Design of a Novel Articulated Hand: Erciyes-1

Yeni Bir Eklemli El Tasarımı: Erciyes-1

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Abstract

This paper aims to present a novel robotic hand system which is called Erciyes-1. The Erciyes-1 robotic hand is a multi fingered dexterous hand. The aim of the design of the Erciyes-1 is to increase capabilities of the robotic hands. The hand comprises of five fingers (four fingers and one thumb), each fingers having three degrees of freedom (DOF) and thumb has 4 degrees of freedom (DOF), which can perform grasping, manipulating and exploring. For the actuation purpose, dc servomotors are used and these motors integrated in the finger’s joints directly. A novel thumb mechanism was developed on Erciyes-1 for reach maximum moving capability in the variety of positions. Additionally, a new force measurement system applied on the end points of the fingers. The paper exemplifies the design for the robotic hand and presents the forces produced at each finger's endpoints of the robotic hand. Also, the standard PID has been applied for control of the joints. A new thumb mechanism and force measurement system have been given perfect results for the movement capabilities and force measurements of the fingers. The new thumb mechanism provides better moving capacity for the hand mechanism than the robotic hands built before.

Keywords: Humanoid hand, Mechatronics, Robotic hand, Robotics, Thumb mechanism

1. Introduction

The application of robotic systems in unstructured servicing environments requires dexterous manipulation abilities and facilities to perform complex remote operations in a very flexible way. In the last decade, many studies have been conducted with the aim of developing a humanoid hand. The main aim of the studies was to built a robotic hand with as many human features as possible such as sensitivity, physical dimensions, gripping and grasping capacity, etc. Some examples of multifunctional hand designs are: the Stanford/JPL hand developed by Stanford University (Salisbury and Roth 1983), the UTAH/MIT hand developed by Utah University (Jacobsen 1986), the Belgrade/USC hand developed by University of Belgrade (Bekey et al. 1990), the Barret hand developed by Barret Tech. Inc. (Townsend 2000), the UB hand developed by Bologna University (Melchiorri and Vasura 1991, 1992), the DLR hand developed by DLR-German Aerospace Center (Butterfass et al. 1998, 2001), the Taut/Karlsruhe hand developed by Tokyo and Karlsruhe Universities (Fukaya et al. 2000), the Robonaut hand developed by NASA (Lovchik and Diftler 1999, Ambrose et al. 2000), the Gifu...
hand developed by Gifu University (Schulz et al. 2001), the Shadow hand developed by Shadow Robot Company Ltd. (Shadow hand webpage) and University Tun Hussein Onn Malaysia developed the UTHM hand (Zaid and Yaqub 2012). A comparison of experimental humanoid hands is listed in Table 1.

As shown in the literature, many research centers have developed different kinds of humanoid robotic hands. In this study, we developed a novel humanoid hand, Erciyes-1, which also includes a novel thumb and force measurement mechanisms. After a brief description of the hand, including the thumb and force measurement mechanisms and control feature; the hardware and software architecture is outlined with particular emphasis on flexibility and performance issues. This paper is outlined as follows: section 2 presents the design structure and describes the prototype of the Erciyes-1, Section 3 presents force measurement and experimental results of the system of Erciyes-1 and, Section 4 is my conclusions. In this article, a novel thumb mechanism and a novel force measurement system first time applied for robotic hand.

Table 1. Humanoid hand designs.

<table>
<thead>
<tr>
<th>Design Name</th>
<th>Design Year</th>
<th>Number of Fingers</th>
<th>Does it have a thumb?</th>
<th>Number of Joints</th>
<th>Degrees of Freedom</th>
<th>Powered By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stanford/JPL Hand</td>
<td>1983</td>
<td>3</td>
<td>NO</td>
<td>9</td>
<td>9</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>UTAH/MIT Hand</td>
<td>1985</td>
<td>4</td>
<td>YES</td>
<td>16</td>
<td>16</td>
<td>PNEUMATICS</td>
</tr>
<tr>
<td>Belgrade/Hand</td>
<td>1988</td>
<td>5</td>
<td>YES</td>
<td>18</td>
<td>4</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>Barret Hand</td>
<td>1988</td>
<td>3</td>
<td>NO</td>
<td>8</td>
<td>4</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>UB Hand</td>
<td>1992</td>
<td>4</td>
<td>NO</td>
<td>13</td>
<td>13</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>LMS Hand</td>
<td>1998</td>
<td>4</td>
<td>YES</td>
<td>16</td>
<td>16</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>DIST Hand</td>
<td>1998</td>
<td>5</td>
<td>YES</td>
<td>16</td>
<td>16</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>Robonaut Hand</td>
<td>1999</td>
<td>5</td>
<td>YES</td>
<td>22</td>
<td>14</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>Tokyo Hand</td>
<td>1999</td>
<td>5</td>
<td>YES</td>
<td>16</td>
<td>12</td>
<td>ARTIFICIAL MUSCLES</td>
</tr>
<tr>
<td>DLR Hand</td>
<td>2000</td>
<td>4</td>
<td>YES</td>
<td>17</td>
<td>13</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>Taut/Karlsruhe Hand</td>
<td>2000</td>
<td>5</td>
<td>YES</td>
<td>24</td>
<td>1</td>
<td>DC MOTOR</td>
</tr>
<tr>
<td>Ultralight Hand</td>
<td>2000</td>
<td>5</td>
<td>YES</td>
<td>18</td>
<td>13</td>
<td>HYDRAULIC</td>
</tr>
<tr>
<td>Gifu Hand</td>
<td>2001</td>
<td>5</td>
<td>YES</td>
<td>20</td>
<td>16</td>
<td>SERVO MOTOR</td>
</tr>
<tr>
<td>Shadow Hand</td>
<td>2002</td>
<td>5</td>
<td>YES</td>
<td>23</td>
<td>23</td>
<td>PNEUMATIC MUSCLES</td>
</tr>
<tr>
<td>Uthm Hand</td>
<td>2012</td>
<td>5</td>
<td>YES</td>
<td>20</td>
<td>20</td>
<td>PNEUMATIC MUSCLES</td>
</tr>
</tbody>
</table>

2. Design structure of the Erciyes-1

ERCIYES-1, a multi-sensory articulated hand, see Fig.1, is a five-fingered hand with total of sixteen degrees of freedom which is designed and built for this study. It consists of a thumb, which is designed for this study, and four other fingers and parts of the control system. The control system consists of control cards for each axis which act upon signals coming from a computer. The actuation system is uniformly based on DC servomotors with screw-drive, which are integrated in the hand’s palm and in the fingers directly. At each finger joint there is a position sensor to get accurate position control.

ERCIYES-1 is constructed of high tensile strength aluminium alloy components. Individual finger parts are held rigid by cross members and linked by an aluminium plate. This construction technique is lightweight and at the same time contributes to the rigidity of each part of the fingers. Its operation ranges are: -180° to +180° (maximum speed 40°/s) for wrist rotation, 0° to +90° (maximum speed 70°/s) for each finger’s phalanxes and -40° to +40° (maximum speed 70°/s) for the thumb.
Motion commands are generated from a computer and all commands and communications are employed by using the serial ports of the computer. ERCIYES-1’s position repeatability is ± 0.1 mm for each axis.

2.1. Design of the fingers

Motions of the fingers are generated by DC servomotors which consist of gearboxes which decrease angular velocity and increase the torque of the motor unit. DC servomotors are used with screws and nuts to enable each phalanx to move (Fig.2). The servomotor’s position data is measured by position encoders which are directly connected to the motors. Because of the finger mechanism’s simple structure, it can be produced easily and can achieve different positions without any difficulty.

2.2. Design of the thumb

A novel structural thumb design was developed and built in order to perform grasping tasks. The thumb reaches the required position for grasping by turning around the center of a circular base plate (as shown in Fig. 3-a).

Here \( q_1 \) is the finger’s angular position on the circular base of the thumb, and \( q_2 \) is the angular position of the thumb’s proximal phalanx from the base of the thumb. The thumb is powered by a DC servomotor unit. As can be seen from Fig. 3 (b), which shows the reverse side of the system, the thumb gear is connected to the DC servomotor by a gear system which was designed for this study. This new system consists of a DC servomotor and a reductor mechanism, which is fixed on the palm of the hand and to the thumb with the gear unit. This gear unit does not have any central connection or bed mechanism. Because of this special design of the thumb mechanism, ERCIYES-1 reaches many positions without any difficulty. Parts of the thumb mechanism shown on Fig.3-b:

1. Gear unit integrated on fingers.
2. DC Motor for angular movement of the thumb.
3. Encoder for measurement of the angular position of thumb.
4. DC motor gear unit for power transfer from motor to finger gear unit.
5. DC motor and gear unit for wrist movement.

The novel thumb mechanism increases the abilities of the ERCIYES-1 with its flexible movement capability. So, different kind of parts can be grasped by ERCIYES-1.
In this system, main body of the finger last phalange (2) carrying all mechanical parts of the force measurement system. Grasping reaction force is applying on the head of the part (5) and by using this mechanism grasping force effects on the spring (4) and part (3). So, the position of the part (3) has been changing as much as value of the effected force. \( L_1 \) is the first position and \( L_2 \) is the second position of part (3). This position change \((L_1 - L_2)\) measuring by inductive sensor (1). This value has been calibrating by known forces.

As known; when we apply force on the spring, the length of the spring changes. In my study we have used this principle to measure applied force by fingers of the hand to the different types of objects.

\[ F = k \cdot x \]

- \( F \): Applied Force (Newton)
- \( k \): Spring Constant (N/m)
- \( x \): Change the length of spring (m)

\[ X = (L_1 - L_2) \text{ (m)} \] for my study and \( k = 0.001 \text{ N/m} \), material is the cold shaped steel and material standard number is DIN 17223-A. Results of the force measurements for different tasks are given in Figure 5.

Trajectory control is one of the most important factors for positioning of the fingers. Many controllers have been tested to improve the tracking performance of robotic hands. Since they have a simple structure and easy design, PID controllers have been widely used in many control applications. In this study, standard PID controller used for position control of the fingers’ joints (Figure 6).

The block diagram for the standard PID controller is given in Figure 6, where \( q \) is actual position data and \( q_d \) is the desired position value. Mathematical expression of standard PID controller is:
As shown in Figure 7, standard PID controller has given perfect results for thumb mechanism.

4. Conclusion

Achieving perfect moving capabilities with a smaller hand mechanism is a major problem for researchers, in the field of robotics. In this study, a novel design for a thumb mechanism and robotic hand mechanism, called the ERCIYES-1, was proposed. It could be used for prosthetic hands and for other robotic systems. Standard PID controller applied on this robotic hand mechanism for control of each joints. Experimental results for thumb have presented. Due to

\[ y(t) = K_p e(t) + K_i \int_0^t e(t) \, dt + K_d \frac{de}{dt} \]  

(1)

The proportional part of the control action repeats the change of deviation. The derivative part of the control action adds an increment of manipulated variable so that the proportional plus derivative action is shifted ahead in time. The integral part of the control action adds a further increment of manipulated variable proportional to the area under the deviation line. \(K_p\), \(K_i\), and \(K_d\) coefficients are determined by experimental study and the results of these experiments presented in Figure 8.

![Figure 5. Results of the force measurements for different tasks.](image)

![Figure 6. Standard PID controller.](image)
improved thumb design, it can be easily built and has more flexible moving capabilities than other similar systems. Because of force measurement system, used on ERCIYES-1, it can measure different forces very easily and inexpensively.

5. References


