THE BIOMECHANICAL APPROACH DURING THE DEVELOPMENT OF INDEX FINGER FOR UFMG HAND PROSTHESIS

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Abstract. *Many underactuated mechanisms have been under development during the development of hand prosthesis. These prosthesis present components as springs, cables sometimes bulk mechanisms to do anthropomorphic movements. The size and the weight of these mechanisms must be minimal because hand prosthesis can not be heavy and there is not enough space in the palm of the hand for many components, motors circuits and sensors. This work presents a biomechanical approach during the project of a functional structure of index finger for the UFMG hand prosthesis, which allow the development of the structure for the index finger with underactuated anthropomorphic movements. The weight of the finger was also reduced with the development of a new mechanism to control it.*
Keywords*: Underactuated, hand prosthesis, biomechanical approach*

1. INTRODUCTION

In robotics, human have been representing a great inspiration source for the development of a new technology (Dario et al., 2002). The hands are one of the most advanced parts in the human body, when this comparison is made in regard to the control of human movements.

A similar prosthesis hand should match some requirements of a human hand, as size, mobility, weight and it must be perceived as part of the natural body (Carozza et al., 2004). In a biomechanical approach these prosthesis must present a great similarity to the human hand, like size, weight, functionality and some authors emphasize that the way how the finger moves is important too (Peter J.Kyberd et al., 2001; C.M.Light and P.H.Chappell, 2001; Cunha et al., 2000).

It means that the prosthesis needs to perform anthropomorphic movements (Peter J.Kyberd et al., 2001; Cunha et al., 2000; Cura et al., 2002), present a great mobility and be light .

To implement an antrophomorphic movement in hand prosthesis it is necessary to be acquainted with the fingers movements. During the analysis of the fingers and hand movements, goniometry (Murugkar et al., 2004) and photography (Vergara et al., 2004) can be used for static analysis, IMR images (Natsuki Miyata et al., 2005), stereophotogrammetry (Yokogawa and Hara, 2004; Degeorges et al., 2005; Carpinella et al., 2005; Chiu et al., 1998; Li and Tang, 2006), and gloves can be used for dynamic analysis. 3D stereophotogrammetry is a method that has been used by a large number of researchers to capture and analyze the movements but for the best performance of this method the clusters need to be fixed on the premises with minimal skin movement (Leardini et al., 2005). These 3D stereophotogrammetry (Yokogawa and Hara, 2004; Degeorges et al., 2005; Carpinella et al., 2005; Chiu et al., 1998; Li and Tang, 2006) methods are expensive, delay a long time and required complex analysis. Cura , V. O et al (Cura et al., 2002) presents a fast and low cost method to analyze movement specific for a hand prosthesis but it can be used only for index and middle finger.

In anthropomorphic hand prosthesis, the fingers movements, size and weight must be similar to the human hand. The robotics hands are the mechanical structures most similar with the human hand when this comparison is made in regard to human movements and degrees of freedom (DOF). But these hands present many different structures and sophisticate transmission mechanisms to simulate the human movement(Lotti et al., 2002; Lotti et al., 2004; Diffler.M.A. et al., 2003), and can not be used as prosthesis because of its weight, size and control method. In prosthesis, the mechanisms must be small, simple, lightweight, present a little energy consume, high torque, and generate the minimal heat (Cura et al., 2003). The prosthesis hand, must present many DOFs, but must present the least numbers of actuators as possible to control it. One kind of mechanism that can be used in prosthesis is called underactuated. This mechanism is present in the most advanced prosthesis that have been developed (Carozza et al., 2001; Dario et al., 2002; C.M.Light and P.H.Chappell, 2001; Peter J.Kyberd et al., 2001)

Using underactuated mechanisms, it is possible to generate in the hand prosthesis the same movement as the human finger for different kind of grasps. Some prosthesis projects can use only two or three motors to control all hands movements.

In this work there will be a method to capture and to analyze the finger movement, specific for hand prosthesis, and a new underactuated mechanism will be present based on an elastic tendon to control the finger movement.

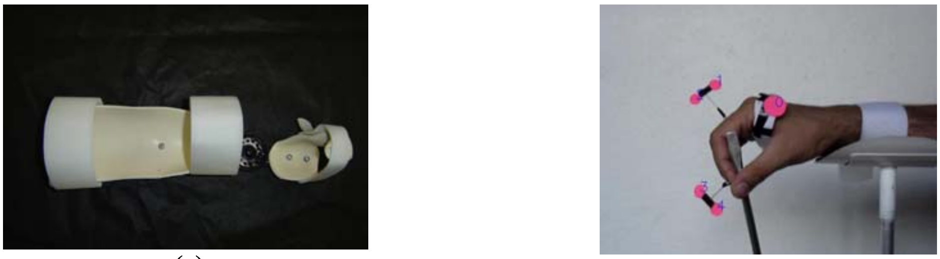
2. METHODOLOGY

To build a prosthesis hand it is necessary starting with the basic component of the hand, the finger. In regard of that it is necessary to developed a mechanism to move the artificial finger as a human finger. The human finger presents complex relations into muscles tendons and bones, and because of it the fingers present unique movements, which allowed the hand to adapt to any object. To implement this movement into hand prosthesis it is necessary before to determinate the angular relations between the joints.

2.1 – Motion Capture

Using the methodology developed by Nagem (2007) to capture functional movements of fingers, except of thumb, the angles of each joint of the fingers, were determinated during pinches.

It was used an orthosis, Figure 1a, to fix the wrist in a functional position (Ge Wu et al., 2005), and then a ring with a little stick and two cluster were fixed in the middle of the phalange proximal and distal, Figure 1b.



(a) (b)

Figure 1 – (a) Orthosis to hold wrist, (b) The markers on hand, during capture motion.

The distances between each cluster and the respective joint were measured, Figure 2. It is possible determinate the position of each joint, using trigonometric relations (Nagem et al., 2007)

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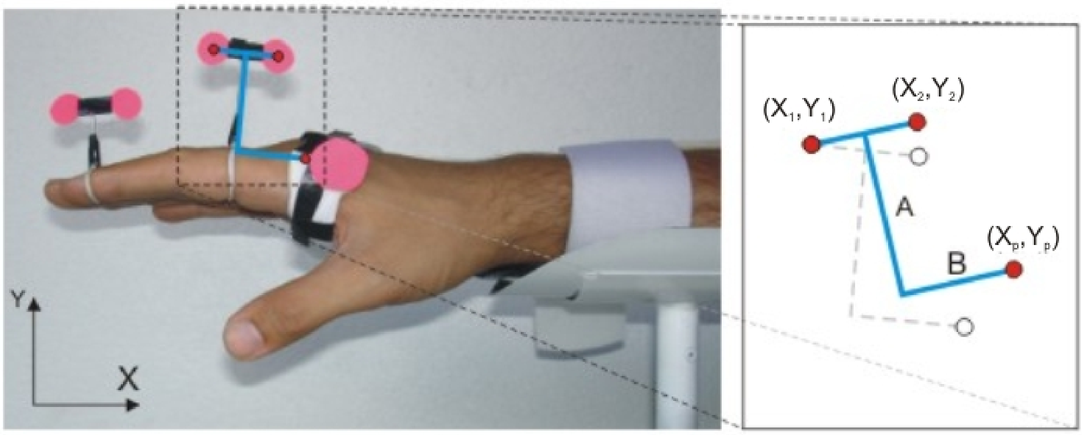

Figure 2 - Detail for joint position analysis

The equations (1) and (2) shows the relations between the clusters position (x_1, y_1) (x_2, y_2) and the position of the joint (x_p, y_p). With the joints positions it is possible to determinate the angle of phalanges during the movement in a bi-dimensional analyzes.

$$x_p = \frac{x_1 + x_2}{2} + \frac{a(y_2 - y_1) + b(x_2 - x_1)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \tag{1}$$

$$y_p = \frac{y_1 + y_2}{2} + \frac{b(y_2 - y_1) - a(x_2 - x_1)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \tag{2}$$

2.2 – Mechanism design

After an analysis of different kinds of actuators and mechanical systems used in the most common prosthetics hands (Cura et al., 2003), it was decided to use a pulley system for UFMG hand prosthesis. Each joint is connected with two cables in a main axis, one to control the flexion and the other the extension (Figure 3a).

This transmission system allowed controlling the angular position of each joint tendon based on the position of the main axis. The angular position of main axis (θ_{main}) and its radius define the cable motion (Δx). The position of each joint is a function of main axis, each previous joint and its own diameter, as it can be seen in Fig. 3 b and 3 c, and Eq. (4)(5) .

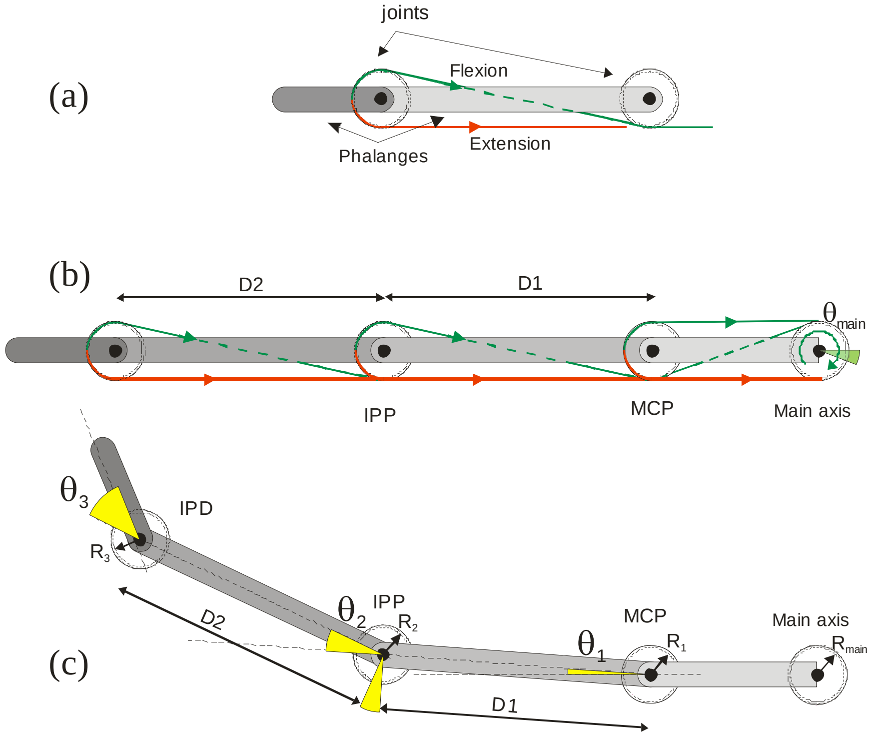

Figure 3 -(a) Common mechanism. (b) Finger with tendons. (c) Linked movement

$$\Delta\theta_3 R_3 = \Delta x + \theta_2 R_2 + \Delta\theta_1 R_1 \tag{3}$$

$$\Delta\theta_2 R_2 = \Delta x + \Delta\theta_1 R_1 \tag{4}$$

$$\Delta\theta_1 R_1 = \Delta x \tag{5}$$

Using common types of cables, rigid one, to move fingers, the phalange movement is proportional to the movement of the other phalanges, despite any external force applied on fingers. This kind of mechanism can not allow a complete and safe grasp on objects with complex geometry. This happens because one phalange can touch the object before the others, and this will stop the finger movement (Figure 4 a).

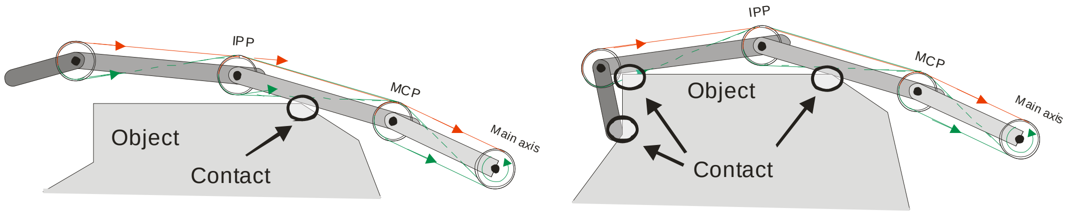

Figure 4 - (a) Common mechanism. (b) Underactuated mechanism.

An artificial elastic tendon has been developed to be used in UFMG hand prosthesis, and it allowed an underactuated movement, Fig. 1b. This tendon presents elastics and non elastics parts; it works as a tension spring, and present easier assembly in prosthesis than the common springs. The joint position, using elastic tendon instead of rigid cable, is a function of main axis, the other phalanges angles and the torque in it.

The joint position ($\theta_{elástico}$) is defined using Eq. (6) and (7).Where x represents the elastic deformation by the torque (T) applied to the joint.

$$\theta_{i-elástico} R_{i-elastico} = \theta_{i-rígido} R_{i-rígido} - x_{elastico} \tag{6}$$

$$T = R_i f(x)_{elástico} \tag{7}$$

3. RESULTS

3.1 – Motion Capture

The graphic displays phalange path during some functional pinch movement, Figure 5. It is possible to observe that the movement during flexion is different than the movement during extension. This difference is a function of tendons, pulleys, and muscles in the hand. This can prove that the mechanism to control the flexion is different than the mechanism to control the extension.

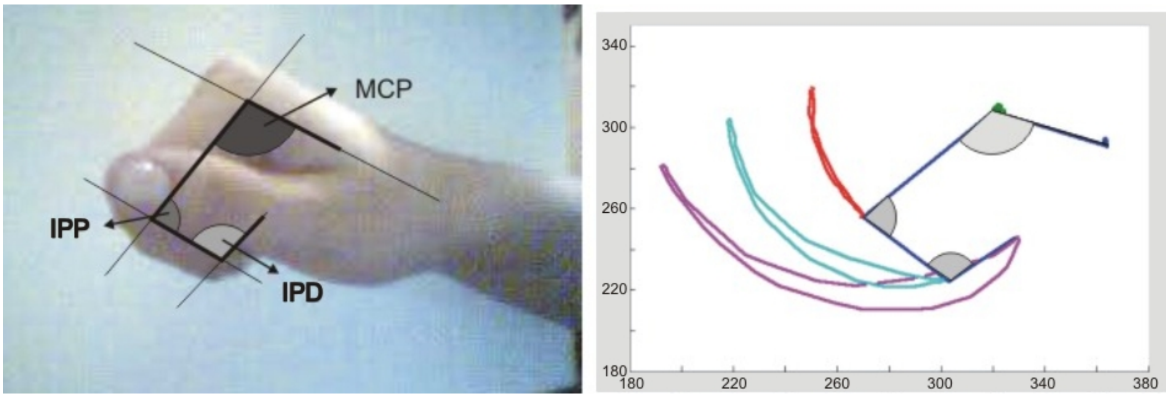

Figure 5 - (a) Hand in lateral pinch, (b) Graphic phalange path display.

The phalange angles, for each finger, during functional lateral pinch were measured using the methodology developed in Nagem, D. A. P *et al* (2007), and was showed in Fig. 6.

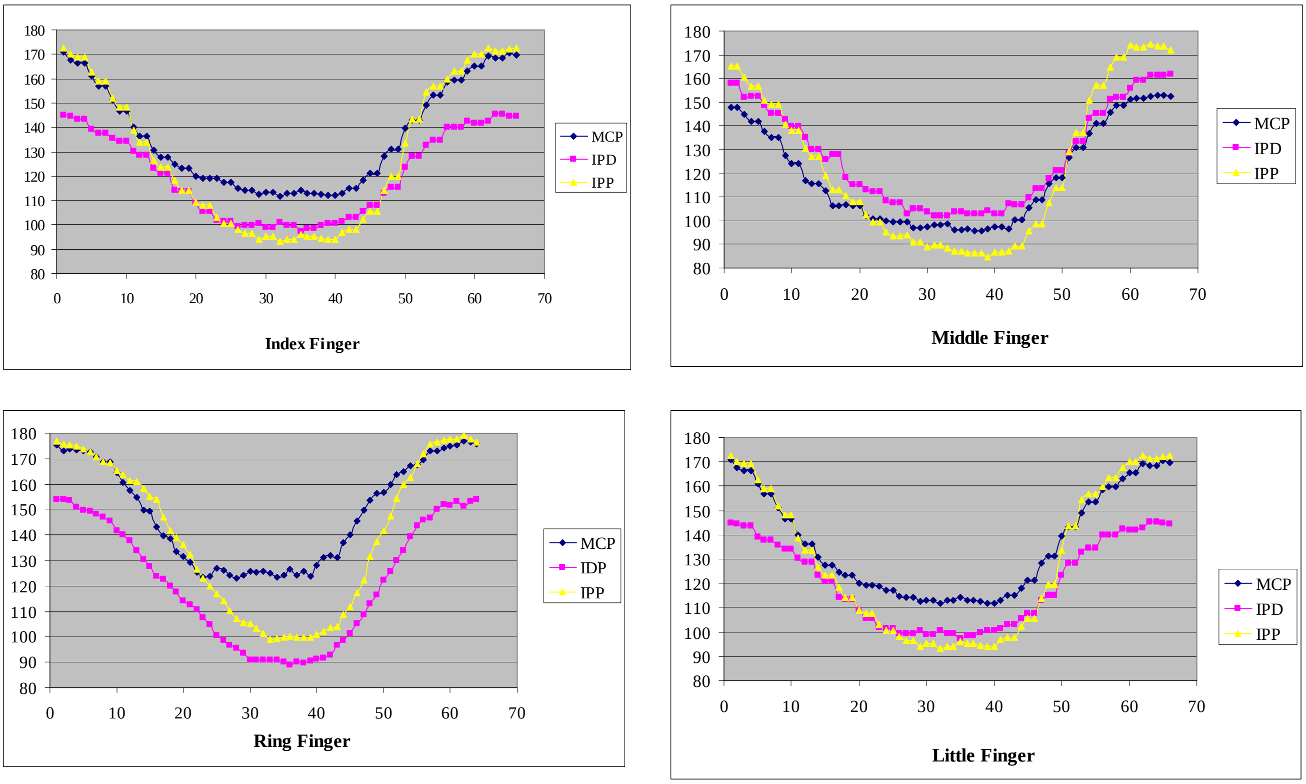

Figure 6 – Angle position for index, middle, ring and little finger during lateral pinch

These angles represent the movement of finger during a period of two seconds, one second for flexion and one for extension. To construct a prosthesis with movement similar to a human hand these movement patterns must be implemented in each finger of this hand prosthesis.

These patterns represent one kind of pinch, and were chosen because during that the fingers almost complete the maximal flexion. The other pinches, cylindrical, precision and others, do not have the same angular variation.

3.2 – The underactuated mechanism

For the UFMG hand prosthesis the fingers were designed using the same diameter for work joint axis and a small diameter for the anterior axis in the same tendon (Fig. 7). All the elastic tendons are fixed in a main axis, two tendons for each phalange, one for flexion and one for extension. To generate the movement patter defined by Fig. 6 it is necessary a special geometry for main axis. This geometry will be defined as a function of equations (3) to (5) and the movement pattern defined in Figure 6.

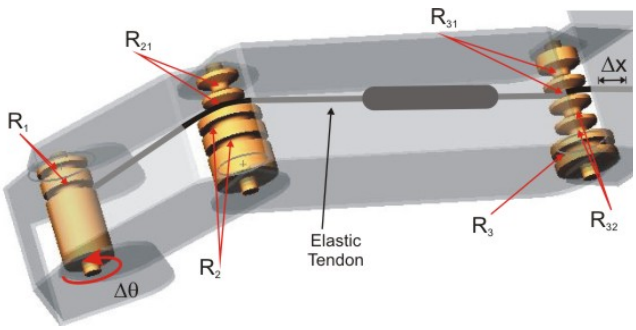

Figure 7– Virtual model of the finger.

A prototype has been build to test the mechanism with a cable and with elastic tendon transmissions system. The Figure 8 shows the free movement of a prototype with common cables transmission system and elastic tendon. The movement of the finger using common cables is only a function of main axis position, but in underactuated mechanisms it depends on the external force. In free movements the inertial and friction forces are the external forces. Because of that during free movements both mechanisms have a similar kinematics.

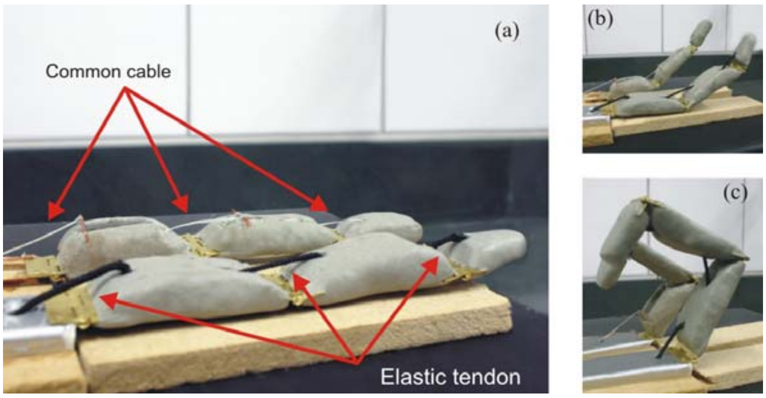

Figure 8 - Free movement of index finger. Three different positions.

During grasp of complex geometry, it is possible to understand how the underactuate mechanisms can provide a better stability to the grasp than a common mechanisms, Figure 9. The movement of the finger is a function of the main axis position and the external force applied in finger phalanges.

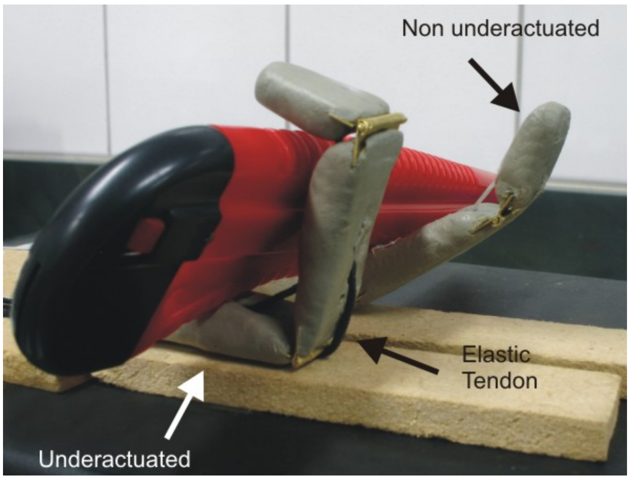

Figure 9 – Grasping a complex object.

The prototype can adapt to complex geometry because of its underactuated mechanism, the elastic tendon.

4. CONCLUSIONS AND DISCUSSION

During the biomechanical approach for the development of hand prosthesis it is necessary to know the physics and kinectical characteristics. The method developed to capture and analyse the hand motion can be used to establish a movement gauge to any human hand, and it can be applied in prosthesis.

For the hand prosthesis user this method can be applied to determinate the healthy hand motion pattern and it can be used into prosthesis development.

The developed mechanism is underactuated and it can provide a safety grasp controlled by only one actuator.

Future works will be focused in the design and construction of the main axis with a geometry based on the developed methodology. It has been developed a methodology to analyze and determinate the elastic characteristics of elastic tendon.

6. ACKNOWLEDGE5

The authors are gratefully acknowledge CAPES for their financial support.

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