Development of a Prosthetic Hand Based on Human Anatomy

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***Abstract*—Prosthetic hands are artificial extensions that help people who have lost their hands or arms to regain normal activity. One of the main requirements is that it should be as close as possible to the natural hand. Human hand flexibility is largely due to our highly evolved hand structure. To achieve those structures, we have adopted a human-like design concept. We designed the prosthetic hand based on the salient features of the human anatomy, making it have the same structural features as human hands: artificial joints, ligaments and Extensor hood, that should be very similar to the real hands. We tested to control prosthetic hand based on detected coordinates by Leap Motion. Finally, we could succeed in artificial hands to achieve same flexibility as characteristics of the human hand.**

***Index Terms*—human hand biomechanics, prosthetic hand, telemanipulation**

I. Introduction

People who lost their arm or hand in an accident or illness may lose their ability to perform work skills or normal activities in their daily lives. To help them regain these abilities, prosthetic hands have been developed as hand substitutes, that help them carry out daily activities such as grabbing items, eating or dressing.

In the past ten years, a large number of artificial hands with independent fingers have been developed [1]-[6]. For example, Wu *et al*. [7] developed a five-finger humanoid hand: each finger consisting of three knuckles (two thumb joints), and the stretching. Flexion of the fingers are driven by Twisted and coiled polymeric (TCP) muscles. Also, Mutlu et al. used a 3D printable material to make robot fingers more soft for artificial hands [8]. Weiner *et al.* [9] developed a highly integrated five-finger prosthetic hand. The prosthetic hand has an advanced embedded system and an RGB camera at the bottom of the palm and an OLED color display on the back of the hand. Although the above design can make their artificial hands movements similar to human fingers and hold the items stably, in general, it is a very challenging thing to make some flexible actions. In addition, the prosthetic hand also helps the amputee person to restore physical and mental health, it should be as close as possible to the natural hand. In the latest research, Fras *et al.* [10] developed a soft pneumatic hand, based on a 3D scan of a real human hand. It can adapt passively to the handled object due to its mechanical compliance. Although the soft pneumatic hand has an anatomical shape and it is more like a natural hand than other similar devices. However, there is still a lack of important components that provide biomechanics such as ligament, tendon. The biomechanics provided by these parts is an important reason for making our hands flexible. Therefore, in order to develop an artificial hand that is as dexterous as the original human hand and has a natural appearance, it is necessary to design an artificial finger joint based on the structure of the human hand.

In this paper, we propose an artificial hand designed based on human anatomy. The four fingers and the thumb model of the artificial hand are modeled according to the skeleton structure of the human hand so that they can have the same flexion angle as the human hand. In order to make each finger of the artificial hand be able to make the action like the original fingers, we also incorporate the human body structure such as ligament, tendon and tendon sheath into our design. The following sections detail our artificial hand design and an experiment to test the usefulness of our artificial hand.

II. Development of Prosthetic Hand

The design of the artificial hand is based on the idea of anatomically reproducing the bone connection structure and ligaments. In this section, we will introduce the design of our prosthetic hands from the hand features of bones, joints, toughness, palms, and sputum, and explain how we replicate these features.

A. The Bones and Joints Design

As shown in Fig. 1, the human hand consists of 27 bones with four fingers (Index, Middle, Ring and Little) and a thumb. The finger consists of three phalanges and metacarpal bones. The thumb has only two phalanges and one metacarpal bones. The trapezoidal bone at the base of the thumb is a saddle-shaped joint that allows the thumb to move over a wide range. Together with the metacarpal of the thumb, the carpometacarpal joint (CMC) of the thumb is formed. A joint is a connection between two

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adjacent bones whose common contact surface determines the possible movement of the joint.

We use Scanned anatomy specimen Human Hand Bones as our bone model. In Fig. 2, based on this skeletal model, we added a link structure at the joints of each finger in order to improve the force transmission efficiency and stabilize the joints. All parts of our artificial hand are made using a 3D printer. The material we used for this project is ABS plastic.

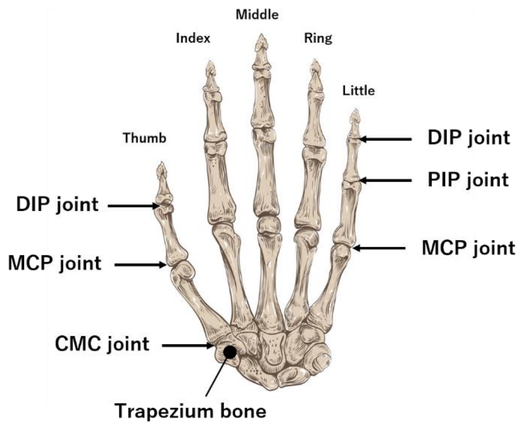

Figure 1. Bones of the human hand.

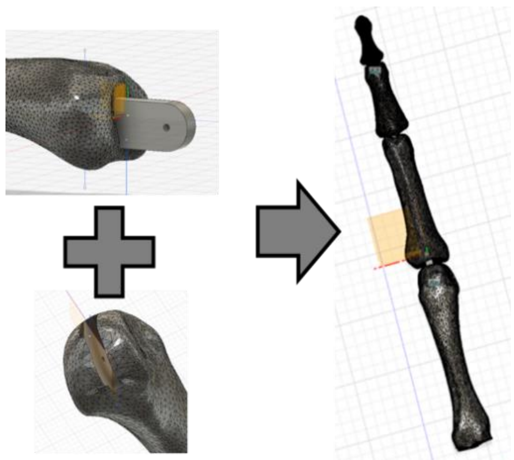

Figure 2. Finger skeletal model.

B. The Joint Ligaments Design

A ligament is the fibrous connective tissue that connects bones to other bones. Each finger joints are supported laterally on each side by collateral ligaments. Due to their positional insertion on the side of the metacarpal, the collateral ligaments become taut when the fingers are bent, and lax when the fingers are stretched. A similar structure can be found in all finger joints. The length, and thickness is depending on the size of the joint, which prevents excessive flexion of each joint. In addition, there is a thick ligament called a volar plate on the palm side, which functions to enhance joint stability and prevent from overstretching.

We made a volar plate using a rubber material with elasticity and strength as shown in Fig. 3 Attaching the copied palm side panel with screws to the position corresponding to Fig. 3, the rubber thread is used to mimic the collateral ligaments on either side of each finger joint and connect the volar plate to the next joint. In addition, the flexion angle of the artificial finger is adjusted to the natural flexion angle of the human finger by adjusting the natural length of the rubber wire.

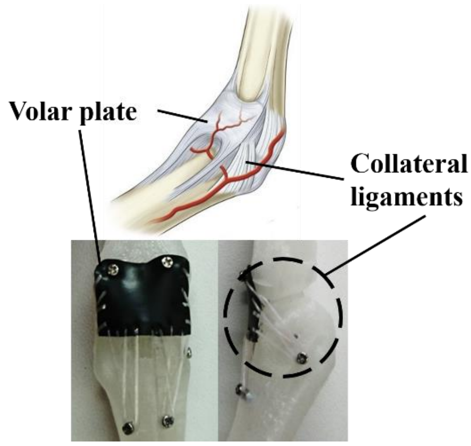

Figure 3. Structure in anatomy and model reproduced.

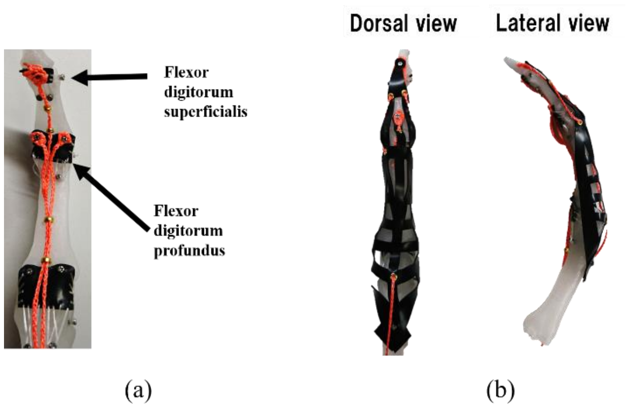

Figure 4. Tendon (a) and Extensor hood sheath (b).

C. Tendon Design

A tendon is a cord of strong fibrous tissue that connects muscle to bone. There are two groups of tendons in the human hand between the bones and the muscles. The ones straightening finger is called the extensor tendon. The ones bending finger is called the flexor tendon. The traction of the two groups of tendons can make the contraction of the muscles drive the movement of different fingers. Flexor tendon consists of flexor digitorum superficialis (FDS) tendon and flexor digitorum profundus (FDP) tendon. FDS tendon adheres to the basal bone of the PIP joint and acts mainly to bend the PIP joint. FDP tendon adheres to the base of the terminal bone of the DIP joint and acts to bend the DIP joint. The Extensor tendon and extensor hood are integrated constructs, and we will introduce the construction of the extensor tendon in the next section.

Our artificial hand mimics is in the construction of the flexor tendon and extensor tendon. As shown in the Fig. 4(a), a tendon is inserted into the artificial finger according to the human hand. The tendon is made of 0.33 mm PE line (X-CORE, JP). Because it has high strength (250N breaking strength), high stiffness, flexibility and its ability to slide smoothly through the sheath. We also used a servo to control the movement of the Extensor tendon. Those two servos are used to simulate the contraction motion of the FDS tendon and FDP tendon so that the DIP joint and the PIP joint can be bent independently.

D. Extensor Hood Design

Extensor tendon have one central fiber bundle reaching the bottom of the middle phalanges, while the two lateral fiber bundles are fixed to the bottom of the distal phalanx. To these lateral tendon bundles, the majority of the interosseous and insect-like muscle tendons adhere and fuse with it, thus stopping at the bottom of the distal phalanx. But a part of these fibers reaches the central tendon bundle under the lateral muscle bundle and combines them. In addition, arcuate connecting fibers that follow the joint capsule wall exist on the back of the phalanx. The mesh structure formed by this structure called an extensor hood. In the volar side of the finger, a confrontation tendon (called the flexor) is connecting from the bone insertion point to the extrinsic muscle located on the forearm to effect a flexion movement.

In Fig. 4 (b) is the extensor hood. We simplified the multi-layer structure of the extensor hood and then cut the highly elastic rubber sheet into the shape of the bellows and attached it to the corresponding position on the phalanx to simulate the effect of the bellows to achieve its biomechanical function.

III. Movement of the Finger

To evaluate the performance of the artificial hand we performed a finger movement experiment on the index finger and the thumb part of our artificial hand. In this movement experiment, the operator uses fingers corresponding to the right hand to move from the extension motion than to the flexion motion, and then repeat the same process again. This process is called an extend-flex manipulation. During the extend-flex manipulation, the movement of the artificial hand is controlled by the operator's hand movement. We used Leap Motion to detect the coordinates of the individual joints of the operator's hand. The detected coordinates will feed back to the computer, and the angle at which the artificial finger is currently bent is calculated by the following formula:

$$\theta = 180 - \arccos\frac{z}{\sqrt{x^2 + y^2 + z^2}} \quad (1)$$

here, x, y, and z are the joint coordinates detected from Leap Motion. As a preliminary experiment, we tested the flexion angle of the index finger PIP joint detected by Leap Motion. The test results are shown in Fig. 5 The detected flexion angle is larger than the flexion angle that can be achieved by the human hand. We adjusted the flexion angle of the joint detected by Leap Motion. Then, according to the coordinates of each joint, is converted into the control of the servo motor that moves the wire to simulate the tendon movement.

The action of the index finger and thumb flexion and extension during an action experiment is shown in Fig. 6 and Fig. 7. We can observe that the movements of the operator's fingers can naturally be transferred to our bionic prosthetic hands. This shows that our design successfully preserves the biomechanics of the human hand.

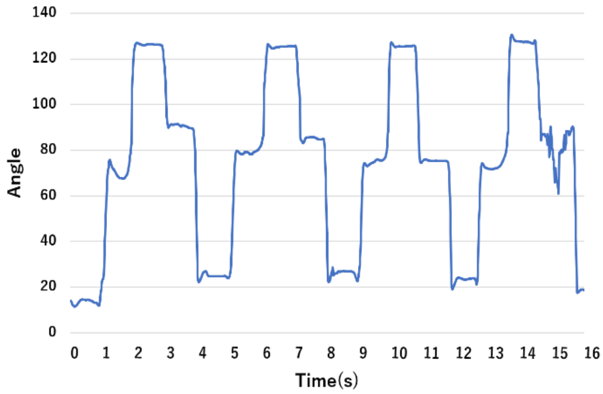

Figure 5. Flexion angle of the PIP joint.

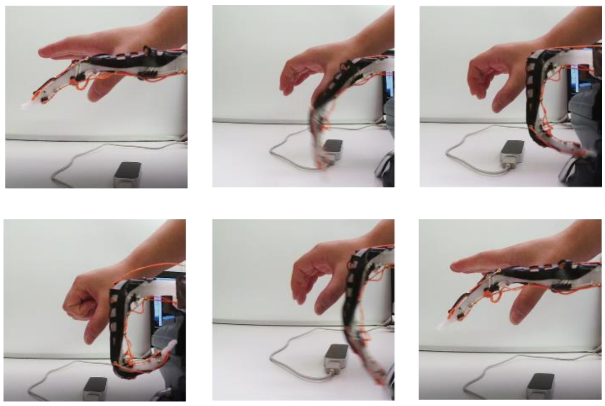

Figure 6. Index finger movement.

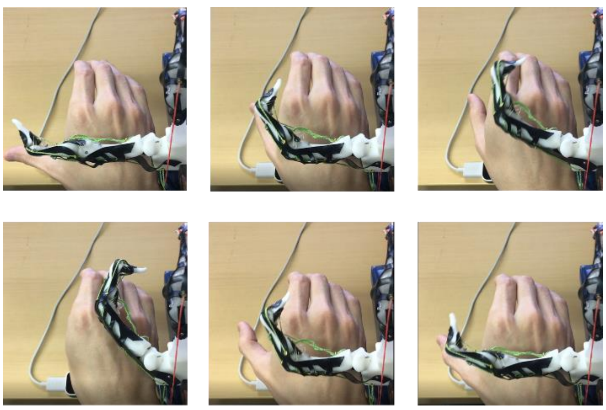

Figure 7. Thumb movement.

IV. Conclusions and Future Works

In this work, we designed and produced a highly anthropomorphic artificial hand with artificial joints and ligaments that are very similar to the biomechanics human hands. Then, we have experimentally proved that our proposed artificial hand design has good mobility in finger movement. This helps to increase the flexibility of the artificial hand and better apply it in daily life. Through a remote operation to grasp and manipulate the various everyday objects in the fingertip workspace under the current design.

In the future work, we plan to integrate the artificial human hand design and the artificial skin that are we about to develop into our prosthetic hands. In addition, due to the inherent similarities between our prosthetic hands and human counterparts, we will compare the trajectories and velocities of our artificial and human fingers to more deeply analyze the performance of the artificial hand we developed.

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