# Hand Rehabilitation Device to Prevent Contracture for Finger Joints using Pneumatic Soft Actuators

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**Abstract- There has been increased interest in use of pneumatic actuators in many fields, such as medical care and welfare. In particular, proposed pneumatic soft actuator with soft material has many advantages such as low mass, flexibility, safety and user-friendliness. We therefore focus on the pneumatic actuators as a drive source of a rehabilitation device. This paper describes the concept, design, prototype and evaluation of the rehabilitation system with the actuators. The system has two difference actuators, stepping motors and pneumatic soft actuators. The stepping motors are used for moving the pneumatic actuator at right position for finger rehabilitation. The pneumatic soft actuators are also used for the range of motion (ROM) and relaxation exercise. We measured the flexure and extension angles in the rehabilitation test. As a result, we confirmed that the rehabilitation system is able to provide ROM exercise.**

**Keywords – Pneumatic Soft Actuator, Rehabilitation Device, Contracture, ROM**

## I. Introduction

Patients with impairment of motor functions have been increasing steadily over time by several accidents and diseases. If the recovery of motor function does not improve, a contracture is occurred in some joints and muscles. The contracture causes restricted range of motion in the joint. Therefore, it makes daily life difficult for the patients. For example, contract around the joints of leg makes walking by oneself difficult. Furthermore, if the contract is associated with severe disease, a rehabilitation therapy causes acute pain to the patients. These mean that it becomes especially difficult to control the body, thus it is very important to start the rehabilitation therapy before developing the contracture. Normally, range of motion (ROM) exercises for fingers are prescribed by occupational therapists to prevent the joints contracture and improve the patient's symptoms. The occupational therapists also massage the hand and fingers to reduce swelling of them before doing ROM exercises. However, the patients cannot receive enough rehabilitation, because the time of therapy from the occupational therapists is limited. In addition, the occupational therapists will be generally less numerous than the patients, they will expect to increase workloads.

Contractures often tend to occur in fingers and a thumb of hands. These are the most important body parts for living a daily life. Many researchers have been developed mechanical finger rehabilitation devices to improve movement disabilities [1-6]. However, these devices are able to exercise only range of finger joint motion. We therefore have developed the finger rehabilitation device which provides not only the ROM exercises such as flexion and extension movements but also to execute a massage therapy for the muscles of the hand and fingers. Firstly, we focus on a pneumatic soft actuator as the drive source of the device. This actuator has many advantages such as lightweight, flexibility, safety and with a high affinity for people. The rehabilitation device is more likely to be popular with users since safety is essential for them.

In this paper, we report the finger rehabilitation device using the pneumatic soft actuators. We fabricated them with mechanism elements and pneumatic equipment. We also confirmed the performance of our proposal through experiments.

## II. HAND REHABILITATION DEVICE

### *A. Concept*

We investigated hand function rehabilitation exercises performed by an occupational therapist from the Department of Rehabilitation of Tsuyama Central Hospital. Figure 1 shows the method of investigation. Our investigation revealed the following. There are four types of joint range of motion (ROM) exercises. ROM exercises have several motions such as flexion/extension and abduction/adduction of the thumb and fingers. In addition, spreading fingers and arching a hand which move thumb closer to a little finger are included in ROM exercises. Flexion is also divided into four different types of motion. The first motion is called 'fist' that metacarpophalangeal (MP) joint, proximal interphalangeal (PIP) joint and distal interphalangeal joint are flexed at the same time, the second motion is called 'straight fist' that MP and PIP joints are flexed, the third motion is called 'hook' that PIP and DIP joints are flexed and the fourth motion is called 'table-top' that only MP joint is flexed. In the case of serious contractures of joints, only a single flexion movement is more likely to injure joint cartilage. Therefore, it is also necessary to flex the finger while pulling it at the same time. Furthermore, we found that rehabilitation performed with the assistance occupational therapists does not merely consist of joint ROM exercises, but also of muscle stretching exercises such as kneading massage of the patient's muscles and compressing the hand to remove swelling. The purpose of muscle stretching is to remove patient tension and to enhance the effect of joint ROM exercise, and is therefore performed before beginning joint ROM exercises. Our investigation revealed that it is important that rehabilitation exercise to prevent and improve joint contracture involves not only ROM exercises, but also muscle stretching. Based on these findings, we cite the following items as necessary features of the device developed in this study.

(1). A device has the ability to perform rehabilitation of both the left and right hands.

(2). A device has the ability to perform rehabilitation with hands of various sizes.

(3). A device is based on ROM exercises such as finger flexion/extension motion and the muscle massage of the hand and fingers.

(4). A device needs to fit for various hand sizes with minimal change of the design.

(5). A device ensures safety and is easy to operate by myself.

Figure 1. Investigation of therapy methods by occupational therapist

### *B. Design and driving principle of the hand rehabilitation device*

Finger rehabilitation is carried out for the thumb through to the little finger. However, the thumb has a higher degree of freedom compared with the other fingers and often undergoes rehabilitation independently. We therefore designed the present hand rehabilitation device so that muscle stretching, flexion, and extension of the index to little fingers (excluding the thumb) are performed simultaneously. A conceptual diagram of the hand rehabilitation device is shown in Figure 2(a). In this figure demonstrating the muscle stretching motion using the rehabilitation device, the left-hand actuator is labeled A1 and the right-hand actuator is labeled A2.

Muscle stretching is achieved by compressing the fingers between actuators A1 and A2. Thereafter, the application of pneumatic pressure is stopped, the truck is moved, and pneumatic pressure is once again applied. Muscle stretching is achieved with this motion by repeatedly applying pressure from the fingertips to the back of the hand. For the flexion motion (fist) the MP joint is first flexed 90 degrees by the A1 actuator. Next, the PIP joint is flexed by the A2 actuator, and finally, the DIP is flexed by sandwiching the hand between A1 and A2. Figure 4 shows the device setup for flexion. For the extension motion, the back of the hand is held in place by the A1 actuator and the fingers are extended when pressure is applied by the A2 actuator.

Figure 2(b) shows the fabricated rehabilitation device. The device is 470 mm in width, 300 mm in height and 463 mm in depth. The arm is placed on a fixed base and secured with a Velcro strap during rehabilitation. A pulley is mounted to the fixed arm base and can be moved backwards and forwards according to the size of the hand. A feature of this device is the structure that allows the pneumatic soft actuators to directly act on the fingers. The actuators are fixed to a truck and the trucks move along a rail, which was made from a flexible curtain rail. Two stepping motors (56 mm square, Originalmind Co., Ltd., Nagano, Japan) and timing belt were used to drive the trucks. The stepping motor was chosen with the necessary torque for finger flexion and extension. The timing belt was attached to the belt fixing parts of the trucks and by engaging the pulley attached to trucks and stepping motor as well as the timing belt attached to the truck, the movement of the trucks rotates the motor. An aluminum frame was used for the frame of the rehabilitation device, around which a control circuit board, pneumatic solenoid valve, regulator, and pressure gauge were mounted.

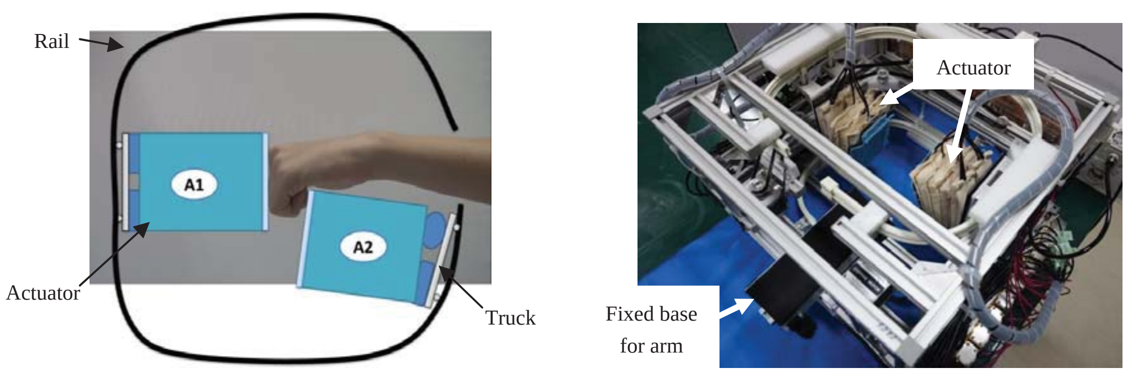


Figure 2. (a) Rough image of the rehabilitation device using multi-stage pneumatic soft actuators and (b) Prototype of hand rehabilitation device

## III. EXPERIMENTAL METHOD

ROM exercises for the finger joints require the finger to be moved to its maximum ROM. In addition, the joints of patients without contracture can be considered the same as the joints of healthy individuals. Therefore, to verify the problems with the rehabilitation device related to finger joints with unlimited ROM, we assessed the muscle stretching motion and measured the flexion and extension angles of the MP, PIP, and DIP joints using the right hand (180 mm from the wrist to the tip of the middle finger, 79 mm long middle finger, 76 mm in width from the MP joint of the index to MP joint of the little finger, and 26 mm thick middle finger) of a healthy individual (20-year-old man). We also asked an occupational therapist to test the device and provide their assessment and thoughts on improvements.

Flexion and extension angles were measured as follows. First, reflective markers were attached to each joint of the index finger. Compressed air, which was adjusted by an electro-pneumatic regulator, flowed into the actuators at 0.05 MPa. Then, finger motion during operation of the rehabilitation device was captured with a high-speed camera (HAS-L1, DITECT Co., Ltd., Tokyo, Japan). Movement of the reflective markers attached to each finger joint was then analyzed from the captured footage using motion analysis software (Dipp-Motion PRO, DITECT Co., Ltd.). This allowed us to calculate the flexion and extension angles of each joint. We considered repositioning and fixing the middle finger, ring finger, and little finger so that they were the same level as the index finger in order to rehabilitate all four fingers in one bunch. Using a cord, we secured the thumb so that the reflective markers would not enter the blind spot of the camera. The setup of the rehabilitation test is shown in Figure 3. The measurement method and target values for each joint angle were based on the "Joint range of motion demonstration and method measurement" determined by The Japanese Orthopaedic Association and The Japanese Association of Rehabilitation Medicine.

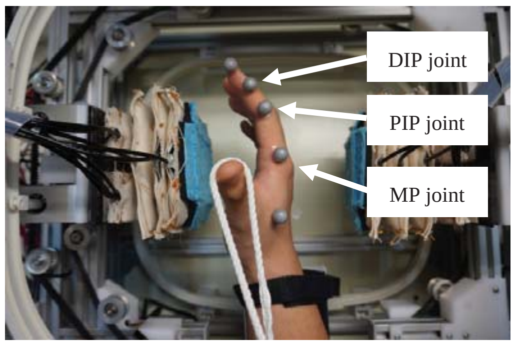


Figure 3. Set up for finger joint motion analysis

## IV. Experimental Results and Discussion

### *A. Massage therapy for the muscles of the hand and fingers*

Figure 4 shows the setup for muscle stretching. By applying pneumatic pressure with each actuator, the fingers are sandwiched between the actuators and compressed. We confirmed that muscle stretching could be achieved by performing this motion from the fingertips to the back of the hand by moving the trucks. However, as the effects of muscle stretching have not yet been verified, future studies are required.

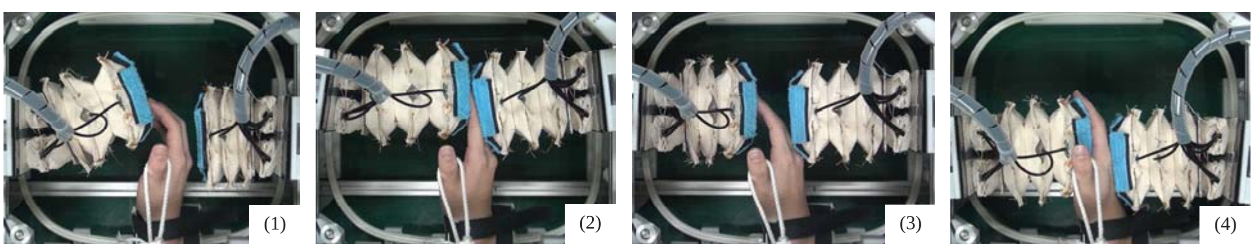


Figure 4. Photograph of massaging the muscles of the hand and fingers

### *B. Flexion movement*

We attempted the flexion motion referred to as the "fist" with all finger joints. This motion involves moving the joints until the limit of their ROM. Figure 5 shows the fist motion with the rehabilitation device and the its motion from an occupational therapist is shown in Figure 6. The flexion angles for each joint were 48 degrees for the MP joint (target value: 90 degrees), 91 degrees for the PIP joint (target value: 100 degrees), and 71 degrees for the DIP joint (target value: 80 degrees). We confirmed that the flexion angles of the PIP and DIP joints were close to the target values. However, the MP joint could only be flexed to about 50% of the target value. This appeared to be because the actuator comes into contact with the bulge at the bottom of the palm and cannot act properly between the DIP joint and fingertip. Moreover, although the occupational therapist wraps the fingers and flexes all joints at the same time, the rehabilitation device flexes each joint individually.

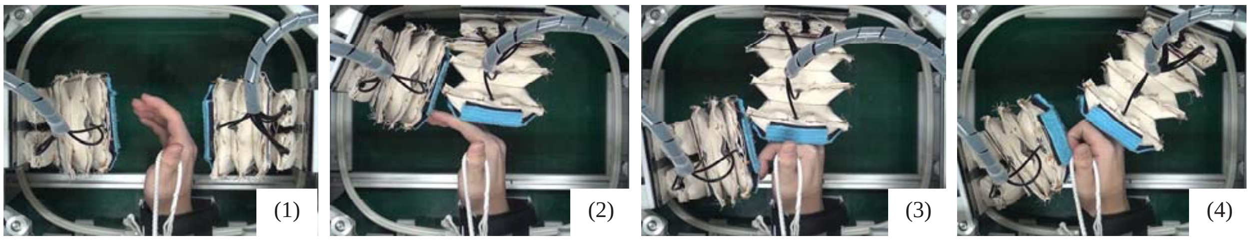


Figure 5. Flexion movement measurement results

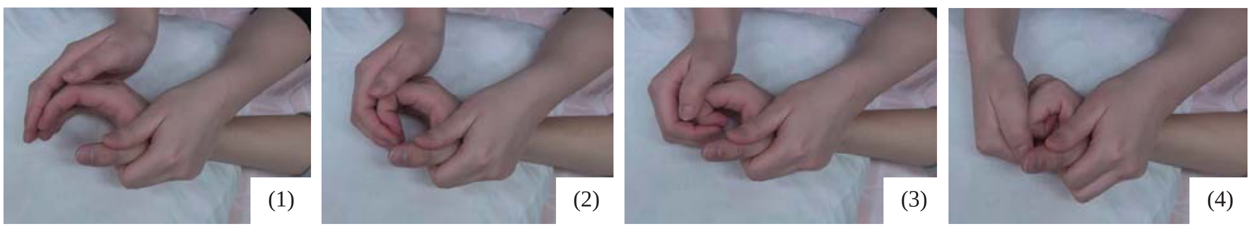


Figure 6. Flexion movement from an occupational therapist

### *C. Extension movement*

The results of the extension motion test with the rehabilitation device are shown in Figure 7. The extension motion from an occupational therapist is also shown in Figure 8. The extension angle of each joint was 34 degrees for the MP joint (target value: 45 degrees), and 0 degrees for both the PIP and DIP joints (target value: 0 degrees). These results show that the target angle was achieved for the PIP and DIP joints, but only 75% of the target angle was achieved for the MP joint, indicating that the joint could not be moved to its maximum ROM. This appeared to be because the wrist was not secured adequately, which caused the wrist to warp the direction of extension. Furthermore, the actuator in contact with the back of the hand used to hold the wrist in place may have inhibited extension of the MP joint. We also noted that the extension motion performed by the rehabilitation device bent each joint with the same timing and method as the motion performed by the occupational therapist.

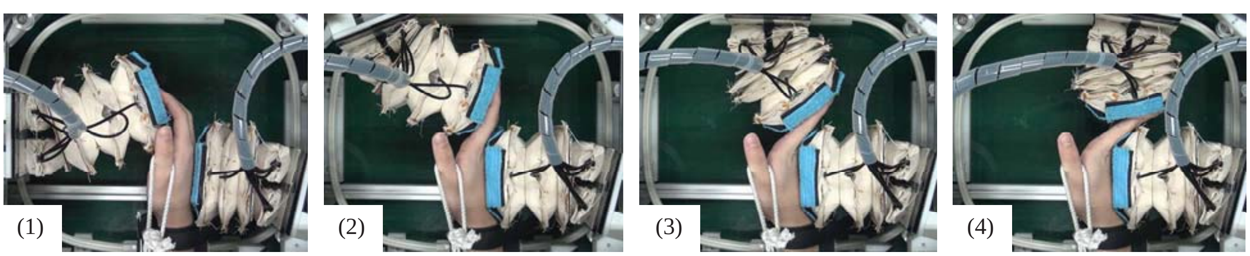


Figure 7. Extension movement measurement results

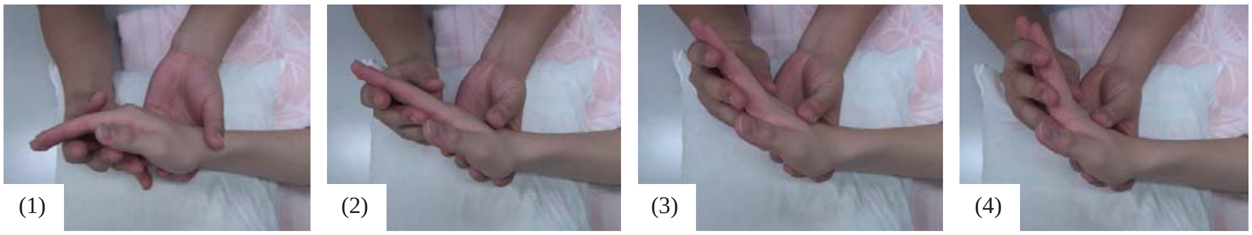


Figure 8. Extension movement from an occupational therapist

## V. CONCLUSION

In the present study, we built a prototype hand rehabilitation device for the finger joints using multi-stage pneumatic soft actuators. We then tested muscle relaxation exercises and joint ROM exercises. This device was built so that the pneumatic soft actuators directly acted on the fingers. A stepping motor controlled the positions of pneumatic soft actuators fixed to trucks, and each rehabilitation exercise was performed by combining this with the driving force of the pneumatic soft actuators.

In the muscle stretching motion test, a muscle massaging motion was achieved by successively repeating compression and relaxation from the fingertips down to the back of the hand. Next, in the test of flexion and extension joint ROM exercises, we measured the ROM of the MP, PIP, and DIP joints. Our results revealed that for the flexion motion, the PIP and DIP joints achieved approximately 90% of the target value, whereas the MP joint only achieved 50%. For the extension motion, both the PIP and DIP joints could be moved to 0 degrees, which was the limit of the joint ROM. However, the MP joint only reached about 70% of the target value. We also asked occupational therapists to test this rehabilitation device, which revealed several areas for improvement.

## VI. ACKNOLEDGMENT

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