BME003

Design and Development of a Pinch Rehabilitation Device

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Abstract

Some stroke suffering people are restricted to perform hand movement in activities in daily lives. One of the movements is a tip pinch. This research aims to design and develop a simple mechanism to rehabilitate this pinch action. The device has one degree of freedom that couples the motion between the index and thumb joints. The actuated joint is driven by a dc motor with a round cable transmission system. The mechanism aims to adapt with regular hand sizes based on the average distance according to bone's length literatures. The coupling transmission ratio between 2 joints is calculated to ensure a proper motion for a pulp contact. The prototype is developed and tested by subjects. The average force for pinch action is about 1.6 N. The experimental results will be presented and discussed.

***Keywords**:* Rehabilitation, Pinch, Simple mechanism

1. Introduction

Stroke patients have a tendency to suffer from paralysis which restricts them to perform some body movements. The abilities can be relearned through the stroke rehabilitation methods.

In Thailand, a number of stroke patients were escalating respectively between 2001-2010 as reported by Thai Ministry of Public Health [1]. Also, there is an increasing in the number of Thai aging people, a group of people who is likely to suffer from stroke most [1-2]. Therefore, there will presumably be higher quantities of stroke patients in the future.

The principle of rehabilitation method is to let the brain relearn skills via performing actions together with recovering brain perception. This can be conducted with a help of physiotherapist.

However, the increasing in therapist demands might not be congruous with that in the number of physiotherapists themselves. Therefore, many medical devices have been invented to fill this gap. Two types of this solution were introduced, a functional electrical stimulation (FES) system and a hand orthotic exoskeleton. The former stimulates muscles that are no longer receiving signals from the central nervous system. Nonetheless, some obstacles, such as fast fatigue and forbidding inflicted local trauma muscle patients to use, were reported from this solution. The latter was then established to unravel the problems by providing assistive force to the user's fingers [3].

Typically, two distinctive types of hand orthotic exoskeletons having been proposed are range of motion movement promoting, and activities in daily lives movement controlling.

Those forcing hand to follow indicated range of motion, for example, are wire-driven 4-bar exoskeleton [4], focusing on controlling each finger joint to be passively moved as required range of motion by using wire driven actuators along with underactuated characteristic of each joint, IOTA [5], inducting thumb opposition movement by locating abduction joint at thumb carpometacarpal joint, and the one from Rehabilitation Lab, Zurich, Switzerland, creating a thumb-finger opposition as well [6].

The second type manipulating hand to move in activities in daily lives movement are an EMG-Controlled Hand Exoskeleton for Natural Pinching [3], proposed to allow pinching motion in wide range by using natural sequence of muscle activation controlled by cable driven by a pneumatic piston, and five-fingered assistive hand [7], proposed to allow both grasping and pinching motion in wide range as well. However, tip pinch motion assisting used variously in some activities such as buttoning, signature, and buckling and gripping of some small objects such as medical pills has never been mentioned before. Though the commercial product such as SaeboReJoyce [8] promotes tip pinching, it is not in the form of an exoskeleton and cannot directly control the hand. Tip pinching rehabilitation device will not only provide a wearer force in pinching but might also pave the way for fine pinch movement motion assisting applications in the future.

Thus, this paper is about to propose the design and development of a novel pinch rehabilitation device focusing on tip pinch movement. The device aims to control a hand to perform tip pinching and be able to adapt with regular hand sizes. The idea, design process, prototyping and experimental results will be presented and discussed respectively.

2. Design procedure

2.1 Anatomical details

The human index finger has three joints and four degree of freedom. As shown in Fig. 1 and Fig. 2, from the distal end, the located joints are DIP (distal interphalangeal) with flexion/extension, PIP (proximal interphalangeal) with flexion/extension and MCP (metacarpophalangeal) with both flexion/extension and adduction/abduction. In fig. 3, the thumb has three joints and five degrees of freedom. From the distal end are located IP (interphalangeal) with flexion/extension, MCP (metacarpophalangeal) and CMC (carpometacarpal), both of which have flexion/extension and abduction/adduction.

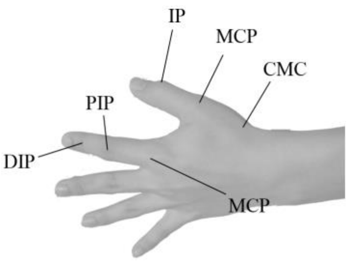

Fig. 1. Index finger's and thumb's joints

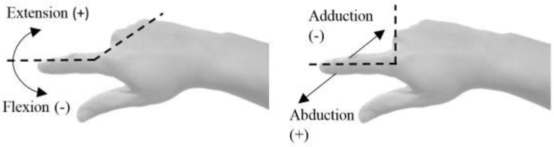

Fig. 2. Index finger joint motions

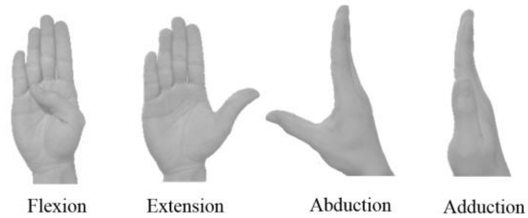

Fig. 3. Thumb's CMC joint motions

In tip pinching, all joints shown in an index finger must be flexed. For a thumb, CMC must be flexed and adducted with flexion in MCP and IP. To get full tip pinching movement, both pulps must also be in contact.

As mentioned above, two directions, index finger joints' and thumb's CMC flexion, must be reached from hand's neutral position. In order to simplify the mechanism which still guarantees tip pinching, CMC is statically in flexion throughout the movement, hence the movement is compelled in planar direction, which allows transmission system to be only on the lateral side of a hand and does not obstruct any space on rear and palmar side.

2.2 Specifications

In our work, essential elements of design consideration are anatomical link lengths of a hand, rotational center position of joints, joint angles for tip pinching, and pinching force.

To specify the link lengths, we utilized normative hand and bones' length data published by Alexander [9] and Crisco [10]. The derived data provided our design to be adaptable with different hands and finger sizes. In addition, the rotational center could be further calculated from the earlier research [11]. The summarized sizes of link lengths are shown in Fig. 4. and Table. 1.

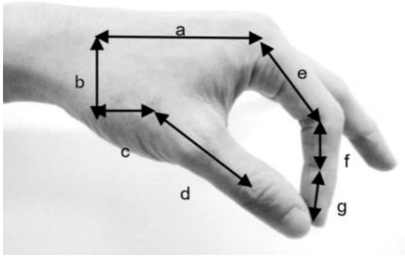

Fig. 4. Lengths data in variables

Table. 1 Summarized lengths data in correspondence with Fig. 4

Variable	Length (mm)	Variable	Length (mm)
a	70.46	e	39.78
b	15.22	f	22.38
c	9.62	g	15.82
d	31.57		

To seek for rotational center position of joints and joint angles for tip pinching, we made use of frame coordination system. Consider Fig. 5, {B} represents base frame coordinate. The subscription, 'i' and 't' stands for the index and the thumb joints. Θ_i and Θ_t are the index and thumb joint angles respectively.

According to a sticking model of healthy hand subjects recorded repeatedly with motion analysis method [12] and adduction angle of thumb's CMC joint [13]. We simulated the tipping motions in CATIA V5R20 in Fig. 6. All range angles are listed in Table 2.

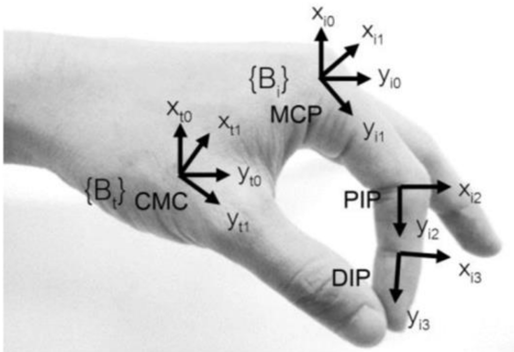

Fig. 5. Frame fixed joints

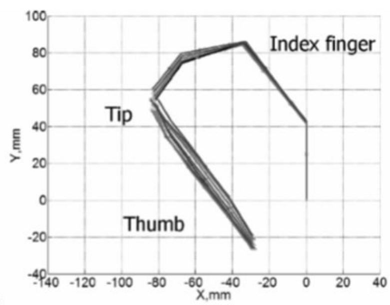

Fig. 6. Sticking model [12]

Table. 2. The starting and pinching angles conforming to variables in Fig. 5.

Variable	Starting angle (deg)	Pinching angle (deg)
Θ_{i1}	0	38
Θ_{i2}	0	66
Θ_{i3}	0	36
Θ_{t1}	44.6	36

The other key parameter is the pinching force acted between the pulps. Some maximum pinch forces were available in some papers. However, to get the force required in this design, which is not the maximum but a natural pinching force, the pinching force experiment was conducted. We performed a natural pinching force using a force pad sensor with 25 healthy subjects. Each subject was required to perform pinching five times. Therefore, the average pinching force is 1.05 ± 0.35 N.

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2.3 Mechanical design

From required angles, many joints must be moved concurrently in a planar view. To simplify the design, the DIP and PIP of index finger were intentionally fixed at 66 and 36 degree respectively. Thus, moving joints were two MCPs in the thumb and the index fingers. The required joint angles are shown in Table 3.

Table 3 Angle ranges in each joints

Variable	Angle (deg)
Θ_{i1}	0 to 38
Θ_{t1}	44.6 to 36

In this circumstance, we coupled the motions of Θ_{i1} and Θ_{t1} and thus required a transmission of 4.1 : 1 in counter direction. Here we selected a round cable system to transmit the power thru the system. The system enabled counter-directional motion that we needed by just crossing the cable.

2.4 Prototype

The CAD model, which is shown in Fig.7, was designed in CATIA. Most mechanical parts are made of low-weighted aluminum. The standard round cables are made of rubber. The index end is made of a bended acrylic plate and connected to the aluminum base with clicking buttons. A DC motor was used as the actuator. The device was attached to a user hand with an elastic glove and elastic bands to provide comfort feeling. There is a hard stop to limit the thumb CMC movement. Additional limit switch is used to reset zero

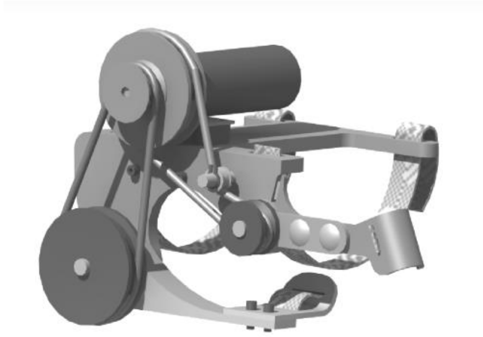

Fig.7. CAD Model

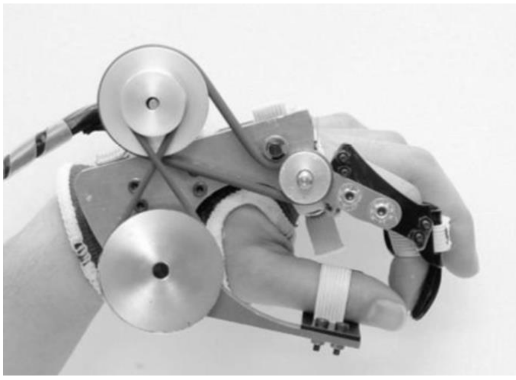

Fig. 8. The prototype

3. Controlling System

The controlling module consists of Pololu MC33926 motor driver, Arduino MEGA and additional electrical components such as button, a switch, a power supply and etc. The controlling module is set up in a portable container as shown in Fig. 9.

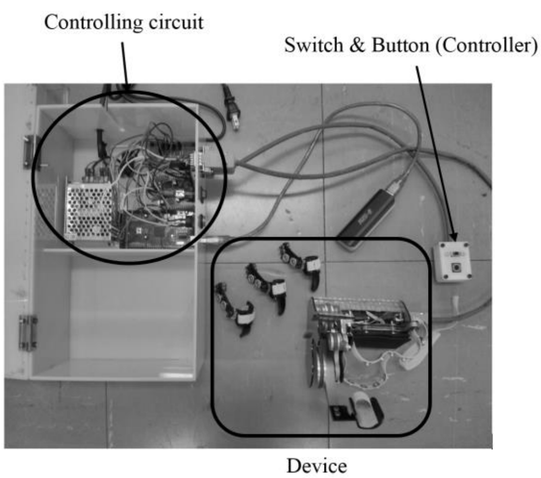

Fig. 9. The portable system

There are two operating modes, pinching and rehabilitation modes. The mode is selected by shifting the switch.

For the pinching mode, once the button is pressed, the device then starts actuating fingers to perform pinching. When both finger pulps reach an object, the holding force is then controlled by current feedback. If the user presses the button again, the device will open the fingers and stop the operation once reaching the limit switch.

In the rehabilitation mode, once the button is pressed, the device will automatically perform the repeated tip pinching the button is pressed again.

4. Evaluations and Discussions

The testing section was separated into two tests, a pinch movement test and a range of motion test.

The pinch movement test was to observe the tip pinching ability. To fully achieve this objective, the pulps had to be attached together. Additionally, the subjects were obliged to pinch and hold a 0.8-cm diameter glass bead. Throughout the operation, we observed the pinching performance of the device as well as checked the pinching force.

Ten subjects performed tip pinch experiments. The average measured force was 1.64 ± 0.49 N or 60% higher than the designed data. The measured force data is shown in Table. 4. All subjects could perform tip pinch perfectly; however, two of them could not hold the glass bead firmly, as shown in Fig. 10., due to the fact that their thumbs were bended more than others'. This is, nonetheless, can be improved by attaching a thumb support fixture.

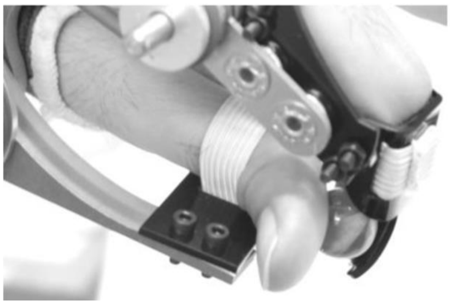

Fig. 10. The natural bending characteristic of thumb's DIP joint

Table. 4 Measured force data

Subject No.	Measured Pinch Force (N)
1	1.354
2	2.092
3	1.128
4	1.49
5	1.868
6	2.356
7	1.142
8	0.904
9	2.302
10	1.764
Average	1.64
S.D.	0.487

The range of motion was measured by using the photographs taken at the start and end position, one of the example of which is shown in Fig. 11., and was summarized in Table. 5. It was found that the moved range of motion is close to what we had specified.

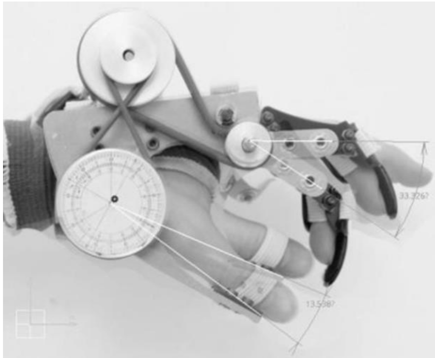

Fig. 11. The example picture used in range of motion test

Table. 5 Experimented range of motion

	Required range of motion (deg)	Measured range of motion (deg)
Index's CMC	38	30.08 ± 3.10
Thumb's MCP	8.6	8.78 ± 3.34

Lastly, the users were asked about their feelings throughout the operation. They asserted that the device was easily moved but its heaviness was likely to put a burden on their hand in the long hour process.

5. Conclusion

This work proposed the design and development of a novel pinch rehabilitation device focusing on tip pinch movement. The device has one degree of freedom that couples the motion between the index and thumb joints driven by a dc motor.

The device can perform pinching motions of various subjects. The design is also adaptable to various hand sizes and enables a user to catch and have their fingers' pulps in contact with the object. This work can be further improved in mechanism's weight and comfort. The middle finger may be considered to include as well for the stronger support..

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