Development of an Upper Limb Patient Simulator for Physical Therapy Exercise

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Abstract—Physical therapist plays an important role to help people to regain the social life from disease and physical handicap. However, they can obtain their skills only from their practical experiences. The physical therapist trainee can enrich his experience only from the clinical practical training and this opportunity is limited. Therefore, we have been developing the upper limb patient simulator, which reproduces the stiffness of elbow joint to allow trainees to increase the opportunities to obtain the practical exercise of the physical therapy. The system reproduces the diseases by generating stiffness of the elbow joint, when the trainee tries to flex the elbow joint of the patient. We developed a mechanical part and a control system to realize the patient conditions and the full system has been evaluated by veteran physical therapists.

Keywords; patient simulator, physical therapy, training

I. INTRODUCTION

The physiotherapy plays an important role to allow patients to resume their social life from disease and physical handicap. To obtain skills in physiotherapy, practical training is required; furthermore it requires the cooperation of the patients. Unfortunately there are not enough opportunities to do training. In the training courses of physiotherapy in Japan, the trainee normally practices with healthy persons who play the role of patient. However, actual symptoms like tension of muscle cannot be sensed from this kind of training. In the field of medical, there exist training machines and haptic devices that uses the technology of virtual reality to earn the experience [1][2]. However, training machines for the rehabilitation rarely exist. Therefore, it is important to develop a patient simulator with whom the trainees of physiotherapy can earn experience without the need of patients.

We have been developing the upper limb patient simulator for the training of physiotherapists who can train iteratively. In this paper, we describe a mechanical design of simulator which has same motion of human arm and reproduce the stiffness of Spasticity that is often seen in patients who received strokes and with paralyzed shoulder. In addition, we evaluated the reproducibility of the stiffness with our system.

II. UPPER LIMB PATIENT SIMULATOR

2.1 Concept

The patient simulator imitates the real human body. It is supposed to be used to train the act of treatment. There exist patient simulators for the injection, the suture, the diagnosis etc. Most of these systems are designed for simulate single symptoms. There exist simulator for nursing training of senior people [3]. However, this system emulates the human body. Therefore, it cannot be used for the simulation of rehabilitation. We have been developing the patient simulator which aim is to reproduce the symptoms of Spasticity with a simple mechanism of one degree of freedom.

2.2 Mechanism of the patient simulator

Fig.1 shows the mechanical part of upper limb patient simulator. Fig.2 shows an enlarged view of elbow joint. This system simulates from the fingers to the shoulder region. In the actual rehabilitation, physiotherapist takes various postures according to the posture of the patient: sitting down or lying on the bed. To perform physical therapy in the practical rehabilitation, the physiotherapist supports the upper arm with one hand from the bottom and supports the forearm with the other hand, to flex the elbow joint of patient, and then to the muscle and prevent disease. To allow this kind of motion with the system, a cantilever mechanism is introduced in the shoulder part. The rotation of the actuator is transmitted from the elbow joint part to the shoulder joint part, with a timing belt and a pulley mechanism. The size of the device is similar to the mean of human body size, defined in the database [4]. The length of the upper arm and the forearm can be adjusted from the outside. In this simulator, the forearm of an real person is imitated. It is composed by two shafts and moves on
an oval orbit. This imitates two bones and movements of the forearm of a real person. Moreover, the movement of the forearm pronation and supination is reproduced. These are reproduced with the parts shown in Fig.3. The cam is made with an oval shape, the follower, fixed to the forearm, operates parallel to the cam, and the forearm moves along the oval orbit. Spherical bearing is used to reproduce the forearm pronation and supination. The angle between the upper arm and the floor, which is based on the plane parallel to the floor, can be adjusted in the range of about 90 [deg]. The greatest extension (0[deg]) is observed when the upper arm and the forearm are making a straight line. Moreover, maximum angle of extension is 140[deg]. The imitation skin, to decrease sense of incongruity of the visual appearance, covers the device.

2.3 System configuration

The upper limb simulator consists of a shoulder, a harmonic drive, a MR brake and a DC servomotor. The force exerted by the operator is measured by the strain gauge located in the medium of the forearm and a rotary encoder measures the rotation angle of the elbow joint. The force is displayed by the MR brake and the DC servomotor. MR brake gives the resistance against the rotation of the elbow joint, it can display viscosity. In case of displaying force of active symptom, the DC servomotor is used simultaneously.

![Fig.1 Upper limb patient simulator](image1)

![Fig.2 Enlarged view of the elbow joint](image2)

III. REPRODUCTION OF SYMPTOM

3.1 KIND OF SYMPTOM

The kind of muscle diseases in the upper limb, which requires rehabilitation, are: Spasticity, Rigidity, and Contracture. We focused on the symptoms of Spasticity and Rigidity.

Spasticity is the disease characterized by the symptom of feeling resistance in the joint, when the patient tries to move. About Rigidity, there are two kinds of it: Lead-pipe Rigidity and Cogwheel Rigidity. Lead-pipe Rigidity is a disease whose symptoms are an almost constant resistance in opposition to the elbow joint movements. Cogwheel Rigidity symptom is a repeated intermittent resistance to the rotation of the cogwheel when the elbow joint is moved.

These diseases occur when the patient has damages in central nerve system, or receiving stimulus from outside with some deficiency, or by receiving physical and mental stress. Ashworth Scale is one of the evaluation methods for these diseases, which is based on the subjective appraisal of physiotherapist. Therefore, a quantification method for these diseases is under studied [5]. The model for these muscle diseases in general way is hard to build, since the symptoms of the diseases are different individually and because of the differences in the subjectivity of the therapists. Therefore, we are trying to develop an application which the physiotherapist can reconfigure to consider the various symptoms of these diseases. In this paper, we focused on the symptoms of Spasticity and Rigidity, which are strong resistance felt when the extension is started and that reduce and become weak.

3.2 Symptoms simulated by physical therapist

To reproduce the symptom of Spasticity and Rigidity, it is important to measure the property of disease. Two expert physiotherapists play one the role of patient with disease and one the role of the physiotherapist (Fig.3). The symptoms of Spasticity and Rigidity are simulated by one expert physiotherapist playing the role of patient. The other physiotherapist performs the rehabilitation to the simulated patient. The force exerted on the patient is measured by a load cell. To measure the joint angles, markers are attached to elbow, shoulder and wrist of the patient and also to the hand of the physical therapist. All the rehabilitation sequence is video recorded. After the experiment is finished, the movie is analyzed with FrameDIAS to estimate the joint angle of the elbow and the moments that the physical therapist gives. Fig.4 indicates the measured moments and elbow joint angles throughout time of the experiment (Cogwheel Rigidity). At the beginning of winding motion, big force is measured and, as the elbow joint is extended the force given to the patient is gradually reduced. The relationship extract from this experiment is used to reproduce the symptoms of Spasticity and Rigidity.
3.3 Means of expression

The severity of symptoms was assumed to be of three kinds: slight, medium, serious. When the progress of the elbow joint begins, the output which represents the Spasticity resistance are evaluated, and they differ depending on the severity of the symptoms, and they are constant with the MR brake. Afterwards, it was detected that the angle of the elbow joint became 100[deg] by exercising the torque in the direction where progress was assisted by the motor. To obtain the maximum value, when the joint angle becomes 40[deg], the assisted torque has been constantly increased.

When the progress of the elbow joint began, the Lead-pipe Rigidity was expressed by outputting resistance values which differed even only in the end, depending on the severity of symptoms, and was constant with the MR brake at time.

When the progress of the elbow joint began, the Cogwheel Rigidity was expressed outputting the resistance that decreases in different ways, depending on the severity of symptoms, and constantly to the end with the MR brake at time. In this case, it was expressed by repeating time, when the torque was output in the direction where progress was assisted, and the time not done whenever advancing it of 2[deg] by the motor. The assisted torque was assumed to be the same for the three kinds of severity of symptoms.

IV. EXPERIMENTS

4.1 Motivation and method

Spasticity, Lead-pipe Rigidity and Cogwheel Rigidity for which the severity of symptoms is different were treated using the simulator. The system was evaluated by two expert physiotherapists whom used the simulator, and measuring the moment around the elbow joint and the angle of it.

The progress operation is done with an experimental methodology with the forearm at the position at 200[mm] from the elbow joint of the simulator, held by the therapist. In this case, the torque added to the forearm of the simulator was measured with the strain gauge, and the angle of the elbow joint was measured with the encoder.

4.2 Result and discussion

The symptoms of the Cogwheel Rigidity is shown in Fig.5 as one example of the results. In Fig.5, when the progress of the elbow joint start the moment became maximum. Afterwards, the change represents an increase and a decrease repeatedly in the moment when the elbow joint progress is confirmed. It looks higher amplitude and frequency than the result of Fig.4, the therapist feels similar symptoms of the patient.

Fig.6 shows an experimental result of Spasticity We can see the system generates and keeps high resistance until the elbow angle comes about 100 degree and decrease the resistance according to the elbow angle. This result shows the symptoms of Spasticity.

Fig.7 shows an experimental result of Lead-pipe Rigidity. The system generates constant resistance from start to the end of the elbow rotation, it is really Lead-pipe Rigidity.

We obtained a good evaluation from the therapist who had actually operated the rehabilitation in medium and slight. I think that this is because it was possible to tell sense which resistance peg out, almost constant resistance and change that moment repeats an increase and a decrease to the therapist clearly. Moreover, the severity of symptoms of Spasticity, Lead-pipe Rigidity and Cogwheel Rigidity obtained the evaluation that the expression of serious didn’t look like was obtained. I think that is because of not being expressed for a muscular viscous elasticity. Moreover, I think that it is a cause that there is a sense of incompatibility in the expression which resistance by the motor peg out. As this solution, the output to the motor is adjusted and the viscous elasticity is expressed. Moreover, I think that I can solve it by making the model expressed by a MR brake and a DC servomotor a Voigt model. The evaluation of this system shows that it can be used for
training of physiotherapy students, and the study of the symptom of various diseases is possible.

However, the sense of the viscous elasticity that the muscle and the tendon expand, not revealed by the actual system, will be necessary for expert physiotherapist who might want to use the system.

V. CONCLUSION

The upper limb patient simulator which imitates the actual person forearm to train the skills of physical therapist is developed. Reproduction of Spasticity, Lead-pipe Rigidity and Cogwheel Rigidity with the system using both MR brake and DC servomotor is evaluated. It was achieved a good evaluation of reproduction of the medium and slight movements from therapists.

Consideration of the models for Spasticity, Lead-pipe Rigidity and Cogwheel Rigidity is next step to evaluate and increase usability of our system. Moreover, a simulation mechanism of biceps brachii muscle will be added to the system to increase more reality in touching.

REFERENCES


