Design of a Rectangular-type Finger Rehabilitation Robot

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Abstract: This paper describes the development of a finger-rehabilitation robot for rehabilitating stroke patients' fingers and other patient's paralyzed fingers. The developed finger rehabilitation robot is composed of a thumb-rehabilitation robot instrument and four finger rehabilitation robot instruments. The finger-rehabilitation robot could exercise fingers of patient for their rehabilitation. A control characteristic test of the developed rectangular-type finger-rehabilitation robot was carried out, and the results confirmed that the robot could be used for the flexibility rehabilitation exercise for the fingers of normal person and patients.

1 INTRODUCTION

A stroke patient's fingers and other patient's paralyzed fingers usually have reduced functions unlike a normal person, because they usually have varying weakness of force. Therefore, their fingers undergo a rehabilitation exercise to rehabilitate their initialization functions. The finger-rehabilitation robot can spread out five fingers and turn them inward perfectly. The robot must perform force control procedures for the patients' safety in the finger-rehabilitation exercise, because the fingers of patients have different spreading extents.

Brokaw developed a finger rehabilitation system using a spring force which assists a stroke patient in grasping an object. Ren developed a system which could spread out and turn inward a patient's thumb, and a system which could spread out and turn inward his/her four fingers. The weakness of that system was that it could not exercise each finger individually. Connelly developed the air pressure gloves system which can blow and deflate air into a patient's gloved hand to spread the hand out and turn the gloved fingers' inward. The weaknesses of these developed systems in the paper are that they cannot exercise the spreading out patient's fingers perfectly, and they also can't safely be used in the exercise for the rehabilitating of patients fingers because they don't have a force sensor and therefore don't have any force controls.

In this paper, the rectangular-type finger-rehabilitation robot which can perform a flexibility rehabilitation exercise was developed for fingers' rehabilitation exercises. The links of five finger-rehabilitation robot instruments were designed using the software Matlab, after which the body of finger-rehabilitation robot was designed and manufactured, and then a control characteristic test of the developed rectangular-type finger-rehabilitation robot was carried out.

2 DESIGN AND MANUFACTURE OF ROBOT

2.1 Design of the Links' Lengths of the Finger-rehabilitation Robot

In order to design the finger-rehabilitation robot instruments, the lengths of a hand and each finger is measured. After which, the movements that spread out fingers and turn the fingers inward are simulated with their data collected to get the links' lengths**.** The average length of a hand, each finger and each knuckle were measured from ten university students, and they are as follows; the length of thumb is 68mm, that of forefinger is 101 mm, that of middle finger 114 mm, that of ring finger 105 mm, that of little finger 87 mm. The spreading angle of each finger is about 85°. The values are to design each finger-rehabilitation robot instrument in the simulation.

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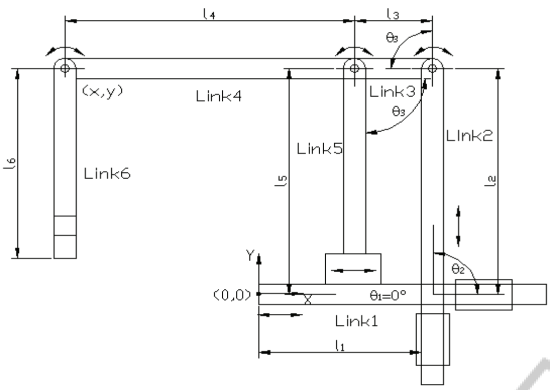


Figure 1: Schematic diagram of links for the finger-rehabilitation robot instrument.

Figure 1 shows schematic diagram of the links of finger-rehabilitation robot instrument for the simulation, and these are composed of link 1~6 with each length of l1, l2, l3, l4, l5 and l6, the angle between the length direction Link 1 and horizontal axis is θ_1, the angle between Link 1 and Link 2 is θ_2, the angle between Link 2 and Link 3 is θ_3. The structure of the finger-rehabilitation robot instrument is as follows; each finger's end knuckle is fixed to the end of Link 6, Link 3 and Link 4 are composed of a body, Link 2, Link 5 and Link 6 are jointed to Link 3 and Link 4, and Link 1 and Link2 move in a horizontal direction and vertical direction respectively. In the simulation, the horizontal length of Link 1, the vertical length of Link 2 and the angle (θ_3) between Link 2 and Link 3 are made in accordance to the movement of the jointed point (x, y), and they then spread out the fingers and turn them inwards. The horizontal length of Link 3 and the vertical length of Link 4 are derived through a simulation using the software MATLAB. In order to create the simulation, equations of forward kinematics and inverse kinematics must be derived. If x and y are variables, the equations of forward kinematics could be derived. The equation for calculating x can be written as follow.

$$x = l_1 - (l_3 + l_4)\sin\theta_3 \tag{1}$$

The equation for calculating y can be written as follow.

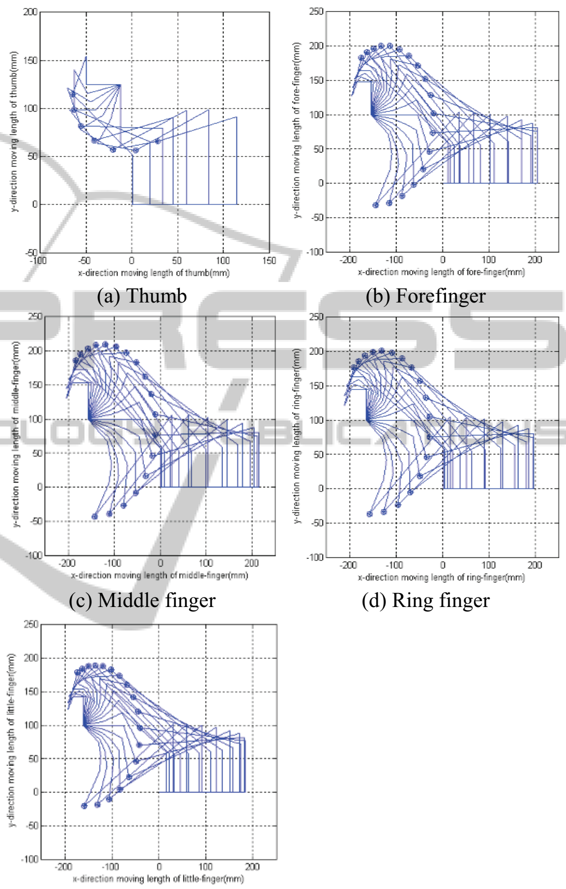
$$y = l_2 - (l_3 + l_4)\cos\theta_3 \tag{2}$$

If the lengths of Link 3, Link 4 and Link 5 (l3, l4, l5) and x, y are considered constant, $\cos\theta_3 = (l_6 - l_2)/l_3$, is the equation of reverse kinematics, the variables l1, l2, θ_3 can be determined as follows.

$$l_2 = \frac{((l_3 + l_4) - l_3 y) l_6}{l_4} \tag{3}$$

$$\theta_3 = \cos^{-1}\left(\frac{l_6 - l_2}{l_3}\right) \tag{4}$$

$$l_1 = x + (l_3 + l_4)\sin\theta_3 \tag{5}$$



(a) Thumb (b) Forefinger

(c) Middle finger (d) Ring finger

(e) Little finger

Figure 2: Graph of the simulation results for the finger-rehabilitation robot instruments.

The simulation of each finger is carried out from the turned inward finger to the spread out of said finger. The lengths of Link 6 and Link3+Link4 for the thumb are 46mm and 90mm respectively, and those for middle finger are 76mm and 225mm respectively. The lengths of forefinger, ring finger and little finger are determined by the equal size of those of middle finger, because the length of middle finger is the greatest. The (a), (b), (c), (d) and (e) of Figure 2 which are depicted graphic form show the results of the simulation using the finger-rehabilitation instruments from the turned inward fingers to spread out fingers. When the thumb is divided into six sections from the turned inward finger (0°) to spread out finger (84°) with an interval of 14°, the horizontal moving distance (x) of Link 1 is 114.4mm, the vertical moving distance (y) of Link 2 is 43.4mm, and the rotational angle between Link 2 and Link 3 is 60.1°. When the four fingers (forefinger, middle finger, ring finger and little finger) are divided into seventeen sections from the turned inward finger (0°) to the spread out finger (85°) with the interval of 5°, the horizontal moving distance (x) of Link 1 for each finger is 192.2mm, 214.0mm, 195.4mm and 167.0mm, the vertical moving distance (y) of Link 2 for each finger is 43.4mm, 54.8mm, 51.1mm and 45.4mm, and the rotational angle between Link 2 and Link 3 for each finger is 60.1°, 86.5°, 80.1° and 69.2°, respectively. As a result of the simulation, the length of Link 6 and Link 3+Link 4 of thumb-rehabilitation robot instrument is 46mm and 90mm respectively, and those of four finger-rehabilitation robot instrument are 76mm and 225mm.

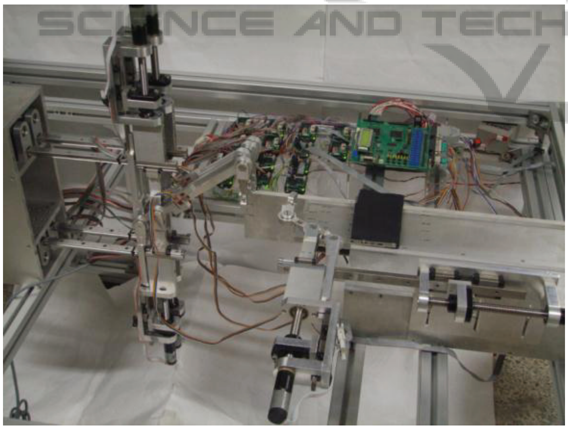


Figure 3: Photograph of the manufactured finger-rehabilitation robot.

2.2 The Design and Manufacturing of the Finger-rehabilitation Robot

The Figure 3 shows the photograph of the manufactured finger-rehabilitation robot. The robot is composed of a thumb and four finger-rehabilitation robot instruments They are composed of a hand support (body), a left and right moving instrument for the thumb-rehabilitation robot instrument, four up and down moving instruments for the four finger-rehabilitation robot instruments, five front and rear moving instruments for the thumb and four finger-rehabilitation robot instruments, a force measurement and transmitting instrument for the thumb-rehabilitation robot instrument and four force measurement and transmitting instruments for the four finger-rehabilitation robot instruments.

The hand support (body) is used to fix patient's left hand, and is attached to the front and rear moving instrument, and its dimensions are 220mm in width, 451mm in length and 94mm in height. Each instrument is composed of a LM guide (RSR9KM), a ball screw (MTF1202-3.7), a motor and gear (349380, 29:1) and a support, and they vertically move the force measurement and transmitting instrument up to 60mm, respectively. The front and rear moving instrument of each finger-rehabilitation robot instrument is fixed to the body and the applied force to each finger is done by moving each finger with the up and down moving instrument in conjunction with each support of force transmitting instrument. Each fixing block of the each up and down moving instrument are attached to a single LM guide rail with each of the front and rear moving instruments. The horizontally movement of the force measurement and transmitting instrument is up to 300mm.

Each force measurement and transmitting instrument of each finger-rehabilitation robot instrument is composed of a finger fixing link, a finger exercising link, a support and an upper and lower moving block. The four two-axis force sensors which measures Fx force and Fy force are manufactured for four finger-rehabilitation robot instruments, and they are fixed to each finger exercising link, and they each have the capacity of 100N. The sensors measure the pulling and pushing forces of fingers. Each force measurement and transmitting instrument is connected to the center of each fixing support and the end of each up and down moving instrument, respectively.

2.3 Control Characteristic Test of Finger-rehabilitation Robot

The flexibility rehabilitation exercise is performed for improving the flexibility of the hardened five fingers, and it is during these exercises which the fingers are spread out and turn inward according to the drawing trace of the last knuckle. Figure 4 shows the photographs of the characteristic test for flexibility rehabilitation exercise using finger-rehabilitation robot instrument.

Figure 5 shows the graphs of the flexibility rehabilitation exercises using the finger-rehabilitation robot. The graphs showed in the cases of the spreading out of the thumb, forefinger, middle finger and ring finger, that the forces were between the range of 0~22s and each had a maximum force

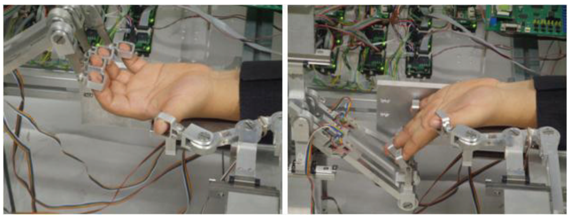
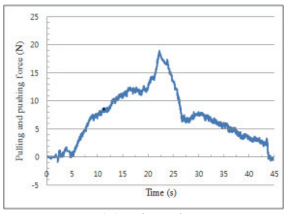
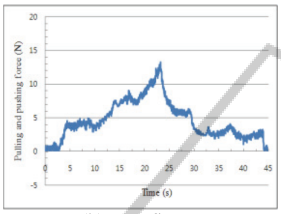


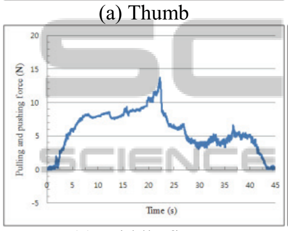
Figure 4: Photographs of characteristic test for finger-rehabilitation robot instrument.



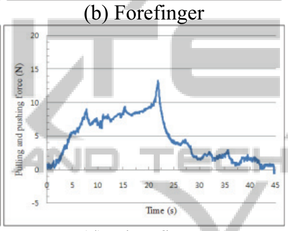
(a) Thumb



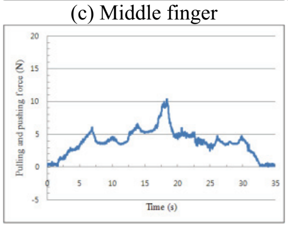
(b) Forefinger



(c) Middle finger



(d) Ring finger



(e) Little finger

Figure 5: Graphs of flexibility rehabilitation exercises.

of about 18N, 13Nm 14N and 13N with reaches of about 22s. In cases where the fingers were turned inward the measured forces were decreased by about 22s respectively. In case of the spreading out of the little finger the graph showed, the forces were between the ranges of 0~17s with a maximum force of about 10N with reaches of about 17s. In case of the little finger being turned inward, the measured force was decreased by about 17s. The graphs showed that the progressions of the tests of thumb, forefinger, middle finger and ring finger, and little finger were finished within 45s, and 34s respectively, because the robot could stop after spreading out the fingers perfectly and would then return to the starting position. Thus, the finger-rehabilitation robot instruments could be used for the finger-flexibility rehabilitation exercises of rehabilitating patients' fingers.

3 CONCLUSIONS

The purpose of this paper is to showcase the rectangular-type finger rehabilitation robot which can perform both the flexibility rehabilitation exercise. The operating characteristic test of each fingers' rehabilitation robot instrument was carried out using five fingers of normal person, and the characteristic tests were safely operated in the flexibility rehabilitation exercise.

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