Rehabilitation Robot Based on Three-axis Force/Torque Sensor

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***Abstract*—We describe the ankle rehabilitation robot using a three-axis force/torque sensor. The manufactured three-axis force/torque sensor which can detect two directional force Fx, Fz and one directional torque Tz, was fabricated, and it was attached to an ankle rehabilitation robot. The robot was designed and manufactured to perform a ankle bending flexibility rehabilitation exercise. The results of a characteristics test for the developed ankle rehabilitation robot showed that it was safely operated while the ankle bending flexibility rehabilitation exercise was performed.**

Keywords-component; ankle rehabilitation robo;, rehabilitation exercise; three-axis force/torque sensor; rated output; interference error.

I. INTRODUCTION

The feet of severe stroke patients are generally not so available as that of normal. In order to use their feet in everyday life, their feet must receive rehabilitation exercises. An ankle-bending flexibility rehabilitation exercise is performed to make the patient's ankle flexible. The ankle-bending flexibility rehabilitation exercise rotates the ankle in a clockwise direction or counter-clockwise direction. It is very difficult to deal with a number of severe stroke patients and because of it, some of the severe stroke patients can't receive adequate rehabilitation exercise.

Developed ankle rehabilitation robot [1] was designed and manufactured for the unique neuromuscular facilitation of stroke patients. An ankle-bending rehabilitation exercise of patient's ankle was performed, and the results were good. A torque sensor was attached to the footrest and the main body of the robot to measure the rotational force of the ankle. Ankle rehabilitation robots [2] has been designed and manufactured to perform a virtual walking exercise using the haptic technology, and the ankle of the subject (normal) was tested by using the robot. The robot was operated smoothly, but the rotational force exerted on the ankle could not be measured. So, the robot can't get the same effect as a rehabilitation exercise conducted by specialized rehabilitation therapists. The ankle rehabilitation robots developed so far can't exert the same effect as a therapist, and can't detect the emergency signal and return to initial state during the emergency situation because the robots have not had the multi-axis force/torque sensor. Multi-axis force/torque sensor for ankle rehabilitation robots must measure the torque of the ankle and the forces or torques during the emergency situation. Previously developed multi-axis force/torque sensors are from two-axis to six-axis force/torque sensors [3][4], but their price are expensive, and they are not appropriate to adhere to the developed rehabilitation robot, and the rated capacity of each sensor is not fit. So the sensor should be newly designed and manufactured.

The rest of this paper is organized as follows. Section II describes the design and manufacture of three-axis force/torque sensor. Section III describes the design of ankle rehabilitation robot. The acknowledgement and conclusions close the article.

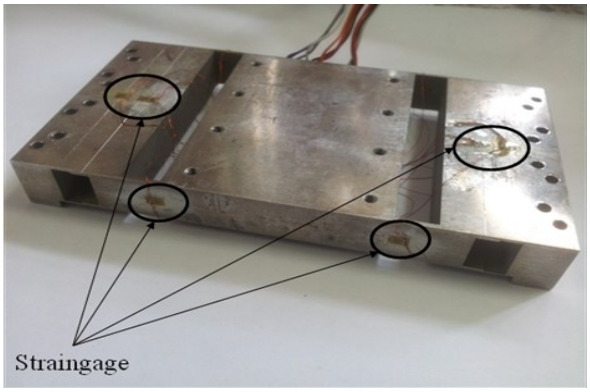

Figure 1. Manufactured three-axis force/torque sensor.

II. DESIGN AND MANUFACTURE OF THREE-AXIS FORCE/TORQUE SENSOR

The three-axis force/torque sensor was designed using by the finite element method (FEM). The rated outputs of the variables for designing the three-axis force/torque sensor are determined by the rated force and torque of each sensor of the three-axis force/torque sensor are Fx=300N, Fz=100N, Tz=15Nm, the size of the sensor is 136mm×74mm×17mm, and the rated strain at the attaching location of strain-gage is about 250 $\mu m/m$. The lengths l1', l1 and l2 are 5mm, 5mm and 10mm respectively, the widths b1 and b2 are 74mm and 14mm, and the thicknesses t1', t1 and t2 are 1.3mm, 0.7mm and 1.4mm respectively.

The three-axis force/torque sensor was fabricated by using the bond (M-200) and the strain gauges (N2A-13-S1452-350, made in Micro-Measurement Company, gauge constant 2.03, size 3×5.2mm), and constructed by Wheatstone bridge. Figure 1 shows the photograph of the

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manufactured three-axis force/torque sensor. The characteristics experiment of the three-axis force/torque sensor was performed with the multi-axis force/moment sensor calibration system developed by Kim [5] and the measuring device (DMP40). The maximum interference error of the three-axis force/torque sensor was less than 1.24%. And the maximum repeatability error and the maximum non-linearity error of each sensor were less than 0.03% and 0.02% respectively.

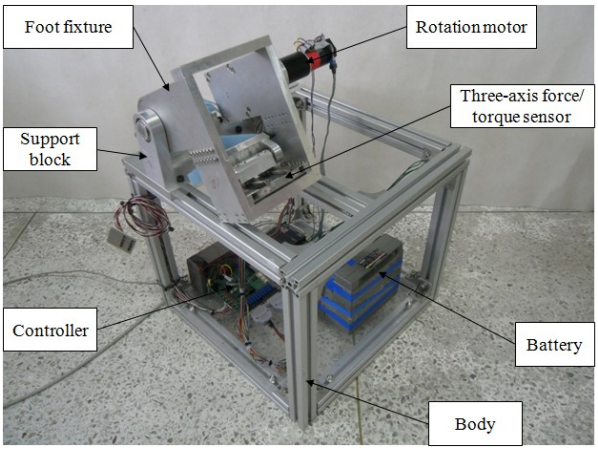
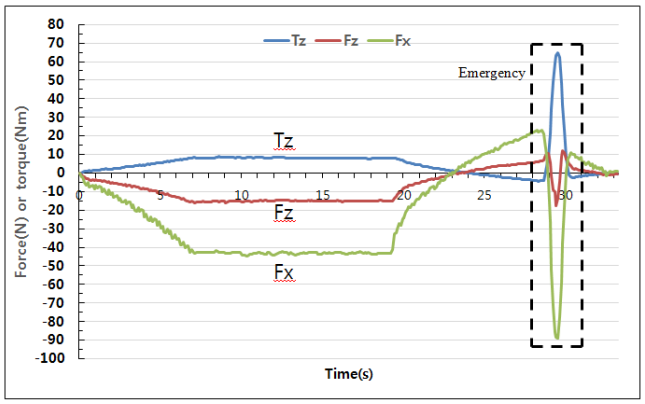


Figure 2. The manufactured ankle rehabilitation robot for the ankle-bending flexibility rehabilitation exercise.

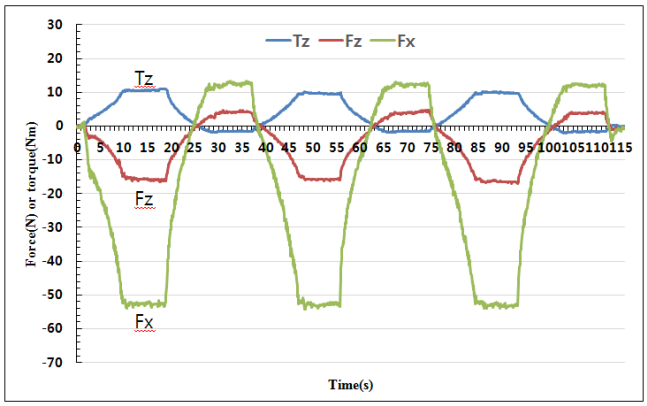
III. DESIGN OF THE ANKLE REHABILITATION ROBOT

Figure 2 shows the manufactured ankle rehabilitation robot for the ankle-bending flexibility rehabilitation exercise. The developed ankle rehabilitation robot is composed of a body, a support block, a three-axis force/torque sensor, a rotation motor, a motor drive, a high-speed controller, a battery, and so on. The Fx force sensor of the three-axis force/torque sensor measures the rotational force of the ankle. Fz force sensor and Tz torque sensor detect the force and torque when the emergency state is generated during the ankle rehabilitation exercise. Figure 3 (a) shows the graphs of emergency characteristic experiment of the manufactured ankle rehabilitation robot. Fx is the graph measuring the rotational force of the ankle when the ankle rehabilitation robot rotates, and Fz is the force that occurs because of the soles of wheat up, and Tz is the torque generated in the case that a force applied on the sole of the big toe part. The emergency situation is generated that more than 10 Nm torque or more than 10N is changed suddenly, and the program was designed after emergency. The ankle rehabilitation robot developed in this paper can securely carry out the ankle-bending flexibility rehabilitation of the patient, because the robot has the ability to stop and return to the initial state when an emergency situation occurs.

Figure 3 (b) shows the graph of the characteristic experiment for the ankle-bending flexibility rehabilitation exercise using the ankle rehabilitation robot. The rotational force (force Fx) in the bending direction was -52.3N, and that in the spreading out direction was 12.1N. The force control in each reference rotational force was carried out with PI control (Kp: 0.79, Ki: 0.04), and the values of the reference rotational forces -52.3N and 12.1N in the bending direction and the spreading out direction were shaken, because the foot moves in each applied reference force status in the bending direction and the spreading out direction.



(a) emergency



(b) ankle-bending exercise

Figure 3. Graphs of the characteristic experiment for the emergency and the ankle-bending flexibility rehabilitation exercise using the robot.

IV. CONCLUSIONS

The three-axis force/torque sensor was designed and fabricated for the ankle rehabilitation robot, and its interference error, a non-linear error and a repeatability error were less than 1.24%, 0.04% and 0.04% respectively. It was confirmed that the developed ankle rehabilitation robot was operated properly in the characteristic experiment for the ankle-bending flexibility rehabilitation exercise. Therefore, it is thought that the developed ankle rehabilitation robot can be applied to severe stroke patient for the ankle-bending flexibility rehabilitation exercise.

ACKNOWLEDGMENT

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