Design and Optimization of Coupled and Self-Adaptive of An Underactuated Robotic Hand Using Particle Swarm Optimization

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Abstract
A large work has been devoted to create and design the novel underactuated robotic hand that mimic human hand in terms of motion and grasps. The objective of this paper is to design and development of four-finger underactuated robotic hand mechanisms with 2-DOF for each finger that is highly underactuated which controlled by single actuator that can be used with wide applications. The principle of this hand mechanism is to use the linkage seesaw differentials and the design of robotic finger integrates segments by pin joints and a tendon, that allowing it easily of grasping and adaptable different objects. Furthermore, the robotic finger was designed with combines advantages of the concept of rigid coupled and self-adaptive into one unit to achieve better performance with simple design. To plan the trajectory of the robotic finger and force-isotropic that resembled the human finger in motion and grasping operation, Underactuated finger mechanism was preliminary analysis to predict the relationship between the joint angles of robotic finger related to mechanical parameters as well as contact forces then, modified by optimized set of parameters using particle swarm optimization (PSO). Where, the parameter design constraints were formulated for a multi objective optimization problem using the evaluation criteria for human finger in motion and grasping. Experiments were conducted in order to validate the theoretical analysis by addition of angles sensors on each segment of fingers and the results show that the proposed hand is able to mimic human hand in terms of motion and adaptive grasps.

Keywords: Robotic hand, underactuated finger, seesaw differentials, coupling mechanism, self-adaptive, particle swarm optimization (PSO).

Table1 Symbol Definition

| Symbol | Description                                      | Units |
|--------|--------------------------------------------------|-------|
| 𝑑𝑖   | The distance between tendon force and joint.     | mm    |
| 𝐹𝑖𝑠𝑖 | The force of stretching spring of the ith spring. | N     |
| 𝐹𝑖   | The reaction force produced by the ith segment on the object. | N     |
| 𝐾𝑖   | The stiffness coefficient of the ith spring.     | N/mm  |
\[ L_i \] The length of segment.
\[ L_0 \] The length of closer tendon turning.
\[ M_i \] Pre-loading torques of the springs in the initial stage.
\[ R_i \] The force applied which produced by the tendon.
\[ S_{1i} \] The length of spring in initial state of the ith spring.
\[ S_{2i} \] The length of spring after motion of the ith spring.
\[ T \] The tendon force created by the actuator.
\[ x_i \] The perpendicular distance from force spring to the joint.
\[ \beta_i \] The angle of ith tendon turning.
\[ \theta_i \] The angle of rotation of the ith joint.
\[ \kappa_i \] The lever arm of \( F_r \).
\[ \tau_i \] The moment of the ith joint.

1-Introduction

Robotic hand have become an integral part of modern human life and the application of robotic hand have increased in the last few decades for both laboratory and industrial environments. Many designs of robotic hand try to mimic human hand in terms of motion and grasps. Where, the main mechanical and software solutions that explicitly exploit the concept of human hand synergies [1]. In order to realize more grasping tasks and implement the robotic hands with precise grasp and active adaptation to the object's shape, dexterous hands were proposed. Where, an actuator is applied for every joint in the dexterous hand and synthesis algorithms and computer control are developed to synchronize the motors [2][3].

In spite of the dexterous robotic hand with many active joint is flexible, but it is difficult to control and complex in grasping tasks and the kinematic constructing in addition, increase the weight, complication and size of hands. Moreover, integration combination of force information from multi fingers are quite complex issues. A possible approach to minimize the complexity is that of reducing the number of actuators(Under-actuated). Underactuated hand is a much more simplified control scheme and decrease the size and weight of hands compared to fully actuated hand[4]. The principle of under-actuation was presented by Birglen and Gosselin [5]. Underactuated hands can be divided to two different types based on the transmission system: tendon transmission [6] and link transmission [7][8]. Also, a several differential mechanism were provided for underactuation between fingers such as: pulley differentials [9], linkage seesaw differentials[10] and gear differentials[11].

On the basis of grasp mode of underactuated hand, the traditional underactuated hand can be divided into two types, including the coupled robotic hand, which the rigid coupled finger moves around the object with a specific path due to the imposed limitation of the joint angles [12] and self-adaptive robotic hand that decouple the relationship between the joints where, if any phalanx is blocked the others links continues moving until the object is enclosed[13]. Both of them have their own advantages and disadvantages[14]. In addition, many types of under-actuated hands was designed to realize the grasping target, such as gesture-changeable underactuated hand (GCUA) [15], underactuated hand with selectively compliant [16] and the underactuated hand based on linkage mechanism including two traditional types grasps [17]. The behavior of an underactuated hand such as its grasping kinematics and force depends greatly on its geometry and stiffness parameters. There for, some requirements for the design, which introduced geometrical parameters to get grasp quality and ensure the desired motion envelop as a result in specified mechanical configuration to obtain better results under desired circumstances. Different optimization
algorithms are adopted with one or multiple objective functions are used to optimization the parameters, geometry to plan the motion of finger and force-production such as [18][19][20].

This paper presents the design and prototyping of highly underactuated four-finger robotic hand with 2-DOF for each finger which actuator by single motor. This mechanism enable to grasp various shapes of object stably and robustly. Where, the design of underactuated fingers can be overcome the shortcomings of rigid coupled and self-adaptive underactuation by integrating the two types into one unit and achieving better performance with simple design and low cost. In coupling motion the main objective is to realize the motion joint angles of the robotic finger similar to the human finger by optimizing the parameters of finger geometry and the spring stiffness of the robotic finger using particle swarm optimization. The distribution of the forces in self-adaptive should be distributed among the phalanges of under-actuated robotic finger in order to avoid the large local forces that will be on the object.

2. Coupled and Self-Adaptive Finger

In term of the grasping mode, the traditional underactuated hand can be divided into two causes, namely rigid coupled hand and self-adaptive hand. In rigid coupled show in Fig (1-a), The finger is rotated about object with imposes a relationship between angles, where, the fixed -motion ratios depend on the mechanical parameters. The second type is the self-adaptation as show in (Fig 1-b), the finger is rotated as a rigid body with straight configuration until the proximal link touching the object then, the other links continue move and contact the object in sequence, this allowing the finger to passively adapt to the object shape [17].

Figure (1). The traditional orientation finger a) rigid coupled b) self-adaptation [17]

This traditional underactuated fingers have some problem as the ejection phenomenon, which its addressed in [21]. It refers, in rigid coupled, if the envelope of the fingers is not completely enclosed the object and the restrain is not sufficiently, the effect of the first contact might move the object away. Also, in the self-adaptation when the proximal link is not in contact object, the grasp on the distal link is unstable.

This paper focuses on designed the underactuated mechanisms finger that able to solve the problems above. Where, The finger was designed to execute rigid coupled and self-adaptive motion as one unit with two stage as shown in Figure 2. In initially, the finger is straightened due to return springs as shown in Fig. (2-a). In the first stage as shown in Fig. (2-b), the rigid coupled finger moves around the object with a specific path due to the imposed limitation of the angles between the links. Where the first stage ends when the proximal link is blocked with the object. In the second stage as shown in Fig. (2-c), the finger alters its motion into
self-adaptation, where the proximal phalanx is blocked and the distal link continues moving until the object is enclosed. The new finger has several advantages by comparing with traditional underactuated fingers. First, the finger flexes is the human-like where, it provides self-adaptation to the object geometry. Thus, it can be used in as universal grippers. Second, it's prevent the object to slide away and reducing the possibility of ejecting the object. Where, If the proximal link blocked the object first, the distal link prevent the object from sliding away due to pre-rotated. If the distal link is blocked the object first, the object is more likely to hold than of causing the ejecting. The coupled relationship and the wrapping movement of the finger around the object depend on design parameters such as return spring, length of links and tendon position (distance from joint). In order to realize the motion law of the finger, the effect parameters of finger can be analyzed kinematically.

Figure (2). The orientation finger with parameters geometry in coupling and self-adaptation into one unit a) initial configuration b) stage 1 c) stage 2

3. Mechanisms of Underactuated Hand

The presented robotic hand as shown in Fig.(3.a) was designed to reproduce the functionality of an under-actuated four finger hand with pin joints and tendon driven by a single actuator. The robotic hand was designed based on Solidworks program, and then the prototype of the robotic hand was built from Ploylactic acid material(PLA) where, PLA is good enough to be used as working parts. Stepper motor was used for accelerates the fingers in both directions, forward to grasp the object and return to original position after finish the task. This motor was connected to a power screw and slider system to translate the rotational motion of the motor to a linear motion. The underactuation between the fingers and within the individual fingers are applied to achieve form closure of all the fingers of a robotic hand via a single actuator. The principle of this hand mechanism is to use two central seesaw bar which are mounted in the slider system on two contrast side as show in Fig.(3.b). Each seesaw bar can be used to drive two underactuated fingers via tendons where, one end of the tendon connected to the seesaw bar and going through holes on every phalanx and the other end fixed to the distal link of finger. The rotation of the bar is used to accommodate the difference of position between two output rods transmitting the motion. This transmission mechanism must be adaptive, i.e., when one or more fingers are blocked, the others finger continue to move, until all fingers envelopes the object and the force among the fingers should be well distributed and it should be possible to apply large grasping forces while maintaining a stable
grasp. Also, two springs were mounted in the joints to enable the robotic finger to get a good adaption motion and return the finger to original position and employ a rotary potentiometer in every joint as an angle sensor to obtain position feedback.

**Figure (3).** a) The prototype of the robotic hand that build via hard Polylactic acid (PLA) b) linkage seesaw mechanism

### 4- Kinematic Analysis of Robotic finger

The kinematic analysis of underactuated robotic fingers is demonstrated analysis of each two stages introduced above by consider three important design parameters including link lengths $L$, spring stiffness $K$ and tendon position $D$ (distance from joint). There are several assumptions was applied in this analysis. First, its assumed frictionless of the finger mechanism. Second, the gravitational effects are neglected due to small of mass of finger. Third, the joint torque is balance during the movement.

#### 4.1 Kinematics Analysis During The rigid coupled Stage

In the rigid coupled stage shown in Fig (2-b), the finger moves around the object with a specific path due to the imposed limitation of the angles. The joint angles coupling process can be determined depend on given the design parameters as the mathematical derivation below. As shown in figure (2-b), the angle of $i$th tendon turning $\beta_i$ can be writing as:

$$\beta_1 = \beta_2 = \theta_1/2, \quad \beta_3 = \theta_2$$  \hspace{1cm} (1)

From the geometry of the finger which shown in Fig (4), the force applied on segments produced by the tendon in turning point (assuming quasi-static processes) can be derived as:

$$\Sigma X = 0$$  \hspace{1cm} (2)

$$T \sin \beta_i = R_i \cos \frac{\beta_i}{2}$$  \hspace{1cm} (3)

$$T \left( 2 \sin \frac{\beta_i}{2} \cos \frac{\beta_i}{2} \right) = R_i \cos \frac{\beta_i}{2}$$  \hspace{1cm} (4)

$$R_i = 2T \sin \beta_i / 2 \quad i = 1 \text{ to } 3$$  \hspace{1cm} (5)
The vertical distance between tendon force and the center of joint can be described as:

\[ d_0 = D \]  

\[ d_i = l_i \sin \left( \psi_i - \frac{\beta_i}{2} \right), \quad i = 1 \text{ to } 3 \]  

Where:

\[ l_1 = \sqrt{l_{01}^2 + D^2} \quad \text{and} \quad \psi_1 = \tan^{-1}(l_{01}/D) \]

\[ l_2 = \sqrt{(L_2 + L_{02})^2 + D^2} \quad \text{and} \quad \psi_2 = \tan^{-1}((L_2 + L_{02})/D) \]

\[ l_3 = \sqrt{L_{02}^2 + D^2} \quad \text{and} \quad \psi_3 = \tan^{-1}(L_{02}/D) \]

\[ R_0 \]  

Figure 4 The geometry of the finger

The moment at each joint due to the force applied which produced by the tendon can be written as:

\[ \tau_1 = R_0 \ast d_0 + R_1 \ast d_1 \]  

\[ \tau_2 = R_2 \ast d_2 + R_3 \ast d_3 \]  

Substitute the above equations in Eq. (9) and (10) yields:

\[ \tau_1 = T \ast d_0 + 2Tl_1 \sin \left( \frac{\theta_1}{4} \right) \sin \left( \psi_1 - \frac{\beta_1}{4} \right) \]  

\[ \tau_2 = 2T l_2 \sin \left( \frac{\theta_1}{4} \right) \sin \left( \psi_2 - \frac{\beta_1}{4} \right) + 2Tl_3 \sin \left( \frac{\theta_2}{2} \right) \sin \left( \psi_3 - \frac{\theta_2}{2} \right) \]
To derive the moment at each joint due to the force of stretching spring, the motion of upper and lower link from initial state(1) to other state (2) are considered, as shown in Fig.(5).

Figure 5. The scheme shows the motion of upper and lower link rotates from initial state to other state.

The angels of stretching spring with respect joint of initial state (1) and any other state after motion (2) are $\psi_{1i}$ and $\psi_{2i}$ respectively, and that can be obtained as:

$$\psi_{1i} = \tan^{-1} \frac{r_i \sin(\phi_i)}{O_i A_i - r_i \cos(\phi_i)}$$ (13)

$$\psi_{2i} = \tan^{-1} \frac{r_i \sin(\phi_i + \theta_i)}{O_i A_i - r_i \cos(\phi_i + \theta_i)}$$ (14)

Where $\phi_i$, $O_i A_i$ are constant depend on selected design and $r_i$ is the radius of the path of the end spring about the joint ($i=1,2$ for upper and lower link respectively).

The length of spring in initial state can be described as:

$$S_{1i} = \frac{O_i A_i - r_i \cos(\phi_i)}{\cos \psi_{1i}}$$ (15)

And the length of spring in any other state after motion can be described as:

$$S_{2i} = \frac{O_i A_i - r_i \cos(\phi_i + \theta_i)}{\cos \psi_{2i}}$$ (16)

The change of spring length $\Delta S_i$

$$\Delta S_i = S_{2i} - S_{1i}$$ (17)

There for, the force of stretching spring $F_{si}$ is:

$$F_{si} = K_i \cdot \Delta S_i$$ (18)

The perpendicular distance of force spring to the joint angle $x_i$ can be obtained geometrically:
\[ x_i = O_i A_i \sin \psi_{2i} \]  

(19)

That lead: The moment at each joint due to the force of stretching spring:

\[ \tau_1 = M_1 + F_{s1} x_1 = M_1 + K_1 \Delta S_1 x_1 \]  

(20)

\[ \tau_2 = M_2 + F_{s2} x_2 - \tau_1 = M_2 - M_1 + K_2 \Delta S_2 x_2 - K_1 \Delta S_1 x_1 \]  

(21)

Where \( M_1, M_2 \) are pre-loading torques in the initial stage due to stretching of the springs and \( K_1, K_2 \) are the stiffness of the springs.

The moment equilibrium at upper joint (assuming quasi-static processes), can be considered by equating of equations (11) and (20):

\[ T \cdot d_0 + 2T l_1 \sin \left( \frac{\theta_1}{4} \right) \sin \left( \psi_1 - \frac{\theta_1}{4} \right) = M_1 + K_1 \Delta S_1 x_1 \]  

(22)

That lead:

\[ T = \frac{M_1 + K_1 \Delta S_1 x_1}{d_0 + 2l_1 \sin \left( \frac{\theta_1}{4} \right) \sin \left( \psi_1 - \frac{\theta_1}{4} \right)} \]  

(23)

Equation (23) is indicated the tendon force \( T \) which supply from actuator is a function of only \( \psi_1 \) with constant the parameters (\( K_1, L_1 \) and \( D \)).

Also, The moment equilibrium at lower joint can be obtained by equating equation (12) with (21):

\[ 2T l_2 \sin \left( \frac{\theta_1}{4} \right) \sin \left( \psi_2 - \frac{\theta_1}{4} \right) + l_3 \sin \left( \frac{\theta_2}{2} \right) \sin \left( \psi_3 - \frac{\theta_2}{2} \right) = M_2 - M_1 + K_2 \Delta S_2 x_2 - K_1 \Delta S_1 x_1 \)  

(24)

That leads:

\[ \sin \left( \frac{\theta_2}{2} \right) \sin \left( \psi_3 - \frac{\theta_2}{2} \right) - K_2 \Delta S_2 x_2 = \frac{M_2 - M_1 - K_1 \Delta S_1 x_1}{2T l_3} - \frac{l_2}{l_3} \sin \left( \frac{\theta_1}{4} \right) \sin \left( \psi_2 - \frac{\theta_1}{4} \right) \]  

(25)

The equation (25) is calculated the relationship between \( \theta_1 \) and \( \theta_2 \). Thus, given the design parameters indicate the rigid coupled between two angles by substituting \( \theta_1 \) into (23) and solving (25).

4.2 Kinematic Analysis of Grasping Stage

In the second stage, the finger alters its motion into self-adaptation, as shown in Fig.(3-c) where, the motions of angles \( \theta_1, \theta_2 \) are not coupled. The relevant analysis of this stage during particular grasped object, is the determination of the grasp force related to the joint angles. The geometric issue in this stage is the same as in the coupled stage and the moment equilibrium is can be modified to obtain:

\[ R_0 \cdot d_0 + R_1 \cdot d_1 - F_1 \cdot \kappa_1 = M_1 + K_1 \Delta S_1 x_1 \]  

(26)

\[ R_2 \cdot d_2 + R_3 \cdot d_3 - F_2 \cdot \kappa_2 = M_2 - M_1 + K_2 \Delta S_2 x_2 - K_1 \Delta S_1 x_1 \]  

(27)

which can be rewritten as:
The functions A and B can be calculated from eqs. (26 and 27) respectively. Equation (28) indicates the grasp force \( F_1 \) is a function of the distal angle \( \theta_1 \), the tendon force \( T \), and the lever arm \( \kappa_1 \); also \( F_2 \) in eq. (29) is a function of \( T, \theta_1, \theta_2 \), and \( \kappa_2 \).

### 4.3 Optimization of the Finger Parameters

The anthropomorphic finger must be designed to fulfill basically similar to the human finger in terms of motion and grasps. Where, the motion angles of the human index finger joint in the process of natural bending movement was studied in Imersion company [22] by used data glove with angle sensors and tabulated as shown in table 2. The main objective in this paper is to realize the motion of the joint angles of the robotic finger as human-like motion and the distribution forces should be among the segment by optimizing the design parameter and spring stiffness of the robotic finger. This optimization depended on two criteria:

| \( \theta_{1h} \) (rad) | 0  | 0.0917 | 0.2733 | 0.3858 | 0.493 | 0.715 | 0.955 | 1.0675 | 1.18 | 1.25 |
| \( \theta_{2h} \) (rad) | 0  | 0.1745 | 0.349  | 0.5235 | 0.698 | 0.872 | 1.047 | 1.221  | 1.396 | 1.57 |

#### 4.3.1 The First Criterion: Mimic Function For Motion

In the rigid coupled stage, the objective function is to minimize the difference between the angles that obtained from the mathematical analyzed in section 4.1 \( (\theta_1, \theta_2) \) and the angles made by human finger that shown in table 2 \( (\theta_{1h}, \theta_{2h}) \), which can be mathematically described as:

\[
\min \mathcal{O}_1 = \sqrt{\sum_{i=1}^{n} (\theta_{1i} - \theta_{1h})^2 + (\theta_{2i} - \theta_{2h})^2}
\]  

(30)

Where \( n \) is the sample number of joint angle

#### 4.3.2 the Second criterion: The grasp forces

The distribution forces of under-actuated robotic finger should be among the segment in order to avoid the large local forces that will be on the object. The objective function in this case is defined as the ratio of the total force on the two phalanges divided by the largest force and the minimum objective function can written as:

\[
\min \mathcal{O}_2 = \sum_{i=1}^{n} \left( 2 - \frac{F_{1i} + F_{2i}}{\max F} \right)
\]  

(31)

### 4.4 Formulation Of Optimum Design

Optimization is the process of searching a global optimum solution of a problem in a finite search space. The optimization was performed using particle swarm methodology (PSO). In (PSO), the algorithm adopted uses a set of particles flying over search space to locate a global
optimum. During an iteration of each particle updates its position according to previous experience and the experience of its neighbors. Where, the of change the velocity and position of the particle according to follow equations:

\[
\vec{v}_{i+1} = w \cdot \vec{v}_i + c_1 \cdot r_1 \left( \vec{p}_i - \vec{x}_i \right) + c_2 \cdot r_2 \left( \vec{p}_g - \vec{x}_i \right) \\
\vec{x}_{i+1} = \vec{x}_i + \vec{v}_{i+1}
\]  

(32)

\[
\vec{x}_i \text{ is the current position} , \ \vec{p}_i \text{ is the best position} , \ \vec{v}_i \text{ is the velocity vector contains a gradient (direction) for which particle} , \ \vec{p}_g \text{ is the global best fitness and } (w,c_1,c_2,r_1 \text{and } r_2) \text{ are constant}.

Starts by taking the initial value of the parameters from table (3) to find all the possible solutions according to the specified objective functions and minimizing the objective functions to obtain the optimal geometric parameters as listed in Table (3).

| Parameters | L1(mm) | L2(mm) | K1(N/mm) | K2(N/mm) | D(mm) |
|------------|--------|--------|----------|----------|-------|
| Initial rang values | 40-50 | 40-60 | 0.5-2 | 0.5-2 | 9-12 |
| Final Results | 42 | 54 | 1.07 | 0.83 | 10 |

After obtained the optimal of design parameters, The relation between θ1 and θ2 was plotted in finger (6) and the contact forces of two link of finger with respect to tendon force with the range of angles combinations from 0 to π/2 was plotted as shown in Fig (7).

![Figure (6). The relation between θ1 and θ2, which demonstrating the rigid coupled Stage.](image)

Figure(7). The contact forces of two segment with the range of angle combinations from 0 to \( \pi/2 \), which demonstrating the grasping stage.

From Fig. 6, it can be concluded that the rigid coupled of angels motion of the robotic finger which obtained from the optimal of design parameters its very closed to the motion angles of the human index finger which are shown in table (2). The results of Fig. 7, indicated that the transmission ratio \( F_1/T \) are relatively high during the change of the two angles and its demonstrated the distribution forces among the segment. Also, it can be seen the contact force of the distal link to tendon force \( F_1/T \) is relatively remains constant during the grasping. However, the transmission ratio \( F_2/T \) is relatively depend on the bend of the proximal link (\( \theta_2 \)) in grasp tasks.

5. Experiments

A prototype of the robotic hand was manufactured with optimum values of parameters according to Sec. 4. Where, all the fingers are controlled by one motor. The Experiments were conducted to validate the rigid coupled motion and grasp.

5.1- Coupled Motion Test

The hand was tested to close without an object and show the finger is flexed in coupled motion. Figure 8(a) shows of the finger during the actual test with the range of \( \theta_1 \) from 0° to 70° for step 10° that provided by the angle sensors. Figure 8(b) shows the plots generated by Matlab of coupled angles of one finger that obtained from theoretical calculation and Figure 8(c) shows the compares between actual and theoretical of coupled angles.

![Figure 8](image)

Figure 8. The Results of coupled motion test: (a) the actual finger(b) theoeretical calculation (c) compares the positions of (a) and (b).

The results of test indicate that the actual coupled motion of the finger is differ slightly from of the kinematics analysis in section 4, which can be attributed to friction resistance in the joints and gravity. Also, It indicates the angle sensors can be provided the high degree of accuracy in the positional information. These results of robotic finger demonstrate a human-like motion characteristic.

5.2 The Grasp Test

In this test, the robotic hand is grasped three objects cylindrical, spherical and irregular shape. while sensory feedback is recorded.
Figure 9. The test of the robotic hand that grasping three different objects.

Figure 9 is clearly shown the robotic hand grasped the three objects by two stages. Where, the fingers moves as a rigid coupled until the proximal link blocked the object and then, the distal link continue rotated towards the object until the object is enclosed. The results of the test indicate that the robotic hand can successfully adapt to different objects and the test show the underactuated finger able to execute rigid coupled and self-adaptive motion as one unit with two stage.

6. Conclusion and Future Work

This paper present a novel underactuated robotic hand made through 3D printing. It has four fingers which are actuated by only one motors. The architecture finger is implemented with pin joints and tendon. In order to realize the grasping stability with motion law, the hand was designed to inherit advantages of the concept of rigid coupled and self-adaptation. Furthermore, this hand analyzed theoretically to predict motion of finger in two stage and optimization the design parameters that achieved robotic finger resembled the human finger in motion and grasping operation using particle swarm optimization (PSO). This hand is equipped with angle sensors, that provide feedback information to obtain knowledge about of coupled motion and grasping. Experiments were conducted to validate the coupled motion and the grasp patterns and the results indicate the actual coupled motion of the finger is demonstrated a human-like motion characteristic and the robotic hand can successfully adapt for a variety objects. This research opens a new approach of underactuated hands design by modifying the parameters of design that can be optimized to selected coupled motion and workspace of the finger and variety of graspable objects can be maximized. Where, These parameters can be adjusted according to application selection. In future research we can be considered several interesting issues. First, utilizing the feedback information from sensors to enhance control and grasp process quality. second, this hand will also be modified as prosthetic hand with the same idea of motion and distribution of force. Finally, utilizing the force and angle sensor to provide more thorough information like object properties and shape.

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