Karaelmas Fen ve Mühendislik Dergisi
Journal home page: http://fbd.beun.edu.tr

Research Article

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 capality for the hand mechanism than the robotic hands built before.

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

Öz

Bu çalışma Erciyes-1 ismi verilmiş olan yeni bir robotik el çalışmasının sunumu ile ilgilidir. Erciyes-1 robotik eli çok parmaklı, kabiliyetli bir el' dir. Robotik el kapasitelerinin arttırılması Erciyes-1 tasarımındaki hedeftir. Bu el beş parmak içerir (dört parmak ve bir başparmak), her parmak üç serbestlik dereceli, başparmak 4 serbestlik derecelidir ki; böylece kavrama, konum değiştirme ve keşfetme kabiliyetleri elde edilmektedir. Tahrik sisteminde DC servomotorlar kullanılmış olup, bu motorlar eklemlere direkt olarak monte edilmiştir. Değişken pozisyonlarda maksimum hareket kabiliyeti elde edilebilmesi için Erciyes-1 üzerinde yeni bir başparmak geliştirilmiştir. Ayrıca, yeni bir kuvvet ölçüm sistemi parmakların uç kısımlarına uygulanmıştır. Bu çalışma geliştirilen robotik eli açıklamakta ve robotik el parmak uçlarında oluşan kuvvetleri sunmaktadır. Standart PID kontrolcü eklem kontrolü için sistemde kullanılmıştır. Geliştirilen kuvvet ölçüm sistemi ve başparmak yapısı hareket kabiliyeti ve kuvvet ölçümünde mükemmel sonuçlar vermektedir. Yeni başparmak mekanizması şimdiye kadar geliştirilmiş olan tüm el yapılarından daha üstün bir hareket kabiliyeti sağlamıştır.

Anahtar Kelimeler: İnsansı el, Mekatronik, Robotik el, Robotik, Başparmak mekanizması

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

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Received / Geliş tarihi : 16.02.2016
Accepted / Kabul tarihi : 09.03.2016

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.

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

Table 1. Humanoid hand designs.

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

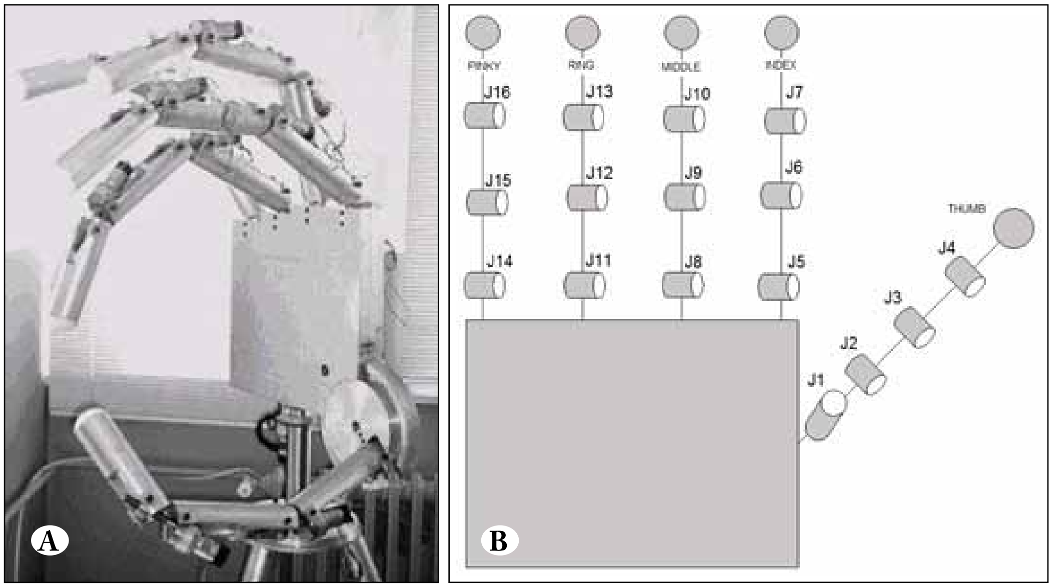

Figure 1. (A) Erciyes-1 articulated hand **(B)** Kinematic Structure of Erciyes-1.

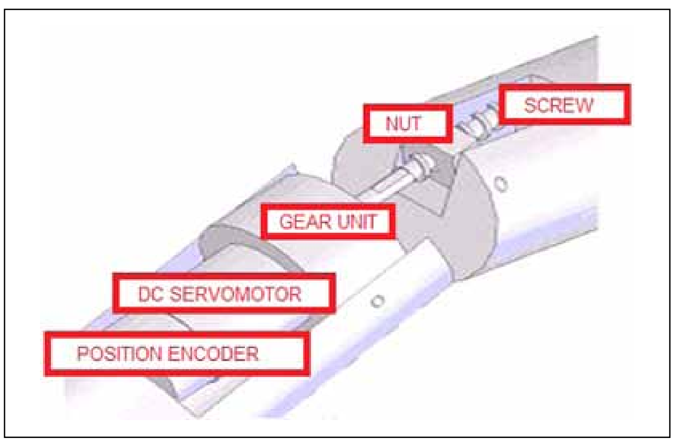

Figure 2. The finger mechanical construction.

speed 60°/s) for the circular base which operates the thumb's rotation. 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 it's flexible movement capability. So, different kind of parts can be grasped by ERCIYES-1.

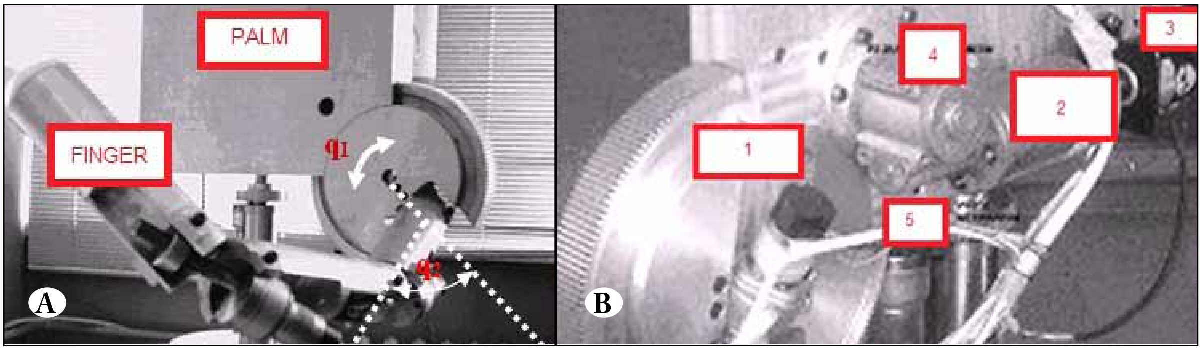

Figure 3. Thumb mechanism of ERCIYES-1hand. **A)** Frontside), **B)**Backside.

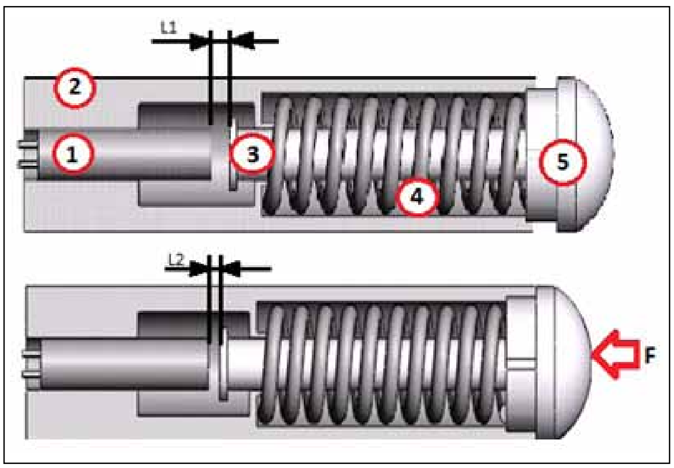

Figure 4. Force measurement system.

3. Results of the position control and force measurements of the fingers

As shown in Fig. 4, ERCIYES-1 grasping objects by using endpoints of the fingers, so the force measurement system applied on the end points of the fingers. Force measurement from these endpoints is enough to protect and grasp the object which is carrying. Different forces for different objects which are made by different materials (wood, glass, food, stone, etc.) could be defined by control system. When the grasping forces reaches the desired values then control system finishes the DC motors movements. The force measurement system showed at Fig. 4.

Parts of the force measurement system are;

1. Inductive sensor
2. Main Body of Finger
3. Moving part
4. Spring
5. Head of the moving part.

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 chance (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.x is the main formula at the force measurement for the springs.

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

X = (L_1 - L_2)(m) for my study and k= 0,001 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:

$$y(t) = K_p . e_{(t)} + K_i . \int_0^t e_{(t)} . d_{(t)} + K_d . \frac{d_e}{d_t} \quad (1)$$

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.

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

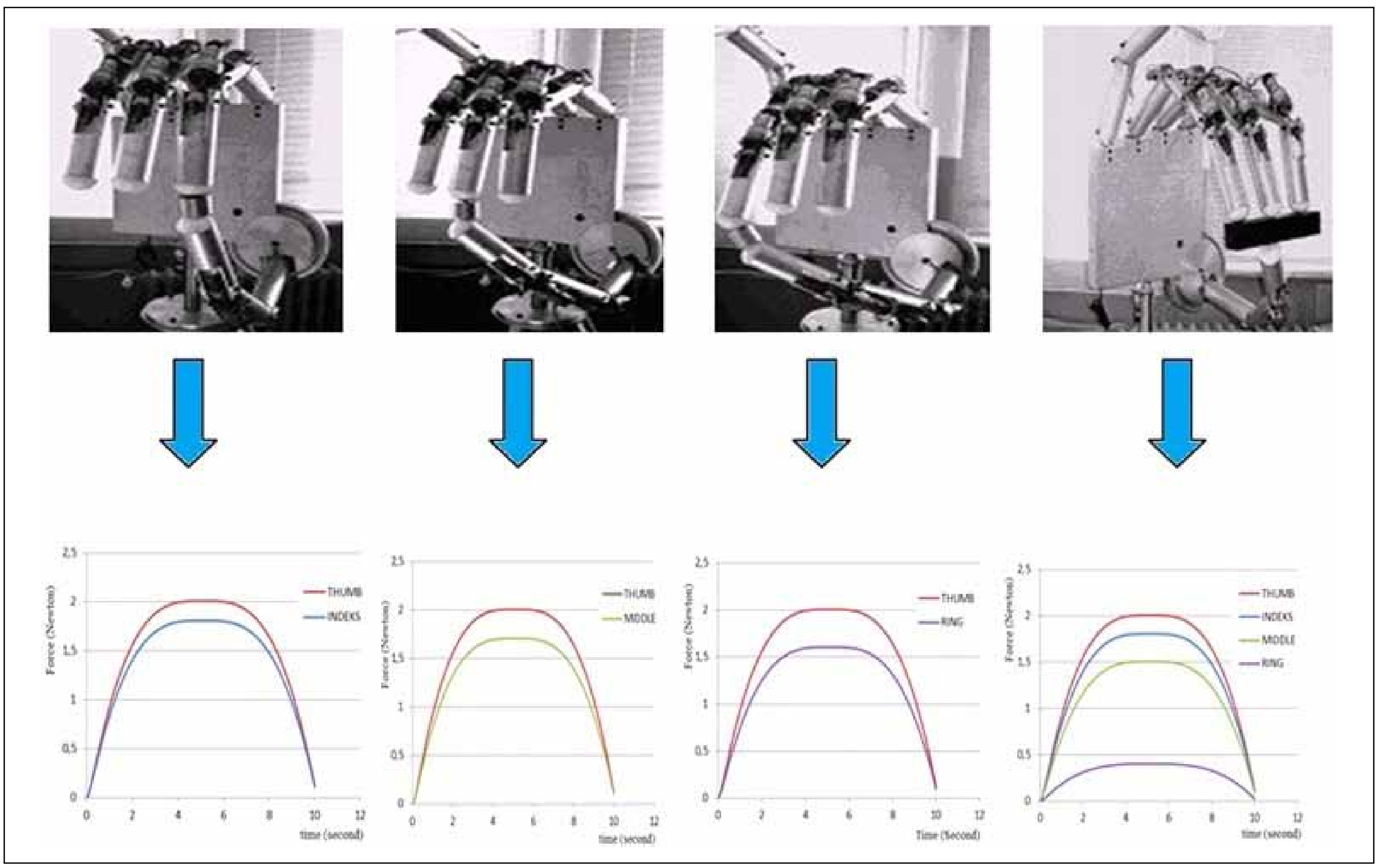

Figure 5. Results of the force measurements for different tasks.

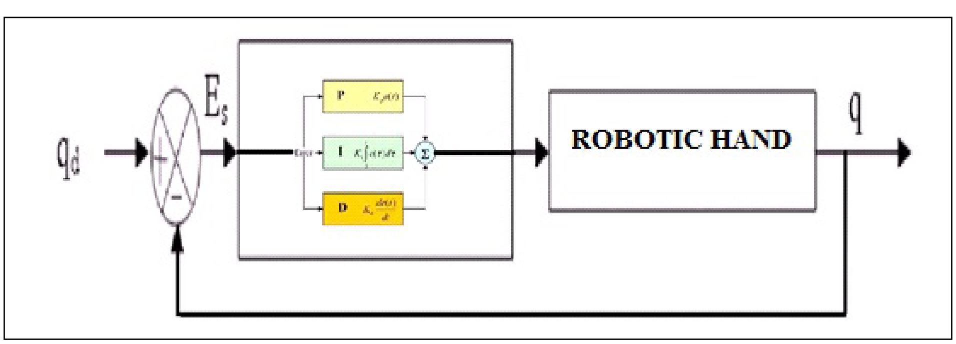

Figure 6. Standard PID controller.

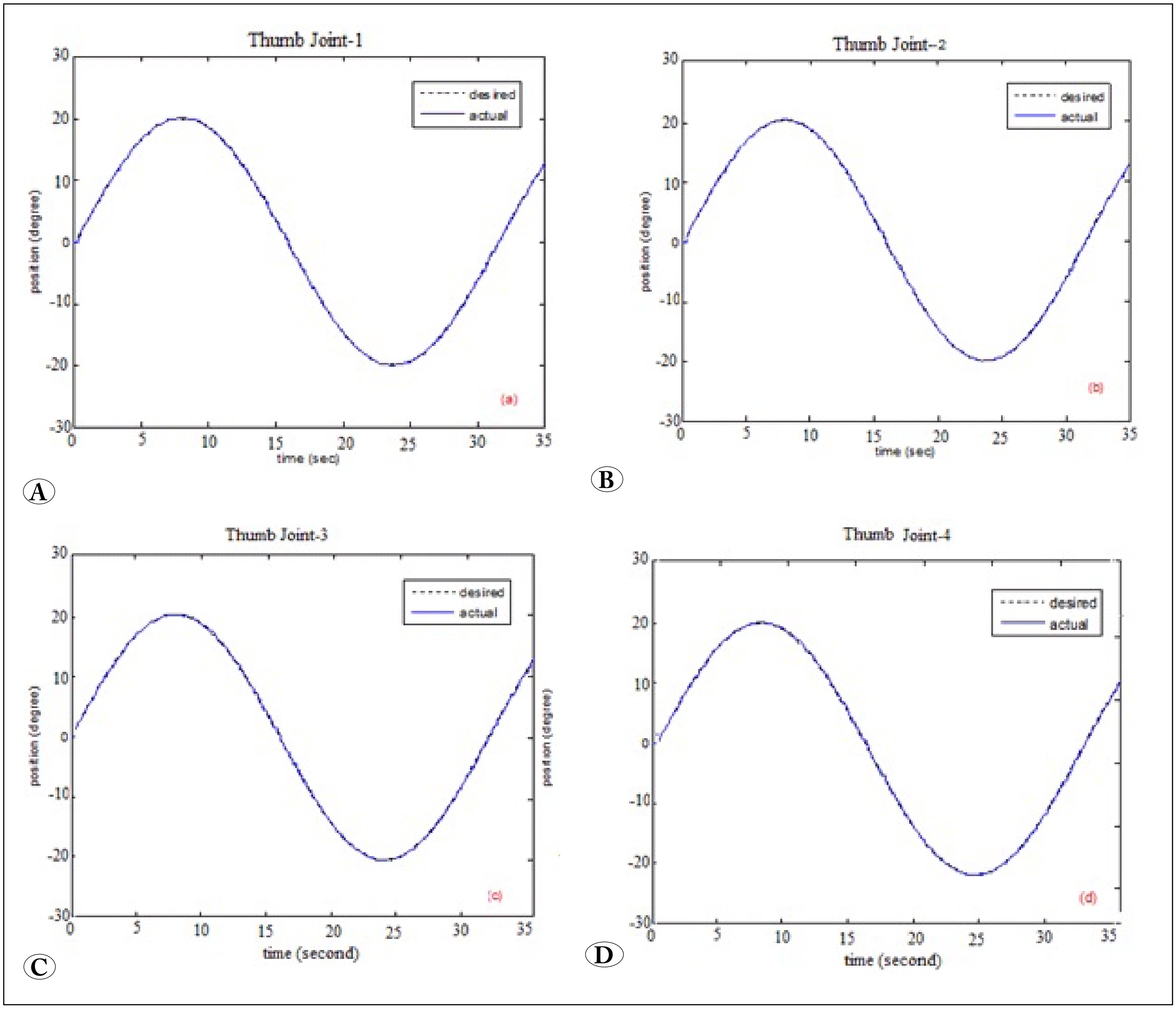

Figure 7. The Standard PID controller results for the new thumb mechanism's joints.

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.

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