OPTIMUM DESIGN OF 1-DOF ANTHROPOMORPHIC THUMB CONSIDERING GRASPING MOTION FOR INDONESIAN LOW-COST PROSTHETIC HAND

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ABSTRACT

This paper presents the optimum design of 1-DOF anthropomorphic thumb considering the human-grasping motion for Indonesian low-cost prosthetic hand. The mechanism is an improvement of the existing model used by LARM Hand. It is constructed by four linkage system with seven length parameters for two phalanxes of thumb. The optimization criterion is the movement path of grasping motion. The grasping motion that is used as reference is the grasping of cylinder object with diameter size appropriates to anthropometry of maximum grasp diameter for Indonesian hand. This optimum design would be used in development of a low-cost prosthetic hand.

Key words: *anthropomorphic thumb, grasping, low-cost prosthetic hand*

1. INTRODUCTION

Human hand plays an important role in performing daily activities, such as grasping and holding object. However, for those who suffered hand amputation are not going to be able to perform these activities. Therefore, to assist them is by providing a prosthetic hand.

Currently, there are many prosthetic hands available on the market, such as The I-limb Hand by touchbionic, Bebionic Hand, or Michelangelo Hand. They are not only a replacement of human hand function but also with natural appearance. They are also electrically powered and controlled by myoelectric signals so that they are easier to use. Unfortunately, those technology causes the price is high.

In Indonesia, those prosthetic hands can be imported at a cost of not less than $21,200 (Susmartini, 2012). That amount is very expensive for Indonesian with an average of percapita income only about $ 3.542 (BPS data, in 2011). Meanwhile, data from the Orthopedic Hospital Prof. Soeharso Surakarta, showed an increasing tendency of prosthetic hand users (Herdiman et al., 2009). Therefore, a low-cost type of prosthetic hands will be required.

In engineering field, many researches have been done to acquire an artificial human hand. Those researches have carried out design for prosthetic device that can imitate human hand motion. For example, prototype of a multi-fingered anthropomorphic robotic hand by Jaffar et al. (2011), The Spring Hand (Carroza et al., 2004) or The Southhampton Hand (Kyberd & Chappell, 1994). But, most of the available multi-fingered prototypes have a high number of degrees of freedom, a complex actuation, and a high cost (Rodriguez dkk., 2006).

Since late ‘90s at LARM; Laboratory of Robotics and Mechatronics, in Cassino design and research activities have been carried out in order to design a multi-fingered robotic hand having low-cost and easy-operation features (Carbone & Ceccarelli, 2008). The driving mechanism used is a push system, that encourage the first phalanx will actuate the second and the third phalanx. By means of 1-DOF, fewer actuator motor is used. In addition, the material used is aluminium alloy that is lightweight and inexpensive.

However, the design of a push system LARM Hand still potentially occurs buckling especially when cheaper and lighter material is used, e.g. plastic. Takaki and Omata (2009) have developed an anthropomorphic robotic hand used flexion drive and force-magnification-drive mechanism with pull system on the first phalanx. With this mechanism, buckling can be avoided.

Besides the buckling risk, LARM Hand is also using the same design for finger and thumb. The design of thumb is not fit the anthropomorphism because it is designed with three phalanxes. The term anthropomorphism denotes the capability to mimic the human hand, partly or totally, as far as shape, size, consistency, and general aspect (including color, temperature, and so on) are considered (Siciliano & Khatib, 2008). The TBM Hand (Dechev et al., 2000) has thumb design with two phalanxes and one metacarpal link. However, no one specifically designs the optimum design of thumb. Therefore, the optimization criterion which is the most essential aspect for anthropomorphism is the movement of grasping cylindrical object.

In Indonesia, research on myoelectric signals has been studied by Susmartini (2012). The study has carried out a system that can capture and process (filter, amplify, and calibrate) myoelectric signals that occur during the muscles contraction. Meanwhile, along with this study at product planning and design laboratory has also developed an optimum design for the finger of Indonesian people. Therefore, research was conducted to obtain the optimum design of 1-DOF anthropomorphic thumb as complements previous research.

2. THEORETICAL BACKGROUND

2.1. Structure of Thumb

Thumb has different structure than the other finger. Thumb consists of two phalanxes (proximal phalanx and distal phalanx) and a metacarpal. The base of the thumb is Trapezoid-Metacarpal joint (TM), for the most distal part is called Distal-Inter-Phalangeal joint (DIP) and central joint is called Metacarpal-proximal joint (MP). Figure 1 shows joint and bone of thumb

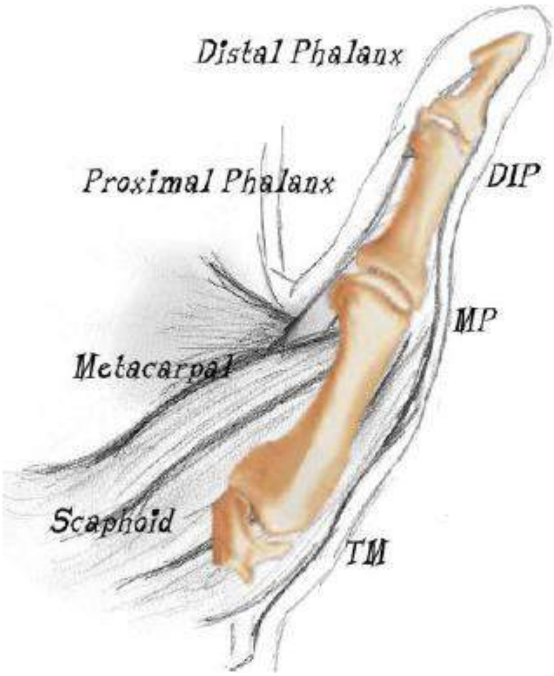

Figure 1. Thumb Joints and bones
Source: Chalon et al., 2010

2.2. Thumb Design of LARM Hand

LARM Hand has been developed at Laboratory of Robotics and Mechatronics, Cassino, Italia. LARM Hand is designed from inexpensive and lightweight material with 1-DOF of driving mechanism (Rodriguez et al., 2006). Currently, the last prototype developed is LARM Hand version 4, which is constructed by three fingers with three phalanxes for each finger. The prototype can be seen on figure 2. In particular, the driving mechanism moves all of the three segments simultaneously with one active degree of freedom to do grasping of cylindrical objects. This movement is enabled by a simple cross-four bar link which can be optimized. Figure 3 shows the kinematic diagram of LARM Hand.

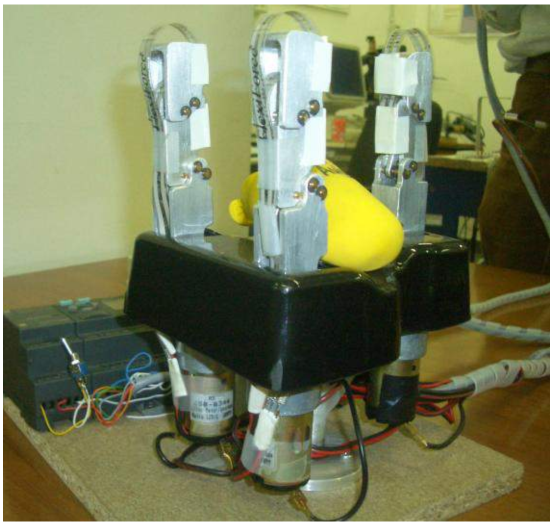

Figure 2. LARM Hand version 4 at LARM in Cassino
Source: Carbone &Ceccarelli, 2008

LARM Hand uses the same design for the fingers and thumb. It is not fit the anthropomorphism for the thumb because thumb has two phalanxes. Therefore, a new design is required.

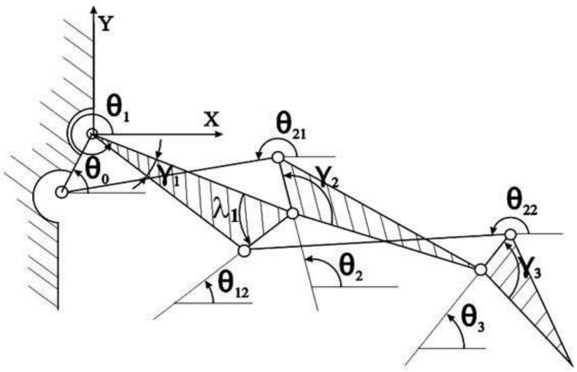

Figure 3. Kinematic diagram of LARM Hand
version 4 at LARM in Cassino
Source: Rodriguez et al., 2006

2.3. Thumb Design of TBM Hand

TBM Hand is developed in Toronto, Ontario, Canada, by Dechev, et al. (2000). It is designed for children hand. The thumb has four links to represent the two phalanxes of human thumb. The caropometacarpal link is designed to be their base. The thumb is able to flex, extend and rotation. The drive cable provides mechanical actuation needed to flex and extend (Dechev et al., 2000). This design is more representative because it fit the anthropomorphism highly. Figure 4 shows thumb design of TBM Hand.

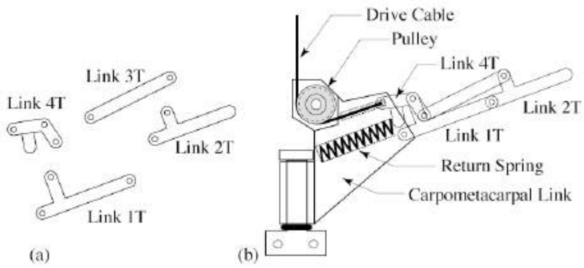

Figure 4. Thumb link design and assembly of TBM Hand (a) distal portion uses four links (b) assembled thumb
Source: Dechev, et al. (2000)

3. RESEARCH METHOD

The initial phase of this study starts from the study of literature on the design of a thumb. Through the study of literature, it defined the purpose of obtaining the optimum design for thumb motion mechanism by considering the movement of grasping cylindrical objects. Design phase through the following stages.

1. Determination of grasping object

Grasping object dimension is determined by anthropometry data of maximum grasp diameter for Indonesian hand. The data used is percentile 50 or 48 mm as referred from Nurmianto (2008).

2. Video recording of grasping motion

The grasping motion is the optimization criterion as the most essential aspect. Before recording, each joint in the thumb is marked. Those marking are used to get the angle of motion (θ_1 and θ_2) and position (x, y) DIP joint as a reference point. Then, record the grasping cylindrical objects motion. The recording is about 1.621 s. The video is processed using freeware of CVMob 3.1 to get the grasping motion angle and the reference point of DIP Joint. Figure 5 shows the grasping object process.

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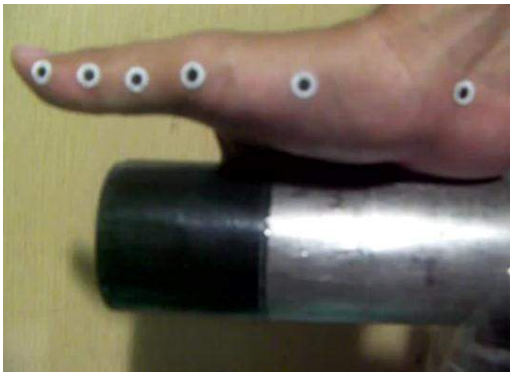

(a)

(b)

Figure 5. Grasping object process, (a) start position (b) end position

3. Determination of initial guess design based on grasping motion angle

Based on the grasping motion angle, θ_1 and θ_2, the initial design for driving mechanism can be determined. As the main initial guess for the first linkage of proximal phalanx diameter (d_1) is 10 mm. Through comparison of the diameter and angle that is formed, the diameter of the distal phalanx (d_2) can be determined. The length of each phalanx is the distance between two joints. The length of the proximal phalanx (l_1) and distal phalanx (l_2) respectively are 29 mm and 20 mm. And the length of the crossed link (l_3) is determined by the tangent line of l_1 and l_2 with the addition of half-angle movement that occurs in the distal segment (θ_2).

4. Determination of reference point

The reference point is the position (x, y) in time (s) which is used as path optimization. The reference point is based on the DIP Joint.

5. Modeling with SAM 6.0 software

The driving mechanism of initial guess design is modeled on software ARTAS SAM version 6.0. The input data that is used are the length of links, input motion angle (θ_1), and process time.

6. Optimization with SAM 6.0 software

After preparing the model, the next step is running the optimization. The optimization is set on automatic mode which is the best solution of the global search is automatically refined in a local optimization. The method used in local optimization is simplex method with max iterations is set 100 and the search is within the boundaries. The type of objective is path (timing) with the reference point obtained previously. And the parameters are set randomly.

4. RESULT AND DISCUSSION

4.1. The Grasping Motion Angle

The angles formed between the thumb phalanxes are denoted as θ_1 and θ_2. θ_1 is the angle formed from the initial position of grasping to the proximal phalanx at the end position of grasping. While θ_2 is the angle formed from the initial position of grasping to the distal phalanx at the end position of grasping. By processing on CVMob 3.1 freeware, θ_1 and θ_2 are obtained at 48° and 94°. Figure 6 shows the motion angle of grasping object. Therefore, 48° is used as the input motion angle for the driving mechanism model in SAM 6.0.

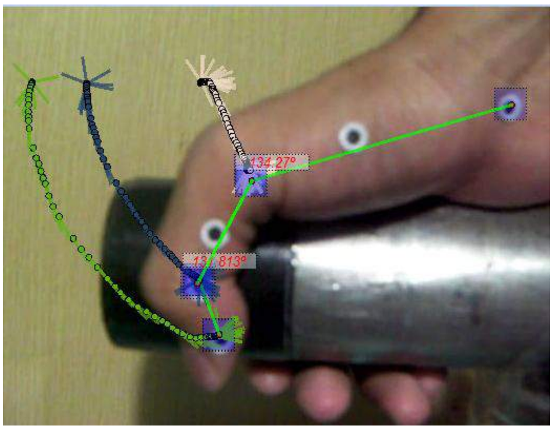

Figure 6. The motion angle of grasping object with CVMob 3.1 freeware

4.2. Initial Guess Design

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The initial guess design for the driving mechanism is built from the length of the phalanxes. Length of proximal phalanx (l_1), distal phalanx (l_2), and the initial length of l_3 respectively are 29 mm, 20 mm, and 5 mm. Figure 7 shows the initial guess design and table 1 shows length of the link.

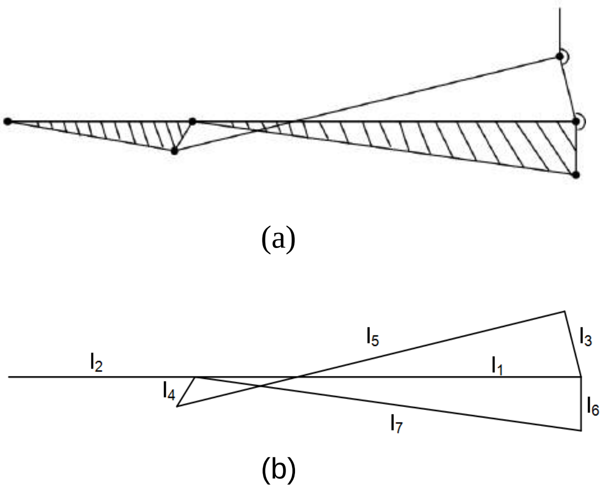

Figure 7. Initial guess for the driving mechanism of thumb (a) four linkage system (b) seven length parameters

Table 1. Length of links for initial guess

No	Link	Length (mm)
1.	l_1	29
2.	l_2	20
3.	l_3	5
4.	l_4	2.565
5.	l_5	29.883
6.	l_6	4
7.	l_7	29.275

4.3. Optimum Design

By running the optimization in SAM 6.0, the optimum design has been reached. It is acquired after the maximum iteration of global search (set 300 iterations and 50 populations) is reached and 0 iteration for the local optimization. Figure 8 shows the optimum design and table 2 shows the length of the links. And figure 9 shows driving mechanism after being optimized.

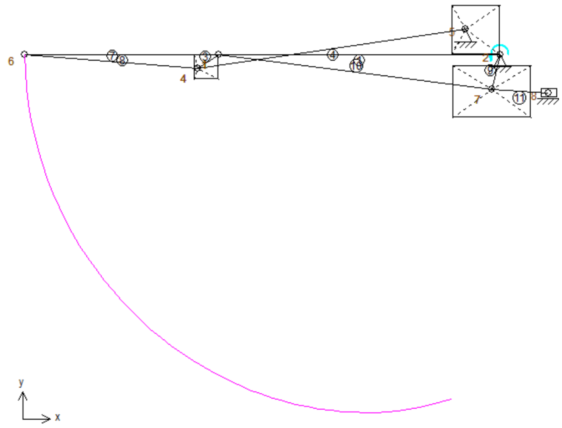

Figure 8. Optimization by SAM 6.0

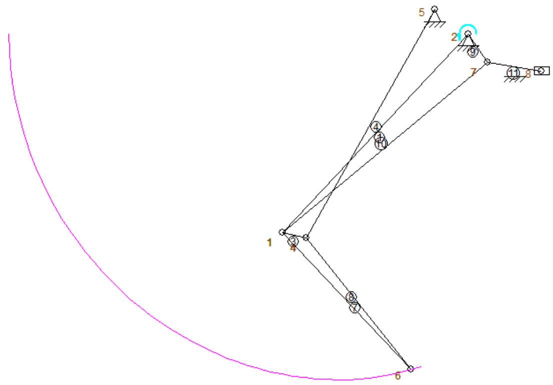

Figure 9. The driving mechanism of thumb after being optimized

Table 2. Links length of optimum design

No	Link	Length (mm)
1.	l_1	29
2.	l_2	20
3.	l_3	4.356
4.	l_4	2.614
5.	l_5	27.927
6.	l_6	3.688
7.	l_7	28.375

5. CONCLUSION

This research has carried out the optimum driving mechanism design of thumb considering the grasping cylindrical object movement of the hand. The mechanism has used pull system. The optimization is based on movement path of grasping motion. As a recommendation for further research, it is needed a basic consideration for determining the search area of the parameters.

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