. After difficulty of training is gradually increased, finally the learner can perform the target motion. Then the weight applied to learner's hand is changed. This enables to develop learner's motor scheme. Furthermore the system presents upper extremity's motion of learner to watch the movement of a hand as previous systems. Thus it is expected that motor learning for the weight-applied motion on learner's hand is improved.

1. Method of Motor Learning

1.1 Motor Learning Utilizing Feedbacks

When human acts any motion, some feedbacks are returned for the exerted motion shown in Figure 1. Human receives intrinsic feedbacks which are information about the volume of muscle power, the distance of muscle contraction, the change of joints and body parts position and the change of motion environment, through his/her sensoria.

Motor learning for speedy motions is typically implemented by repeating to perform the target motion. Then a learner considers how the trial differs from a correct motion referring to gotten feedback information. The error is modified, then the motor learning is proceeded[3].

Additionally, haptic information has also been identified as a significant signal for improving a human's performance in more difficult tasks [4]. Presenting force feedback enables to perform with sense resembled real one. Therefore more effective training can be realized.

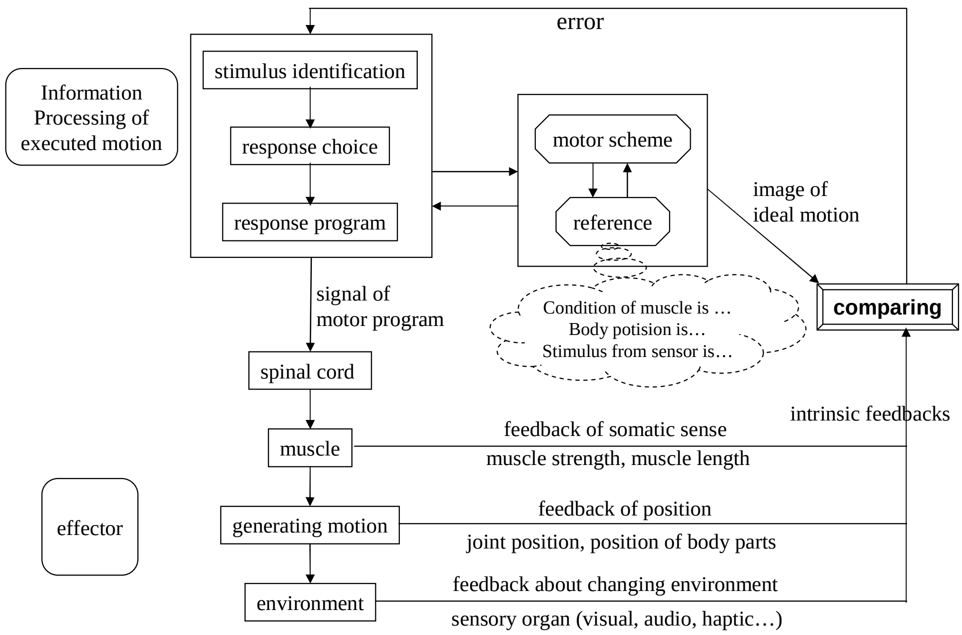

Figure 1 Motor learning utilizing sensory and kinesthetic feedbacks (effect change from reference [3])

1.2 Becoming an Increasing Difficulty

Providing micro world which becomes an increasing complication gradually is effective for learning for difficult skills [5]. The task becomes increasing difficulties, so opportunities to become aware of the error allowed in previous world and improve it are offered.

In this study, a training menu based on *step-by-step* is adopted and we incorporate it in the training using our system.

2. Motor Learning Support System with Force Feedback

2.1 Target motion

A learner moves an upper extremity based on the action of throwing a ball in the training using our system. The learner throws a ball underhanded like a softball pitcher.

Throwing is a speedier motion. Ordinary people cannot simultaneously perform the motion and modify it. They just perform according to a previously programmed motion in their brain. Moreover upper extremity movements in the training using the system are eight kinds of movement, such as flexion and extension of shoulder joints, flexion and extension of cubital joints, supination and pronation of forearms and others. These movements must be often generated at the same time.

2.2 System Overview

System configuration is showed in Figure 2, appearance is showed in Figure 3 and the screen shot is showed in Figure 4. The system consists of the input and output interface, the virtual training environment, the training evaluation module and the ITS module. We mainly focus on the virtual training environment.

2.2.1 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 traini-

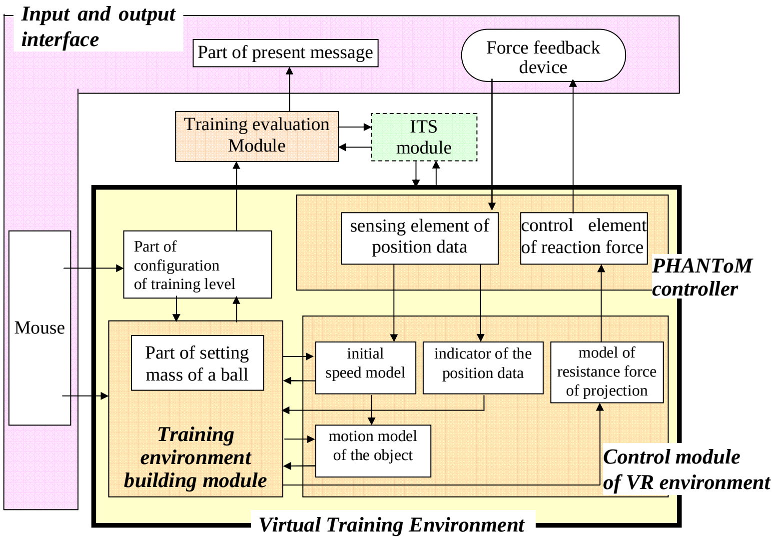

Figure 2 System Configuration

Figure 3 Appearance of a system

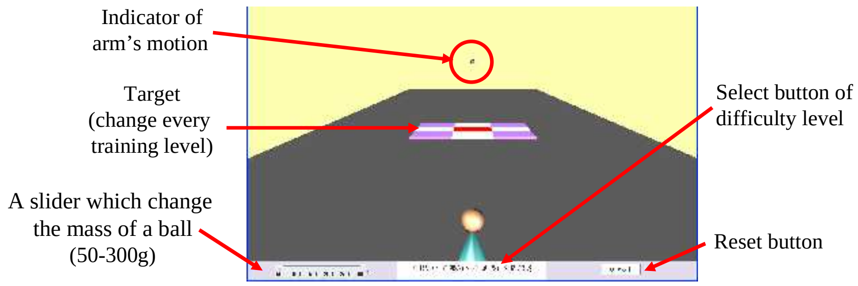

Figure 4 Screen shot (Step 4)

ng. A force feedback device is an interface to the virtual training environment.

PHANToM Desktop [6] (made by SensAble Technologies, Inc.) is introduced as a force feedback device 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, there are learning support systems focusing on experience [7][8]. And, a surgical simulation system [9] and a simulation system of modeling ceramics [10] are also 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 learner acts target motion holding the force feedback device, and an object is moved based on the learner'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 learner and generates appropriate force. The learner can perceive force feedback from the device.

2.2.2 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 as only one structure each. Though, modifying these models enable to build an unlimited and complex training environment.

(1) the initial speed model

This model calculates initial speed of the virtual object. Not only initial speed of horizontal, vertical and cross direction of the learner's view but also the initial speed of motion of PHANToM stylus at the moment of throwing are calculated in accordance with motion freedom of PHANToM.

(2) the motion model of the object

This model calculates the motion of a virtual object. This model calculates three dimensional motion of the object.

This model differs depending on each training level. In the Step 1 that a learner roll a ball forward, the object's motion is expressed by calculating velocity of z-axis and frictional force by the ground. Although a ball is also rolled in the Step 2, the object's motion of not only cross displacement but also horizontal displacement is expressed based on initial speed of x-axis and z-axis. In the Step 3 and 4, the object is thrown in the three dimensional environment, so its motion is expressed based on dynamic movement model about projection.

(3) the model of resistance force of projection

This model calculates the force applying to PHANToM to reproduce reaction force while throwing. We determine that reaction force when the learner throws a ball applies *m* gram of the same force (*m* means value of mass of the object).

2.2.3 The Training Evaluation Module

The training evaluation module evaluates training results. This module evaluates based on stop position of the object.

2.3 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 5) and 2 (Figure 6), a learner rolls a ball simplified throwing motion. In Step 3 (Figure 7) and 4 (Figure 8), a learner 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.

Setting training levels enables a learner to select a degree of difficulty. Kinds of motion are limited needed motion by setting levels in each Step. That is to say the motion which the learner isn't good at by comparing needed motions of upper extremity in each Step.

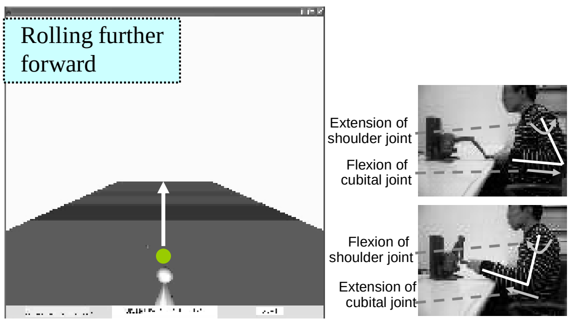

Figure 5 Training on Step 1

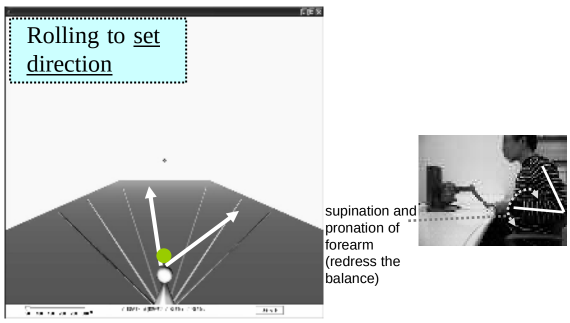

Figure 6 Training on Step 2

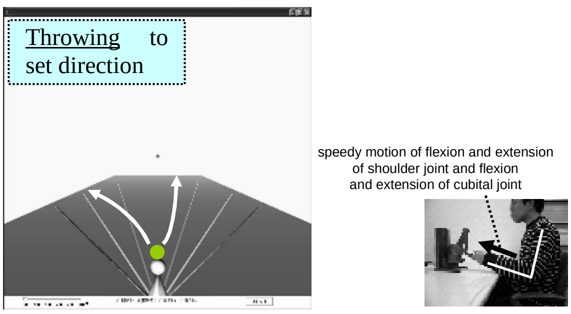

Figure 7 Training on Step 3

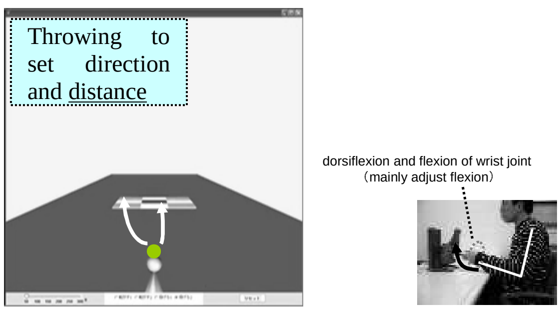

Figure 8 Training on Step 4

2.4 Indication of Upper Extremity Motion

Movement of upper extremity is displayed based on coordinate values of x and z of the PHANToM's stylus. By using this function, the learner can watch the planar movement of upper extremity on a display screen. The situation is shown in Figure 9. When a learner pulls back an arm, a pointer on the screen moves in front of an avatar. And when a learner extends forward an arm, a pointer goes back of the virtual environment. The pointer also moves to horizontal direction in response to learner's motion.

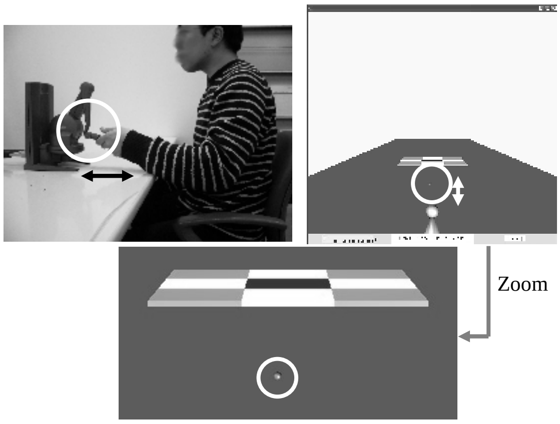

Figure 9 Indication of upper extremity's movement

3. 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.

3.1 Evaluation I: Effectivity of Indication of Upper Extremity Motion

3.1.1 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 gram in both conditions.

Before experiments, participants rehearsed in the environment indicating a pointer for ten minutes to adjust to manipulate the system. In trials, 1) participants threw 20 times in the environment no-indicating pointer at first, and next, 2) they threw 20 times in the environment indicating pointer. The reason that the experiment order was fixed is that fundamental functions of the system were assessed in these evaluations. A conductor instructed participants to throw to the red zone of target in the center. Furthermore in the condition 2), a conductor told participants that movement of a pointer matched to the movement of the learner's upper extremity and it was easy to throw checking the pointer.

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.

3.1.2 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 were 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 was not 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.

3.2 Evaluation II: Effect of Influencing Throwing Action by the Volume of Reaction Force

3.2.1 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 which participants threw to set direction and distance were used. Before experiments, participants rehearsed to adjust to manipulate the system. In trials, participants threw a ball 20 times changing ball's mass. The order of experiments was 1) 0 gram of the mass (that is no reaction force), 2) 100 gram and 3) 300 gram. 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.

3.2.2 Results and Discussion

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

Conclusion and Future Works

A motor learning support system for throwing a ball with force feedback was proposed and the effectivity of force feedback function of the system was considered. A learner can train the movement of upper extremity while he/she perceives feel of weight using the system. Throwing motion is rather difficult because the motion is very speedy and 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.

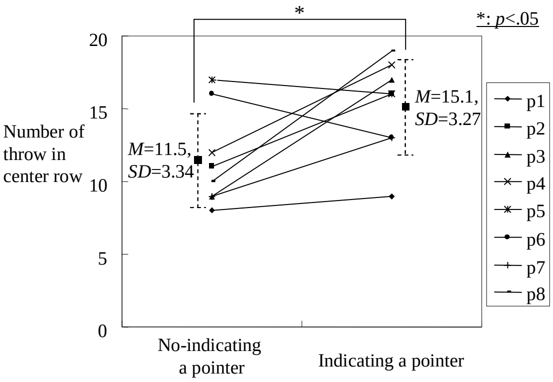

Figure 10 Number of successful throwing on Experience I

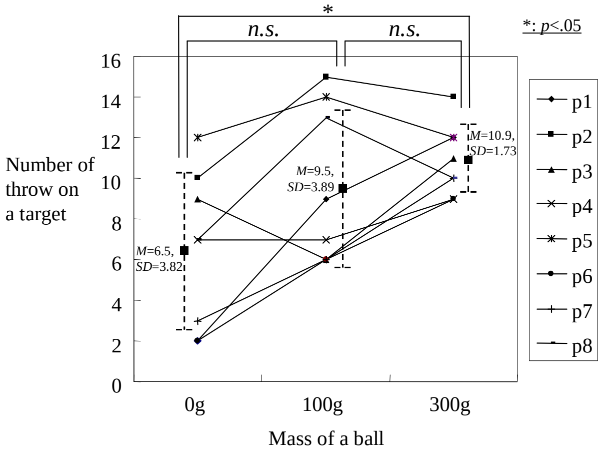

Figure 11 Number of successful throwing on Experience II

Additionally, the motion of upper extremity was indicated to assist accomplishing target motion. In assessment of the feedback functions, we found that the learner can act throwing very well by watching a pointer. And we also found that the learner can throw very well easily by feeling sense of force feedback.

Future works are measuring muscle function during the use of the system and examining the effectiveness for motor learning by using the system.

This research has been made possible through Grant-in-aid for Scientific Research C (No.18500721) from the Ministry of Education, Culture, Sports, Science and technology of Japan.

References

[1] Okamoto, A., Sakurai, S., Ikegami, Y., & Yasuda, T. (2001). Development of 3D-display System for Motor Learning by VRML. *Proceedings of the Virtual Reality Society of Japan, Social Science Computing Review*, *6*, 31-34 (in Japanese).

[2] Hatakeyama, J., Murakoshi, H., Yamaguchi, T., Ishijima, S., & Harashima, F. (2004). A Movement Instruction System Using Virtual Environment. *Journal of Japan e-Learning Association*, *6*, 20-26 (in Japanese).

[3] Schmidt, R. A. (1991). *Motor Learning and Performance: From Principles to Practice.* Champaign, Illinois: Human Kinetics Publishers.

[4] Sveistrup, H. (2004). Motor Rehabilitation Using Virtual Reality. *Journal of NeuroEngineering and Rehabilitation*, *1*(10), 1-8.

[5] Burton, R.R., Brown, J.S., & Fischer, G. (1984). *Skiing as a Model of Instruction, Everyday Cognition: Its Development in Social Context.* Cambridge, Massachusetts: Harvard University Press.

[6] Massie, T. H., & Salisbury, J. K. (1994) The PHANToM Haptic Interface: A Device for Probing Virtual Objects. *Proceedings of the ASME Winter Annual Meeting*, *DSC-55-1*, 295-300.

[7] Kanbe, A., Matsubara, Y., Iwane, N., & Hirayama, K. (2006) Developing a VR-based Projectile System Using Haptic Device for Learning Physics. In Mizoguchi, R., Dillenbourg, P., & Zhu, Z. (Eds), *Learning by Effective Utilization of Technologies: Facilitating Intercultural Understanding*, (pp. 275-282). Amsterdam, Netherlands: IOS Press.

[8] Inoue, M., Matsubara, Y., Iwane, N., Nakamura, M., & Ichitsubo, M. (2005) VR-Based Dynamics Learning System Using Haptic Device and its Evaluation. *Proceedings of ICALT '05*, 917-921, Los Alamitos, California: IEEE Computer Society Press.

[9] Mukai, N. (2002) Surgical Simulation System. *Information Processing*, *43*(5), 513-518 (in Japanese).

[10] Horii, H., & Horiguchi, S. (2002) A Construction of Shared 3D Modeling System for Ceramics with Virtual Haptic. *The Journal of Information and Systems in Education*, *19*(2), 89-98 (in Japanese).