Development of a training machine for elderly people with muscle activity sensor

Sung Jae Yoon*, Seok-Hwan Kim*, Motohiro Tanaka*, Shunji Moromugi*,
Yasuhiko Ohgiya*, Nobuou Matsuzaka** and Takakazu Ishimatsu*

*Department of Mechanical Systems Engineering, Nagasaki University, Nagasaki, Japan
(Tel : +81-95-819-2508; E-mail: ishi@net.nagasaki-u.ac.jp)
**Department of Physical therapy, Nagasaki University, Nagasaki, Japan Engineering, Japan

Abstract

An advanced training machine that can adjust load according to muscle activity is proposed for elderly people. The training machine allows users to have a safe and effective training through exercise close to ordinal motion appears in daily life such as stretching or stooping motion. The activation level of user's muscle is real timely monitored by a muscle activity sensor during the exercise and the training load is adjusted based on the data measured. The training load is exerted and continuously controlled by actuation of an electronic motor.

Keywords: Machine training, Elderly people, Preventive approach, Load control, Muscle activity sensor

1. INTRODUCTION

The welfare issues accompanying by the aging of society are highly concerned in most of the advanced countries. It is strongly hoped that the government provides adequate care and accommodation to people when they become old. However, it is extremely difficult to support all the people perfectly because each aged person needs different care. In addition to the fact, it costs huge and needs many hands to achieve it. Under this situation in Japan, that is one of the most aged society, the government started to focus on the approach to reduce the number of aged people who need nursing care more than to offer perfect caring system for them. The government promotes aged people to maintain enough strength to keep their independent life and allocate budgets for activities to promote the preventive approach against becoming bedridden status. The importance of the preventive approach is currently being recognized among other aging countries as well.

As one of the effective preventive approaches the physical training using machines is recommended. It is reported that the constant physical training is highly effective for aged people to maintain their strength and quality of life. Some care center introduced machine training in their program. However, there are several problems. One is that those machines are designed for sports training not for training of elderly people therefore users cannot use the machines comfortably in some cases. The other is that the exercise required in the machine training is too hard for those aged people. That could be a reason to keep aged people away from the machine training. The third is that too much machine training might cause damage in user's body, therefore it is hard to ensure the safety in the training because aged the people's body is somewhat weakened. Thus the training machine that is designed for elderly people is needed. It should be enough safe and comfortable to use for aged people and also have high adaptability for wide range of the size and ability of aged people.

In this paper we propose a training machine for the elderly people. The machine is developed by introducing power assisting technology.

2. FEATURES OF THE TRAINING MACHINE PROPOSED

An advanced training machine is proposed for keeping elderly people healthy and energetic so that they can keep living an independent life. The training machine let user to work on an exercise to maintain/recover physical abilities to support their body against the gravity. We focus on the leg strength because the ability to support their body or to stand up by themselves is very important both for aged people to keep their quality of life high and for care worker's to care their patients with less energy. This training machine has three major futures as follows.

1) Leg pressing exercise

Usually sports training machines are designed to develop specific muscles through a simple exercise such as knee flexion, elbow extension and twist of main body. It is effective for sports players to shape their body as they desire. However, for elderly people, those machines are not always comfortable because the purpose of the training is different from that of athletes. It is not for strengthening their muscles to compete against other players but maintaining or recovering their physical function to do everyday movements such as stretching or stooping of leg. The training machine proposed in this study is specially designed for aged people to train stretching and stooping ability. By using this training machine users can enforce their strength of both legs through leg pressing exercise. In addition to the physical training effect, it also works for recovering sense of body motion or strong desire to support their own body by themselves.

2) Adjust load with electronic actuator

Training load is generated by weights in the case of most of conventional training machine. Users select preferable load level before the exercise and train under the constant load through the exercise. The proposed training machine uses an electronic actuator. Therefore the training load can be continuously adjusted during the exercise.

3) Feed back of muscle activity on load control

In the elderly training safety issue needs to be considered carefully more than the case of sports training. Different from the sound body of young athletes elderly people's body is generally remarkably weakened. The proposed system monitors the activation level of user's muscles and output force of the leg. It is possible to select optimum load simultaneously and achieve effective and safe training for elderly people.

3. MECHANICAL SYSTEM CONFIGURATION

Figure 1 shows the proposed system. The system is composed of a moving seat, an electronic actuator, step force sensor, muscle stiffness sensor to detect user's muscle activation level, and a PC & FPGA based controller.

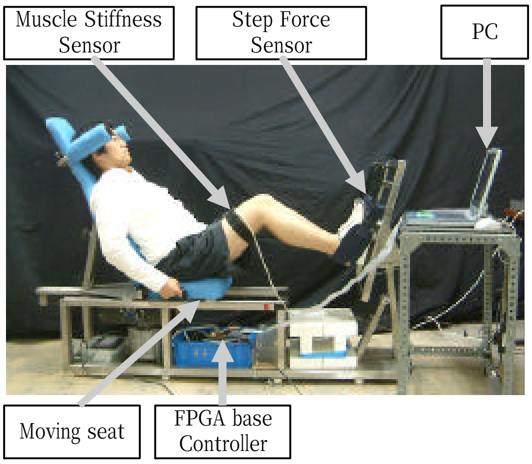
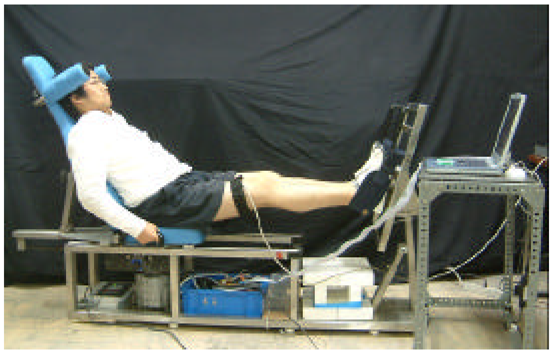


Figure 1 Overview of the system

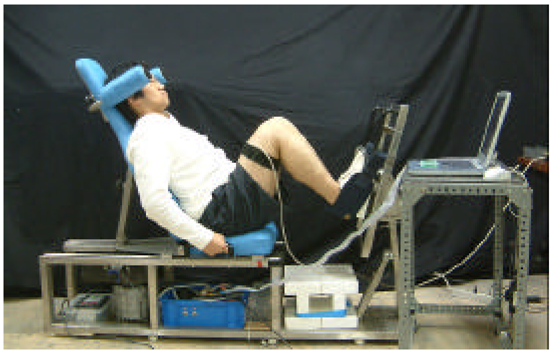
3.1 Moving Seat

While the target of the custom sports training machine is to support user to strengthen his muscle, the target of the proposed training machine system is to support user to maintain his physical ability. In this point, the moving seat is designed to provide user to stretch and to stoop with easy due to the electronic actuator. Basically user's weight is supported by moving seat so that user can exercise without exerting all his weight to leg. So, by just setting the reference load according to one's physical ability, user can enjoy exercise with the proposed system.

Figure 2 shows two status of the system. During the stretching motion, user has to stretch his leg against the pre-defined load generated by the actuator. And during the stooping motion, user does not have to strengthen his leg, just enjoys stooping motion against a light pre-defined load actuated by the motor.



(a) Stretch



(b) Stoop

Figure 2 Two states of leg pressing exercise

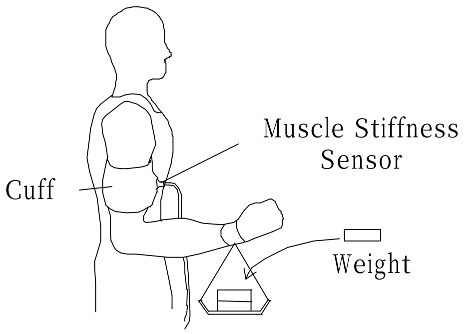
Table 1 Major specification of motor

Model	Honda DDW 2020 L size
Voltage	24 V
No load Maximum rpm	65 rpm
Rated rpm	40 rpm
Rated torque	52 Nm

3.2 Human Machine Interface

Figure 3 Muscle Stiffness Sensor

To detect user intentions of stretching, stooping and controlling the speed, the proposed system adapts two kinds of sensors, one is a stepping force sensor and the other is a muscle stiffness sensor. The step force sensor is used to detect the force between stepping force to the foot plate and the load that is generated by an electronic actuator. With this sensor, the proposed system controls the load on the foot plate in real time base. Figure 3 shows the muscle stiffness sensor. The muscle stiffness sensor is attached to thigh and detects muscle activity as stiffness parameter that shows high similarity with EMG sensor. It is developed as man-machine interface for the power-assisting system. It was confirmed that there was high correlation between the data obtained from this muscle stiffness sensor and the activity level of the muscle through author’s studies. Figure 4 shows change of stiffness parameter according to muscle activity change. The detail of this muscle stiffness sensor is described in [1]-[3]. One advantage of this sensor is that it is easy to put on/off from the body. The other advantage is its high robustness on measurement against the disturbing contacting force from outside. By using this sensor user can work on the training comfortably and safely with this training machine.



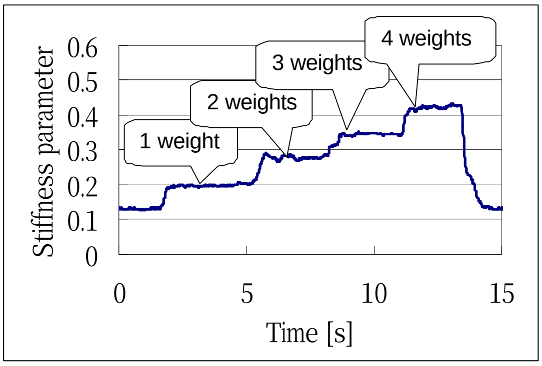


Figure 4. Stiffness parameter versus Muscle activation

3.5 PC & FPGA based Controller

As the controller, PC and FPGA (Flexibly Programmable Gate Allay) based control circuit are adapted. PC interfaces with the user to set up the target load and notices the present state to user. FPGA based control circuit is used to archive position data, muscle stiffness parameter, and stepping force signal through A/D converter, and send control command to the actuator through D/A converter. Figure 5 shows the configuration of the control system.

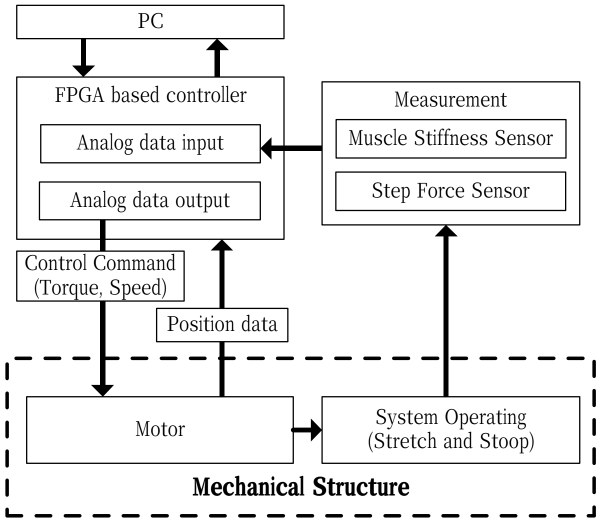


Figure 5 Configuration of a control system

Figure 6 shows the computer screen that is used to set up the reference force and moving distance based on each user, and displays present state during the training. With this program, each user’s training data can be classified and analyzed for the better management.

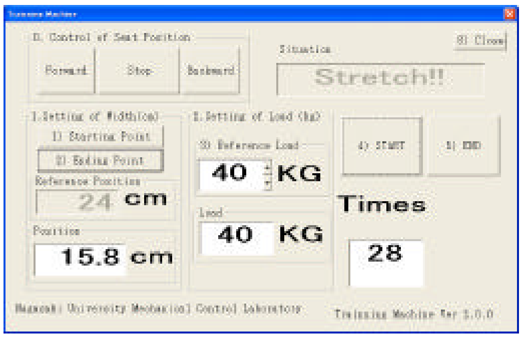


Figure 6 Interface display

4. EXPERIMENT

Experiment is conducted to verify the effectiveness of the proposed training machine system. In this experiment, muscle stiffness sensor is used to detect muscle activity and to trigger stretching or stooping motion. During the training, even if the stepping force is changed, the load to leg is controlled to maintain the reference value. Four kinds of load are tested to evaluate the controllability of the proposed system and its HMI.

Because the proposed training machine adapted the electronic actuator, it can impose load to both stretching and stooping motion. But in this experiment, the load is imposed to only stretching motion, and the actuator executes stooping motion automatically, so that user can enjoy the leg pressing exercise.

Through the experiment, it can be verified whether the system can control the load to leg, the stepping force, in real-time base. Muscle stiffness sensor can be used as human-machine interface that detects muscle activity.

4.1 Control algorithm

Simple control algorithm is adapted for the proposed training machine system as followed:

In real-time base, the error between the stepping force and the reference force is calculated by equation (1).

$$\Delta F = F_{STEP} - F_{REF} \quad (1)$$

where F_{STEP} is the stepping force measured by step force sensor, and F_{REF} is the reference force.

And, based on the error (ΔF), the control force F_M is calculated by Equation (2).

$$\Delta F > 0, \quad F_{M1} = F_{M0} - C \quad (2\text{-}1)$$

$$\Delta F < 0, \quad F_{M1} = F_{M0} + C \quad (2\text{-}2)$$

$$\Delta F = 0, \quad F_{M1} = F_{M0} \quad (2\text{-}3)$$

where F_{M0}, F_{M1} are the previous and present control forces to the foot plate, and C is the control offset. Based on the error (ΔF), C is also chosen by equation (3).

If $|\Delta F| \geq 5, \quad C = 5$ (3-1)

If $|\Delta F| < 5, \quad C = 1$ (3-2)

4.2 Result

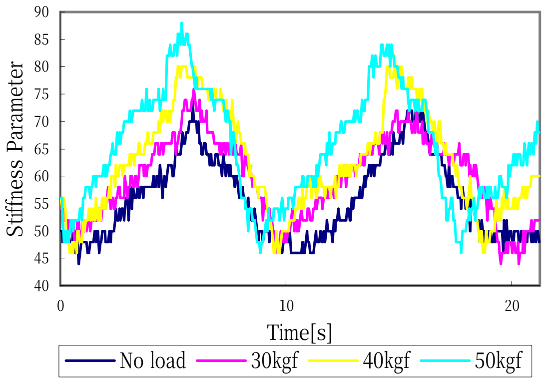
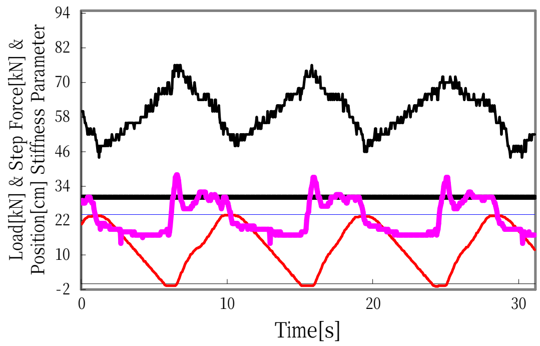


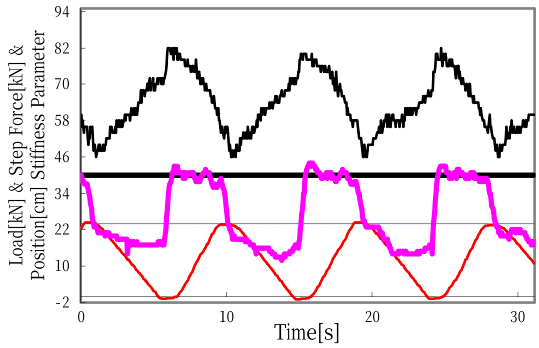
Figure 7. Stiffness change during leg pressing motion under four kinds of load [0, 30kgf, 40kgf, 50kgf]

When the posture of leg changes, correlated muscle makes change in their activity. Figure 7 shows that even there is no load on the leg, stiffness parameter changes during the leg pressing motion (stretching and stooping). And it also shows that stiffness parameter increases according to the increase of the load. It means that muscle stiffness sensor can be used as HMI for the power-assisting devices.

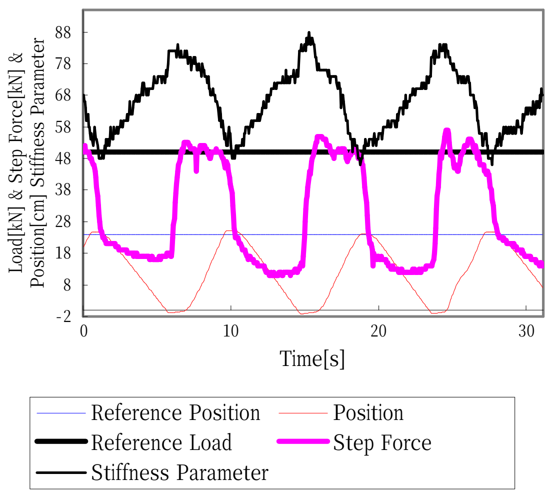
In Figure 8, each (a), (b), and(c) shows graphs of stiffness parameter, stepping force, position data, and reference value at each load 30kgf, 40kgf, and 50kgf. In each case, it is demonstrated that the system succeeds in controlling the stepping force to the reference value.



(a) 30kgf



(b) 40kgf



(c) 50kgf

Figure 8. Experiment data of leg pressing motion

5. CONCLUSION

A new type of training machine is proposed that can help elderly people maintaining their health. A feature of the machine is that a muscle stiffness sensor is incorporated to monitor the muscle status and control the reference load of the training. Through the experiment using a prototype, it is demonstrated that the training load of this machine can be controlled based on both the stepping force and the muscle activity. It is expected that this training machine provides effective and safe training opportunities for elderly people and be a great help for preventive approach against serious situation of aging society by reducing people who needs daily care.

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