공학석사 학위논문

자동형 가변 동력전달장치를 이용한 로봇손의 개발

Development of Robotic Hand with Passive Variable Transmission

2014년 8월

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Abstract

Development of Robotic Hand with Passive Variable Transmission

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This paper presents a way to improve performance of a tendon driven robotic hand using Passive Variable Transmission. The concept of research was inspired by the human pulley mechanism which changes the moment arm of tendon by pulleys, which makes it possible for a human hand to rapidly and powerfully grasp an object. To mimic the pulley mechanism of the human hand, Passive Variable Transmission is applied, which changes the path of the tendon wire passively as the human hand pulleys do.

This PVT Mechanism is a transmission for a tendon driven mechanism, which varies a moment arm of a tendon wire by changing the lengths of compliant material when the tension of the tendon wire is changing. If the tension of the tendon wire is small, the moment arm remains short. As the tension gets bigger, the moment arm increases. Thus, when the joint rotates without load, the moment arm is short and the joint rotates rapidly. On the other hand, if the joint is blocked by an obstacle, the tension increases, which increases the moment arm, and the joint generates a bigger moment.

The goal of this research was to develop a suitable PVT design for a small finger structure. After trying a number of concept designs, the spring type PVT was chosen. This spring type PVT has been tested to certificate that this PVT can change the tendon wire moment arm passively. Before fabricating the robotic hand, the parametric study was conducted. Based on the results of the parametric study, parameters of the spring type PVT was decided, and a robotic hand was fabricated. By comparing with an existing tendon driven robotic hand, H2 hand from Meka, it was confirmed that the fabricated robotic hand used 20% rated output and showed 40% grasping performance.

There has been a structural limitation on robotic hands in mimicking the grasping performance of human hands. This paper will show prospective view of using the Passive Variable Transmission Mechanism to improve the grasping performance of robotic hands.

Keyword: Passive Variable Transmission, Tendon driven mechanism. Robotic hand, Grasping force, Grasping speed, Variable moment arm, Tendon wire

Student Number: 2012-23191

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Chapter 1. Introduction

An underactuated robotic mechanism has been used for robotic and prosthetic hands [1], [2]. It is able to reduce the number of motors, and the system can be designed more simple and lighter. [3], [4] By using this underactuated mechanism, it can also perform adaptive grasping. Adaptive grasping means when one joint is blocked by an obstacle, other joints rotate more as the blocked joint cannot rotate [5], [6].

Many underactuated mechanisms are operated using the tendon driven mechanism [7], [8], [9], [10]. The tendon driven mechanism is an actuating method whose joints mimic biological musculoskeletal systems [11], [12], [13]. A human body rotates its joints as skeletal muscles pull two or more bones together, and tendons transmit power from muscle to skeleton. The robotic hand made from this research used plastic straps to mimic these tendons and pull the straps using actuators, such as motors [14], [15].

However, these robotic hands using the tendon driven mechanism have limitation of performance. Existing robotic hands cannot rotate as fast as human hands do and cannot grasp as powerfully as human hands do. It is because the special pulley mechanism of a human hand. The human body skeletal system has compliant pulleys. Figure 1.1 shows human finger pulleys along the flexor tendon. These pulleys are extended and contracted passively and change the tendon's path. When a man clenches his hands without any obstacle to disturb this movement, these pulleys pull the tendon to the bone, and this remains the tendon moment arm short, so human can rotate his joint rapidly. When a human hand grasps an object strongly, these pulleys are extended far away from the bone by the tension of the tendon, the tendon moment arm increases, and the joint can generate a bigger moment than the tension of the tendon. [16], [17]

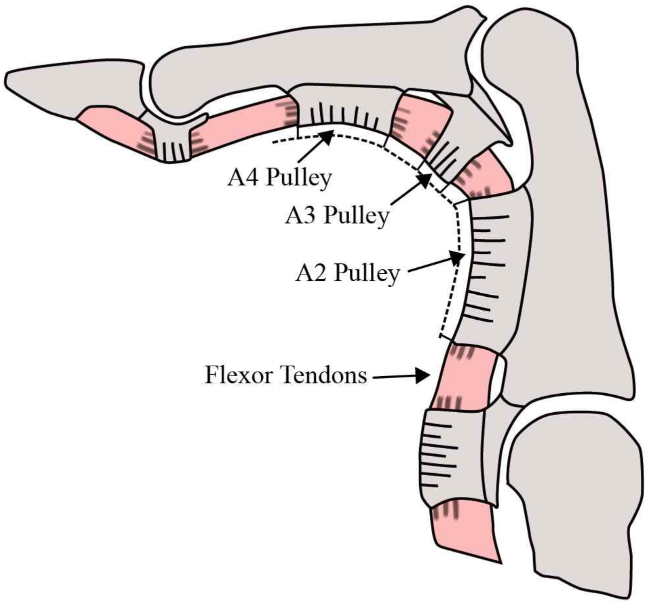


Figure 1.1 The pulley mechanism of a human hand [16], [17]

Inspired by human body pulley mechanism, in this research, I applied Passive Variable Transmission, a transmission mechanism that changes the moment arm of tendon driven joints passively. The PVT Mechanism makes moment arm short when the joint rotates with no load. The PVT changes the moment arm to be long when load causes a big moment on the joint. I made a robotic hand using the PVT Mechanism and confirmed this robotic hand rotates rapidly and makes a big fingertip force [18].

Chapter 2. Passive Variable Transmission

2.1 Concept of PVT

A wire routing path is restricted, and the moment arm of a wire is also unchangeable at most tendon driven mechanisms. Figure 2.1 (a), (b) show the tendon driven mechanism whose wire routing path is fixed. When the wire path is fixed close to the center of rotation, the moment arm of wire remains short (Figure 2.1 (a)). In this case, only short wire variation is needed for joint rotation, and it rotates rapidly. However, because of the short moment arm, the produced moment by the wire is small. On the other hand, when the wire part is fixed far from the center of rotation (Figure 2.2 (b)), the moment arm of the wire is fixed long. It needs long variation of the wire when the joint rotates slowly. However, it can generate a bigger moment than a joint whose moment arm is short [19], [20], [21].

The concept of Passive Variable Transmission applied in this research is shown in Figure 2.2 (c), (d). The transmission ratio of the joint using the tendon driven mechanism is changed by variation of the moment arm of the tendon wire. The moment arm of the joint is varied with the change of the tendon wire geometry and the rotating angles of the joint. By changing the wire path, the compliant part, which is expressed as a spring connected from the finger structure to the pulley, varies the moment arm of the tendon wire. Because of the elasticity of the compliant part, the position of the pulley is changed according to the tension. So is the moment arm of the tendon wire.

Figure 2.1 (c) shows when the joint rotates without any obstacle. In this case, the tension of the wire is small, and the length of the compliant part is short. The moment arm of the wire to the joint is short, and the joint rotates faster than a joint with a longer moment arm. Figure 2.1 (d) shows when load is exerted on the joint. In this case, a big tension is applied to the wire, and the compliant part is stretched. Then the moment arm is increased, and the wire generates a bigger moment than a joint with a shorter moment arm.

Therefore, by using this PVT Mechanism, a joint can rotate rapidly before contact and produce a large moment after contact.

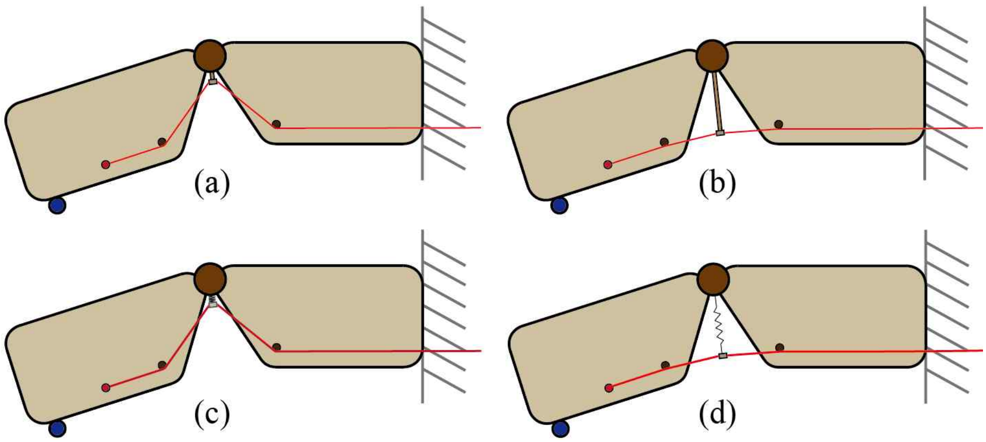


Figure 2.1 The paths of the tendon wires (a) fixed close to the center of rotation (b) fixed far from the center of rotation (c) the PVT Mechanism with a short moment arm, (d) the PVT Mechanism with a long moment arm [18]

2.2 PVT Concept Test

To test the concept of the PVT Mechanism, a special test device has been fabricated. This device is composed of 1 joint and pulled by a wire. 3 different cases are set up with this device. Case 1 does not keep the wire path so that the wire freely gets apart from the center of rotation when the joint is turned by pulling the wire. Case 2 keeps the wire path which does not get apart from the center of rotation using a string. Case 3 is with a PVT concept device. In this case, the wire path is kept using a rubber band. When rotating this joint by pulling the wire, the rubber band keeps the wire path close to the center of rotation. After an obstacle blocks the joint's rotation, the rubber band is extended from the center of rotation. For these reasons, this joint acts as the PVT Mechanism, and this joint rotates rapidly generating a big force.

2.2.1 Rotation Speed Test

The PVT Mechanism rotation speed test was conducted using the fabricated device. At the fully extended joint, the wire has been pulled at the same speed. Figure 2.2 shows the wire path after the rotation ended (from left Case 1, Case 2, and Case 3). The average rotating speed was measured. Case 1 rotated at 0.16 rad/s, Case 2 rotated at 0.52 rad/s and Case 3 rotated at 0.47rad/s. From this test, it was confirmed that a joint using the PVT Mechanism can rotate as fast as a joint length is fixed short.

2.2.2 Fingertip Force Test

Secondly, the PVT Mechanism fingertip force test was conducted using the same test device. Figure 2.3 shows the wire path when the wire pulls the finger. After stopping the joint using an obstacle, the wire was pulled at the same force, and the fingertip force was measured. The fingertip force of Case 1 was 5.5N, Case 2 was 1.5N, and Case 3 was 5N. From this test, it was confirmed that a joint using the PVT Mechanism generates a bigger fingertip force than a short moment join does.

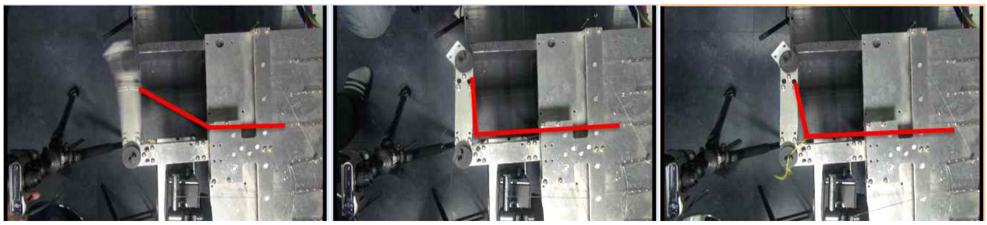


Figure 2.2 The rotation speed test for the concept of PVT (from left a long moment arm joint, a short moment arm joint, a PVT joint)

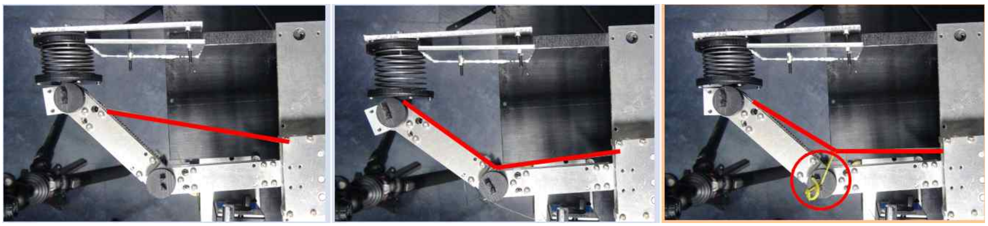


Figure 2.3 The contact force test for the concept of PVT (from left a long moment arm joint, a short moment arm joint, a PVT joint)

Chapter 3. The Spring Type PVT

3.1 Concept Designs of PVT

To apply the PVT Mechanism to robotic hands, in this research, a number of concept mechanisms have been tried. Figure 3.1 shows the tried designs of the PVT Mechanism. Figure 3.1 (a) is a tensile type PVT. Rubber rings were used as a compliant part and the path of tendon wire was changed by extension of the rubber ring. Figure 3.1 (b) is the Compress Type. By compression of the complaint material, the path of tendon wire is changed. Finally, Figure 3.1 (c) is the Spring Type PVT. The spring inside the finger is used as a complaint part of PVT. The elasticity of the spring makes the path of the wire change passively.

However, the space shortage becomes a problem. It is planned for the robotic hand to be fabricated in the same size as a real hand. A human hand is very thin, and there is limitation on the cost to minimize the human hand structure. For a better performance, this robotic hand needs enough space to move the M-part, which is a pulley that restricts the path of the tendon wire and is connected with the complaint part. In the suggested concept designs, the M-part is too big, and variation of the moment arm of the tendon wire is not enough to make a significant performance.

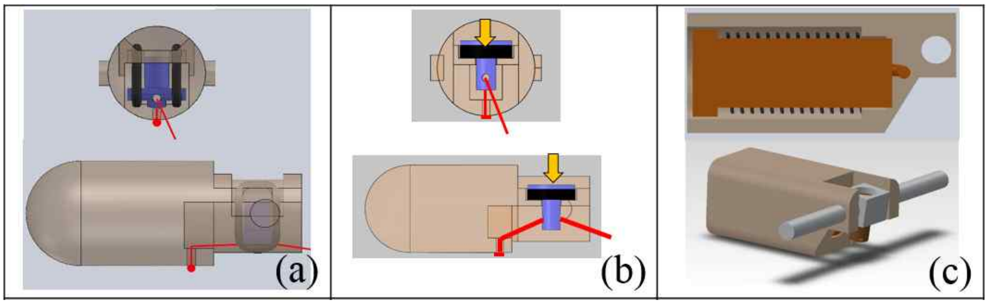


Figure 3.1 The concept designs of PVT

3.2 Design Modifications for Performance

To solve the suggested design space shortage problem, the design concept has been changed. The compliant part is a selected spring. It is because a spring is easy to know the elasticity, and it can secure more space for the M-part by putting the spring between two joints.

It is able to secure more space to miniaturize the M-part. In the previous concept prototype, the M-part was made by using a 3D printer or metal. A 3D printer has an advantage of making a complicated structure. However, 3D printer structures are too weak to use as the M-part, which has to tolerate big tensions. Metal is strong enough to bear big tensions. However, there is fabrication limitation and a cost problem.

For these reasons, a fabric M-part was suggested. Figure 3.2 shows the process to make a fabric M-part. The path of the tendon wire is made by using a teflon tube to reduce the friction between the path and the tendon wire, and two teflon tubes are connected by a fabric and held by sawing. Figure 3.3 shows how the fabric M-part moved. The upper red wire is connected to the spring, and it delivers the tension from spring to the fabric M-part.

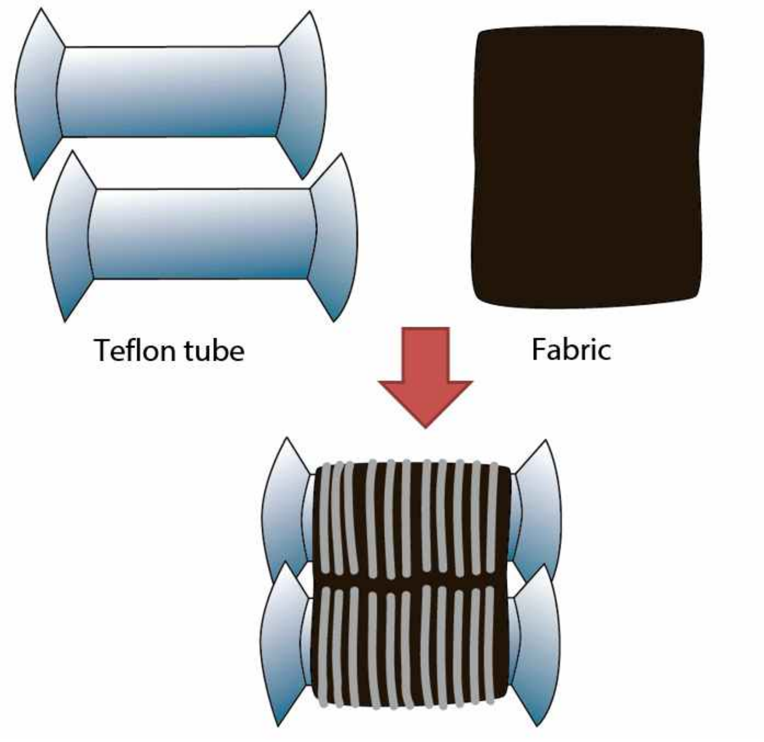


Figure 3.2 The process to fabricate the fabric M-part

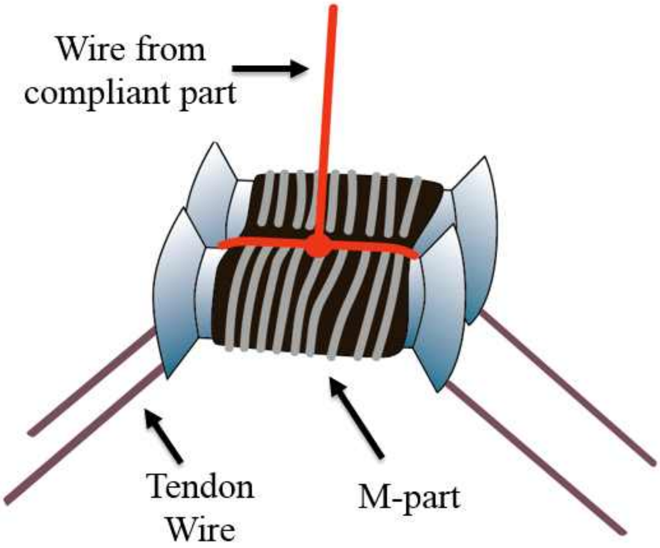


Figure 3.3 The mechanism of fabric M-part

3.3 Spring Type PVT

3.3.1 Mechanism of Spring Type PVT

Figure 3.4 shows the final concept design of the spring type PVT. From a joint, a spring is placed in a distal way of it. A spring is connected to the M-part that delivers the spring's elastic force to the tendon wire and varies the path of the tendon wire.

Figure 3.4 (a) shows that the tendon wire is pulled by a small force. The M-part pulled by this tendon wire pulls the spring at a small force. The spring is compressed less, and the moment arm (the distance from the center of rotation to the yellow dash line) is kept short. In this situation, this joint can rotate rapidly.

On the other hand, Figure 3.4 (b) shows the case that the tendon wire is pulled by a big force. In this case, the M-part is pulled by the tendon wire strongly. This M-part pulls the spring, the spring is compressed, and the M-part goes down. As a result, the moment arm of this joint becomes longer. In this way, this spring type PVT mechanism can change the moment arm passively.

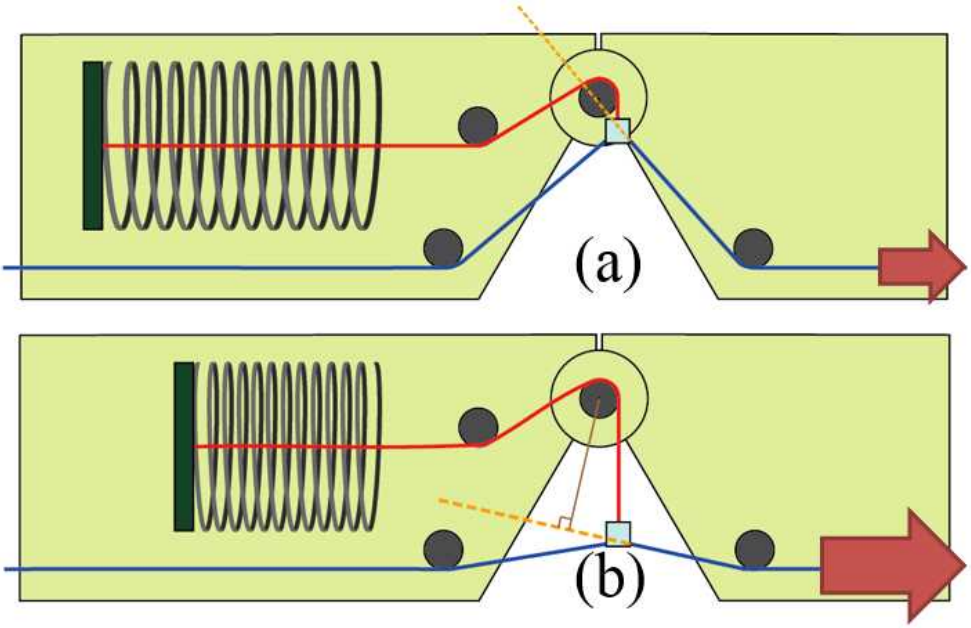


Figure 3.4 The mechanism of the spring type PVT

3.3.2 Test of Spring Type PVT

In this research, a number of tests were conducted to confirm that the spring type PVT shows the PVT's properties. To compare with the joint whose tendon wire moment arm is fixed, two joints were fabricated. The wire path of each joint was restricted to remain the moment arm short or long. The test method is explained in Figure 3.5. The test joint with the spring type PVT was fixed (Figure 3.5 right) and the tendon wire was pulled by a motor (Figure 3.5 left). The tension of tendon wire was measured by a load cell and the pulled length of the wire was measured by using an encoder (Figure 3.5 left). The fingertip force was measured by a 2 axis load cell (Figure 3.5 right). The joint was taken by a video camera, and the rotation speed of the joint was calculated by the video using ProAnalysis. The same test to measure the rotating speed and the fingertip force was conducted with 3 joints, which have a short moment arm, a long moment arm, and a variable moment arm with the spring type PVT.

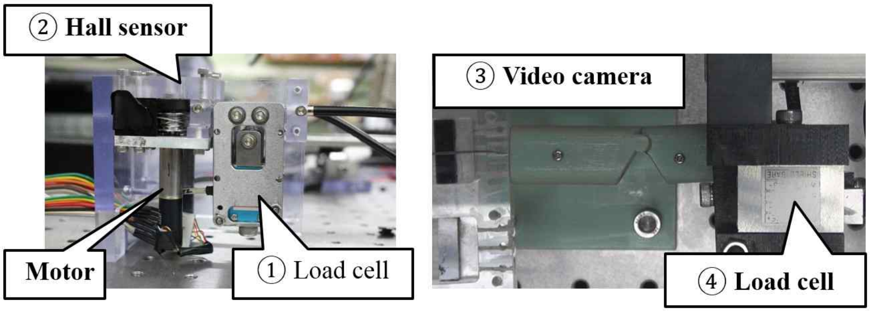


Figure 3.5 The test method of PVT test (the left is actuating part and the right is test joint)

Figure 3.6 is the result of the rotation speed test. This graph shows how the angle of the joint was changed as the pulled length of the tendon wire was changed. The joint with a short moment arm (blue) rotated faster than the joint with a long moment arm (black). The joint with the PVT Mechanism rotated faster than the joint with a long moment arm. From this result, it was confirmed that the moment arm of the spring type PVT joint remains short when the joint rotates without load.

Figure 3.7 is the result of the fingertip force test. This graph shows how the fingertip force was changed as the tension of tendon wire was changed. The joint with a long moment arm (black) made a big fingertip force than the joint with a short moment arm (blue) at the same tension. The joint with the PVT Mechanism made a bigger fingertip force than the joint with a short moment arm. From this result, it was confirmed that the moment arm of a joint with spring type PVT becomes longer after contacting an obstacle.

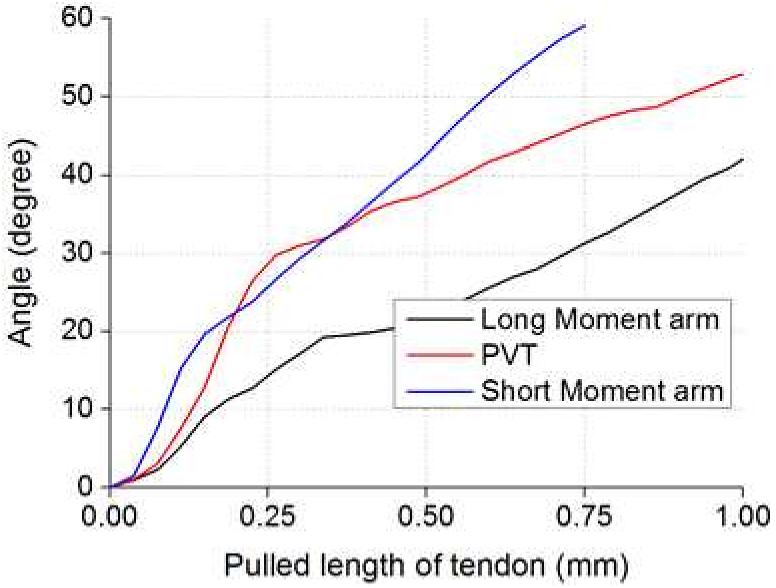


Figure 3.6 The result for rotation speed test of spring type PVT

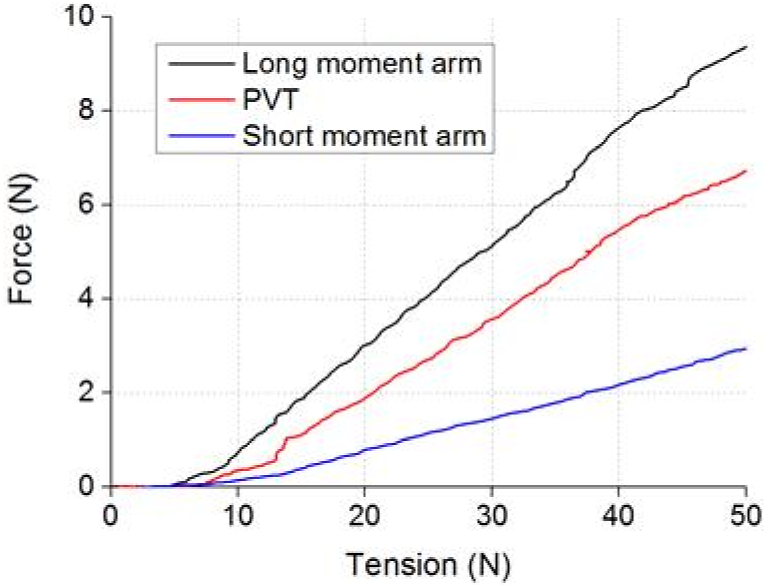


Figure 3.7 The result for contact force test of spring type PVT

Chapter 4. Parametric Study

4.1. Design Parameters of Spring Type PVT

4.1.1 Design Parameters of Spring Type PVT

Figure 4.1 shows the parameters of the spring type PVT Mechanism. The position of the center of rotation is fixed, and two routing points, DP(Distal routing Point) and PP(Proximal routing Point), are set. l means the compressed length of the spring for the pretension of the spring, which makes this joint extend without any other extensor. And R is the radius of the shaft, and M is the position of the M-part [21], [22].

At first, to find the position of the M-part, the values of the angle tangents are expressed on (4.1), (4,2), (4,3).

$$\tan(\theta_W + \theta_M) = \frac{M_x - DP_x}{M_x - DP_y} = T, \tag{4.1}$$

$$\tan(\theta_M - \theta_W) = \frac{M_x - PP_x}{M_x - PP_y} = P \tag{4.2}$$

$$\tan(2\theta_M) = \frac{2M_y(M_x - R)}{M_y^2 - (M_x - R)^2} = K \tag{4.3}$$

The position of the M-part can be calculated geometrically by simultaneous equations of the two expressions (4.4), (4.5).

$$P+T+K(PT-1)=0 \tag{4.4}$$

$$\ell=\sqrt{(M_x-R)^2+M_y^2} \tag{4.5}$$

Figure 4.2 shows the moment acted on the spring type PVT. There are 2 kinds of moment arm on this PVT. The first moment is the flection way moment expressed as a blue arrow. This moment tension which is the tension of the tendon wire and the moment arm can be calculated by using the calculated position of the M-part (4.6), (4.7).

$$T=\frac{k(\ell_{pr}+\ell)}{2\cos\theta_W} \tag{4.6}$$

$$M\_a_{fl}=\frac{M_xPP_y-M_yPP_x}{\sqrt{(M_x-PP_x)^2-(M_y-PP_y)^2}} \tag{4.7}$$

The first moment can be calculated by multiplying two factors (4.8).

$$M_{fl}=M\_a_{fl}\times T \tag{4.8}$$

The second moment is the extension way moment, which is expressed as an orange arrow. This moment is acted by the wire connecting the M-part and the spring. The Moment can be expressed as (4.9).

$$M_{ex} = k(\ell_{pr} + \ell)R \qquad (4.9)$$

The sum of the two moments shows the total moment of the spring type PVT joint (4.10).

$$M = k(\ell_{pr} + \ell)\left[\frac{M\_a_{\ fl}}{2\cos\theta_{W}} - R\right] \qquad (4.10)$$

The ratio of moment (output)/tension(input) can be expressed as an equation (4.11).

$$\frac{M}{T} = M\_a_{\ fl} - 2R cos\theta_{W} \qquad (4.11)$$

This ratio is changed to the spring constant and the initial deformation of the spring. For this result, the spring constant and the initial deformation of the spring are selected as the design parameter of the parametric study.

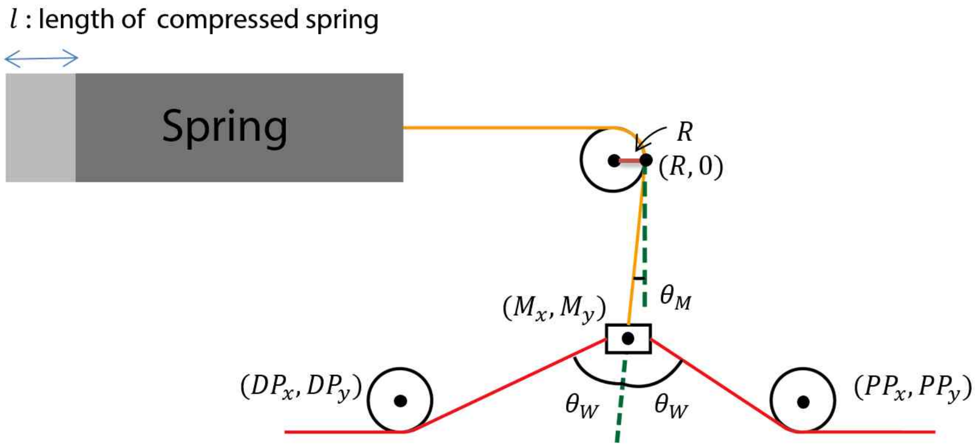


Figure 4.1 The modeling figure of spring type PVT

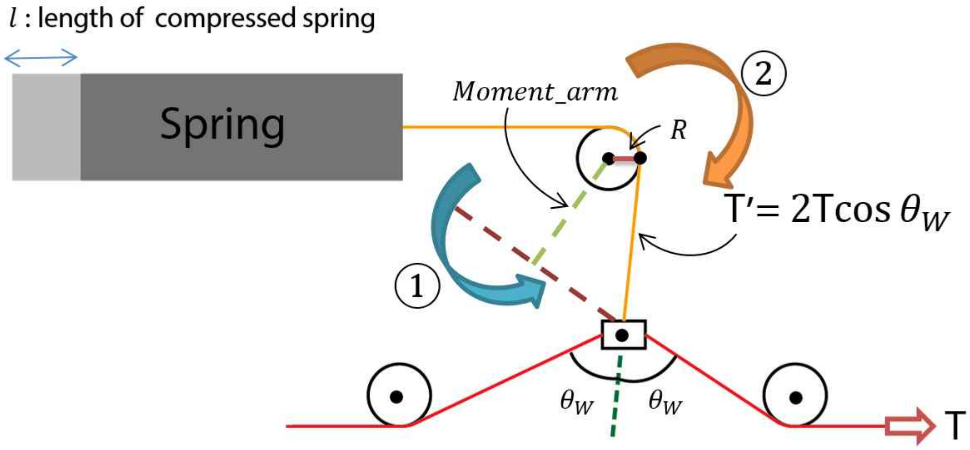


Figure 4.2 The mechanism of spring type PVT

4.1.2 Moment by Design Parameters

There are two main targets of the parametric study. The first one is the moment, and the second one is the rotating speed. First, two simulations were conducted to know how the two design parameters affect the moment of the PVT joint. Figure 4.3 and Figure 4.4 show the result of the simulations. These graphs mean how the moment/tension ratio changed as the two parameters were changed. Figure 4.3 is about the spring constant, and Figure 4.4 is about the initial deformation of the spring.

From this simulation, it is able to predict some tendencies. As the spring constant is smaller and the initial deformation is small, the joint can generate a large moment. This is because the position of the M-part can be easily changed when the two design parameters are small.

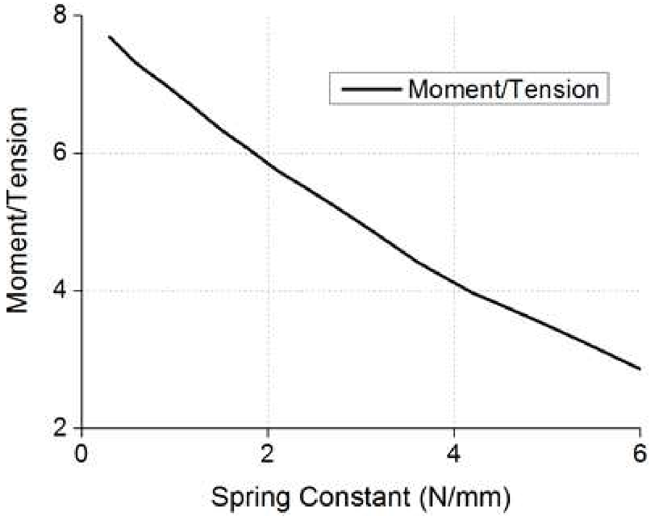


Figure 4.3 The moment/tension for variation of spring constant

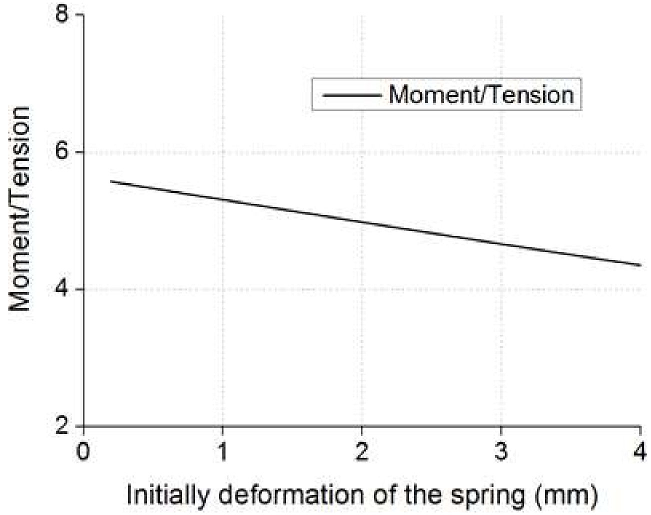


Figure 4.4 The moment/tension for variation of Initial deformation of the spring

4.1.3 Rotation Speed by Design Parameters

To rotate the PVT joint rapidly, the moment arm of the joint has to be kept short. A condition has to be satisfied to remain the moment arm short. The elasticity of the spring has to be larger than the sum of the tendon wire tension (4.12). Figure 4.5 shows why this condition has to be satisfied to remain the moment arm short.

$$k \times \ell_{pr} > 2\cos\theta_W \times T \tag{4.12}$$

From this condition, it is confirmed that the spring constant and the initial deformation of the spring have to be large to remain the moment arm of the spring short.

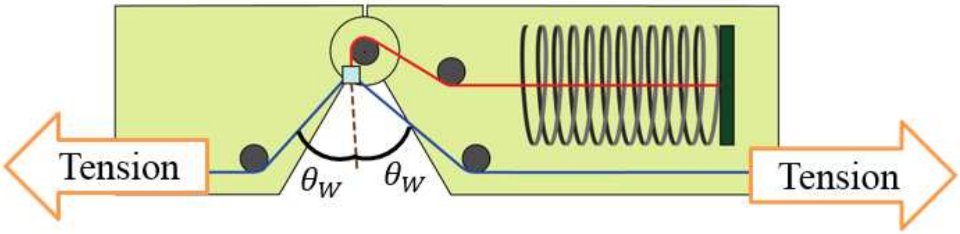


Figure 4.5 The condition that remains the moment arm close to the center of rotation

4.2. Kinematic Properties of PVT

4.2.1 Kinematic Properties for Spring Constant

To compare the properties of PVT with regard to the spring constant, the test that was explained in 3.3.2 was conducted using two different springs. Figure 4.6 shows the test result of a contact force, and Figure 4.7 is about the rotation speed.

From Figure 4.6, it is confirmed that the slopes of the two graphs are different. When the compliant spring was used (black), the gradient was steeper than the joint with the stiff spring (red).

In Figure 4.7, the property is verified. At first, the two joint rotated at the same speed. However, the rotating speed of the joint with the compliant spring became slower when the joint rotated at about 20 degrees. The joint using the stiff spring became slower when the joint rotated at about 35 degrees. From this result, it is confirmed that the bigger the spring constant is, the easier the equation (4.12) is satisfied and the faster joint rotates.

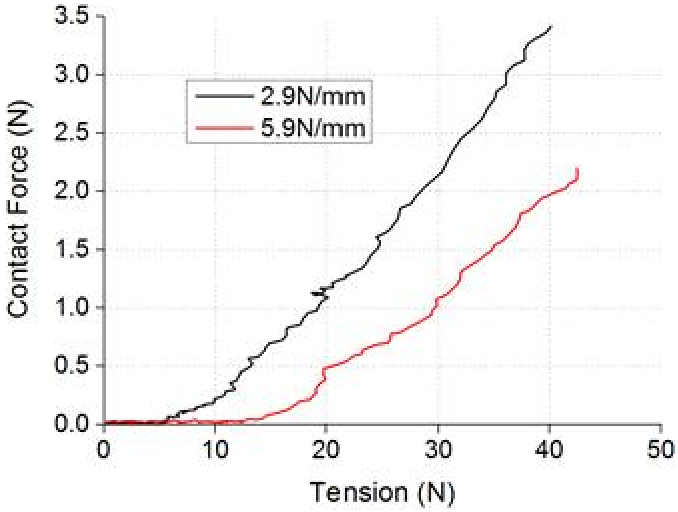


Figure 4.6 The contact force of the tension when the spring constant is changed

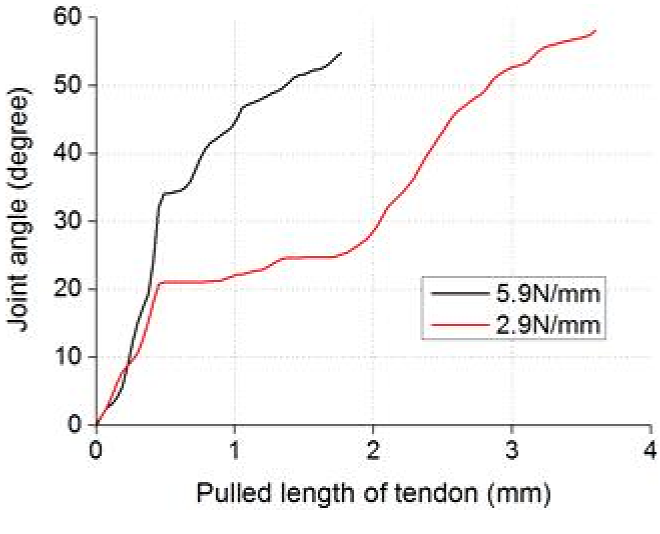


Figure 4.7 The rotation speed of the pulled length of the tendon when the spring constant is changed

4.2.2 Kinematic Properties of Initial Deformation

The same test was conducted with 3 different initial deformations of the spring. Figure 4.8 shows the contact force, and Figure 4.9 is rotation speed about 3 different deformation lengths.

The gradient of the contact force graph shows the larger the initial deformation of spring is, the more gentle the gradient is. From this result, it is confirmed that the initial deformation of the spring makes the moment arm hard to vary.

In Figure 4.9, it is confirmed that the joint with the long initial deformation of the spring rotates rapidly. The longer initial deformation of the spring is easier to fulfill the equation (4.12). This remains the moment arm short when the joint is rotating.

4.2.3 Result of Parametric Study

The moment of the PVT joint is increasing if the spring constant is small or the initial deformation of spring is short. The rotation speed is fast when the spring is stiff or the initial deformation of the spring is long. This parametric study can be summarized that there is a trade-off between the moment and the rotation speed of the PVT joint. If one parameter has design limitation, it can be compensated by the other parameter.

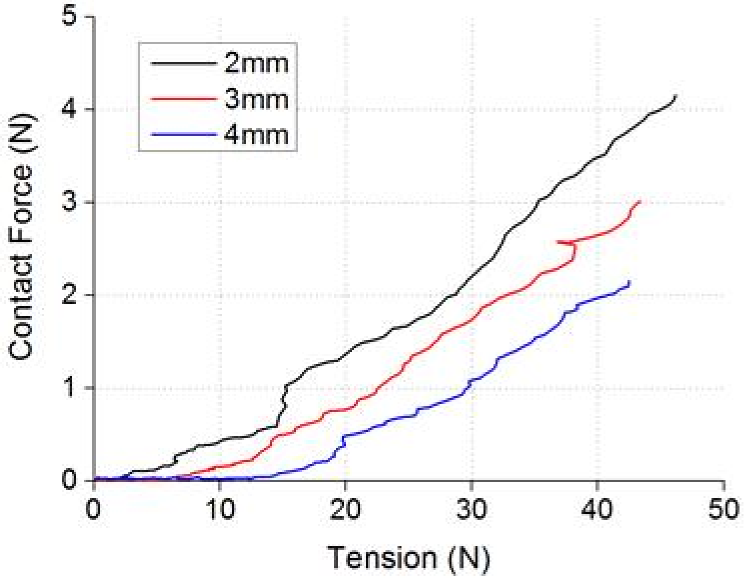


Figure 4.8 The contact force of the tension as the initial deformation of the spring was changed

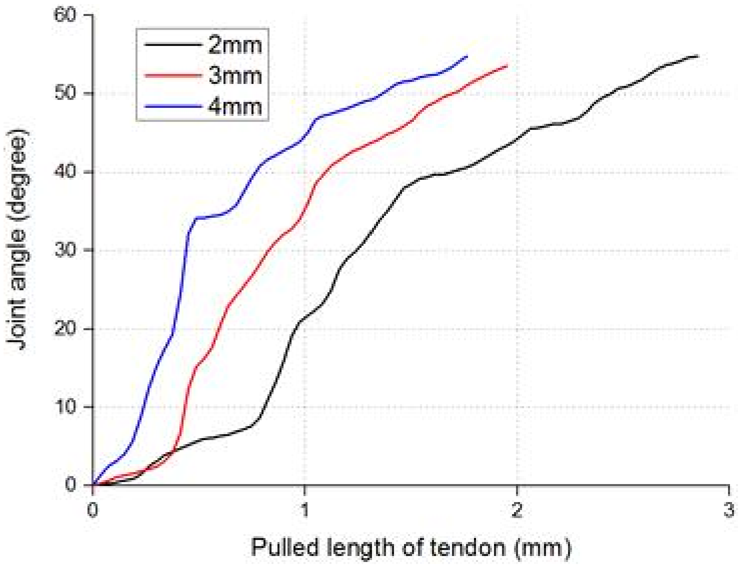


Figure 4.9 The rotation speed for the pulled length of tendon as the initial deformation of the spring was changed

Chapter 5. Robotic Hand

5.1 Finger Design of Robotic Hand

Based on the parametric study, a finger design of a robotic hand was made. Figure 5.1 shows the names of the 3 joints of a finger. In a distal way (left), the joints are called DIP (Distal Inter Phalangeal) joints, PIP (Proximal Inter Phalangeal) joints, and MCP (Metachrpophalangeal) joints. The names of the 2 joints of a finger are from the distal way IP (Interphalangeal) joint and MCP joint. The priority to design the finger has to be set. At first, every PVT of the finger has to be active at the same tension range. If each PVT is active differently, the configuration of the finger can be changed after grasping, and grasping performance can be unstable. Shortening the moment arm is more difficult than making the moment arm longer because of limitation on the design. So, fast grasping was decided as the second priority.

For this priority to satisfy the first option, some parametric conditions have to be satisfied. First, to make the PVT start to extend at the same tension range, the PVTs have to fulfill the following equation (5.1).

$$k \times \ell_{pr} = 2\cos\theta_W \times T \tag{5.1}$$

From this equation, assuming that every joint rotates at the same speed, every θ_W of the joints is the same. When the value $k \times \ell_{pr}$ of every joint is the same, the tension is the same when the PVT starts to be active.

Next, the moment arms of the joints have to be changed as the same ratio. The vertical lengths of each joint (DIP, PIP, MCP) from the center of rotation to the routing point are different. From this, the spring constant of each joint has to be inversely proportional to the length ℓ_R.

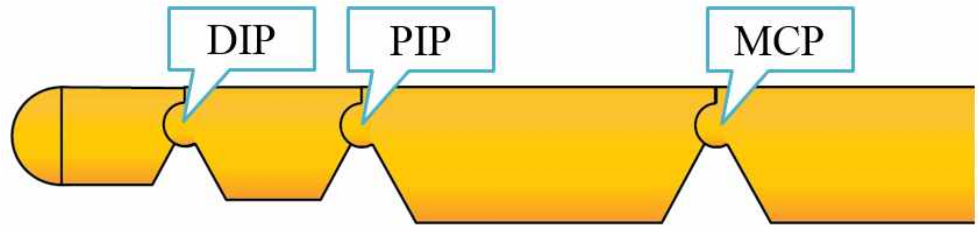


Figure 5.1 The names of the 3 joints of a finger

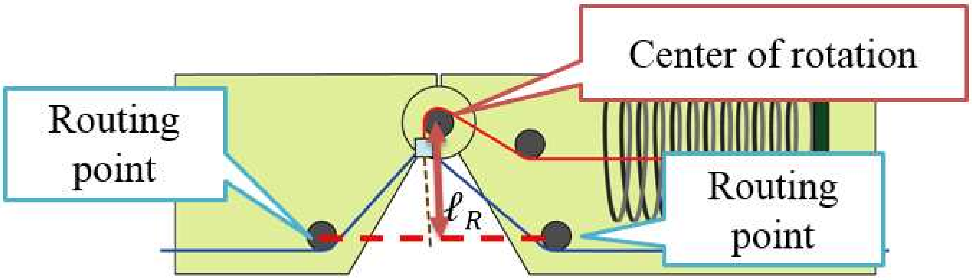


Figure 5.2 The condition that every PVT of the finger has to be active at the same tension range

Based on the set priority, the finger's PVT parameters were decided. Table 5.1 shows the PVT parameters of a 3 joint finger. When deciding these parameters, there is design limitation to increase the initial deformation of PIP's spring, and this parameter was set as 1mm. Despite the design limitation, due to the previous parametric study's result, the desired parameters was able to be found by increasing the spring constant. DIP's spring parameters also have design limitation. So, the spring constant of DIP was selected as 9.8N/mm, and the initial deformation of spring was decided as 1mm. The other parameters were decided based on the set priority. With the same method, the 2 joint finger's PVT parameters were decided (Table 5.2).

Table 5.1 The PVT parameters of a 3 joints finger

	MCP	PIP	DIP
Spring constant	2.9N/mm	5.9N/mm	9.8N/mm
Initial deformation of spring	2mm	1mm	1mm

Table 5.2 The PVT parameters of a 2 joints finger

	MCP	IP
Spring constant	2.9N/mm	5.9N/mm
Initial deformation of spring	2mm	1mm

5.2. Fabrication of Robotic hand

Applying the set PVT parameter, a 3 joint finger was fabricated. The structure of the finger was made by using the 3D printer, Object Eden260V. One finger was actuated by one motor whose rated output was 0.46W, and the property test explained in Figure 3.3.2 was conducted to compare with joints whose moment arm is fixed. Table 5.3 is the result of the test. From this test, it is confirmed that a finger with PVT rotates rapidly and makes a big contact force than other fingers.

Table 5.3 The finger scale test of a PVT joint

	Short moment arm	PVT	Long moemtn arm
Maximum Finger tip force (Fully extended)	1.8N	3N	3.3N
Time	1s	1.5s	2.8s

Figure 5.3 shows the fabricated robotic hand. This was composed of two 3 joint finger and one 2 joint finger. Each finger actuated separately using the same DC motor RA-12WGM whose rated output was 0.46W. A 7.4V battery was used.

The fabricated robotic hand was compared with the existing robotic hand, an H2 hand from Meka. Table 5.4 shows the result of the caparison. The robotic hand with PVT used 20% more motor output than the H2 hand did, but the PVT robotic hand showed 40% more grasping performance than the H2 hand did. This grasping performance is equal to the maximum grasping weight divided by the grasping time.

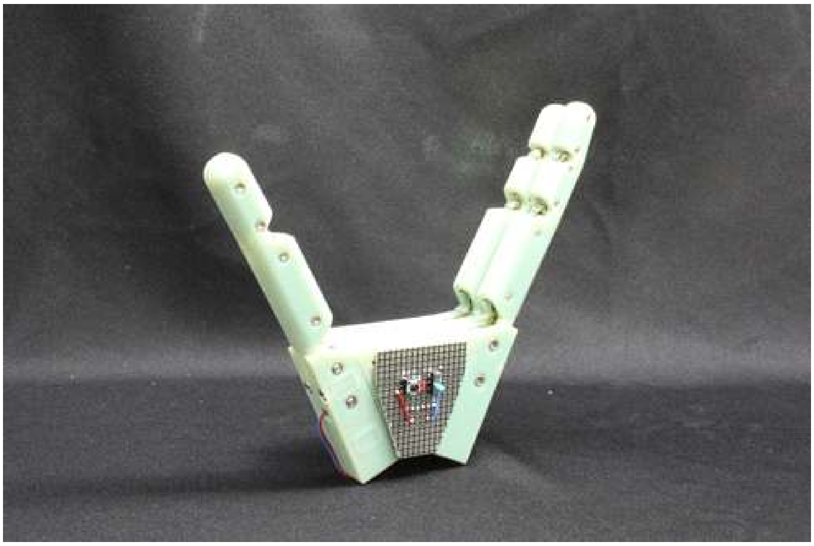
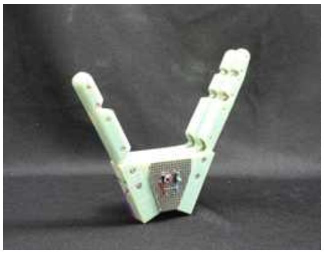


Figure 5.3 The robotic hand

Table 5.4 Comparison of a PVT robotic hand with a H2 hand

	Robotic hand with PVT	H2 hand, Meka
	3fingers, 3motors	4fingers, 5motors
Rated output	0.46W / 1motor	2.25W / 1motor
Grasp time	1.5s	1.2s
Maximum Grasping weight	1kg	2kg
		

Chapter 6. Grasping Performance

Figure 6.1 shows the grasping performance of the fabricated robotic hand. (a) shows the open-handed robotic hand. (a) shows the grasping time from fully open-handed to fully closed-handed. The grasping time was about 1.5 second. From (b) to (f) shows the picture that the robotic hand grasped a paper cup with water, a tape, a spray, a skein of thread, a camera lens. The weight of these objects was from 200g (b) to 1kg (f).

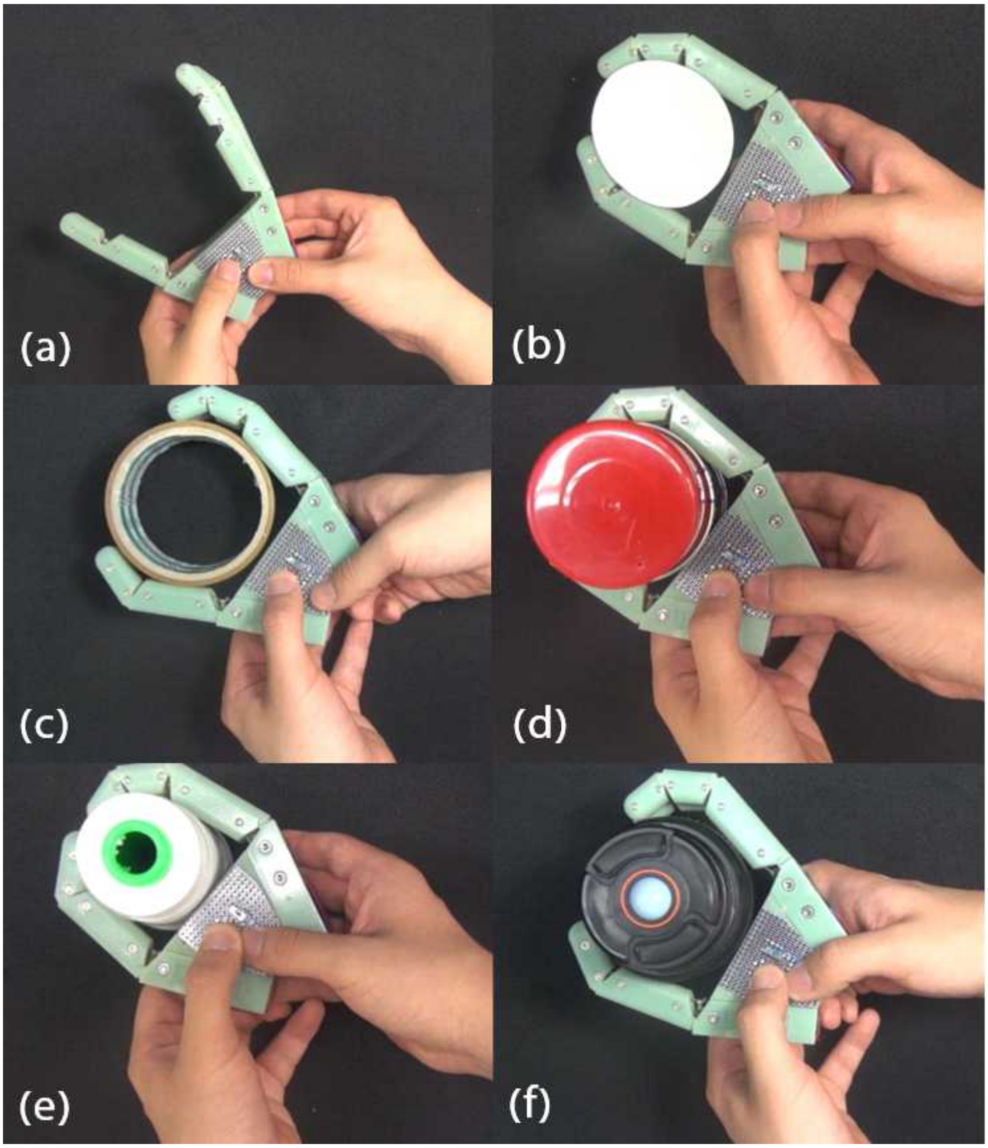


Figure 6.1 The grasping performance of the robotic hand

Chapter 7. Conclusion

This paper presented a successful approach to apply the Passive Variable Transmission Mechanism to a robotic hand and made the robotic hand grasp more rapidly and powerfully than the existing tendon driven robotic hand. The main issue of this research is the structural limitation of the existing tendon driven robotic hands. Most of their tendon wire path is fixed, and the moment arm is unchangeable. For these reasons, the grasping speed and the power of a robotic hand depend on the tendon's movement, which is proportional to the actuator's power. In this research, some attempts were made to improve this issue. Inspired by the pulley mechanism of human hands, which makes the moment arm of the tendon vary passively, the PVT Mechanism was applied to a tendon driven robotic hand to make the moment arm of the tendon wire variable.

The PVT Mechanism makes the moment arm of a tendon wire short when the joint rotates without load. The joint with PVT mechanism can rotate rapidly. On the other hand, if the joint contacts an obstacle, the moment arm of the tendon wire is increased. The PVT joint becomes to generate a big moment. In this research, a simple test was conducted to certify this property of the PVT Mechanism, and this PVT Mechanism showed a rapid rotation and a big power. To apply PVT mechanism to a robotic hand, several PVT designs were tried. The spring type PVT with the fabric M-part was fabricated. Joint with the spring type PVT was tested with joints with a fixed moment arm. From this test, it can be confirmed that the spring type PVT has reasonable PVT characteristics.

To decide the parameters of PVT of a robotic hand, a parametric study was conducted. There are a number of candidate parameters that can be done in a parametric study. For this reason, based on the kinematic modeling of the spring type PVT, the spring constant and the initial deformation of a spring was selected as the parameters for the parametric study, and we got to know a trade-off between the moment and the rotation speed of the PVT joint. Considering the characteristics of PVT's parameters, a robotic hand was designed, and 3 finger robotic hand was fabricated. The fabricated robotic hand was confirmed to improve the grasping performance.

The main contribution of this research is that the PVT Mechanism is applied to the robotic hand. To solve the tendon driven's structural limitation, a number of PVT designs were tested, and the spring type PVT was selected as the best PVT design. It was confirmed that the robotic hand with the PVT Mechanism shows a better performance than the existing robotic hand does. This research will contribute to improvement of the performance of the tendon driven mechanism.

Bibliography

[1] M. C. Carrozza, C. Suppo, F. Sebastiani, B. Massa, F. Vecchi, R. Lazzarini, M. R. Cutkosky, and P. Dario, “The SPRING Hand: Development of a Self-Adaptive Prosthesis for Restoring Natural Grasping,” Auton. Robots, vol. 16, no. 2, pp. 125 - 141, Mar. 2004.

[2] J. Zhao, L. Jiang, S. Shi, H. Cai, H. Liu, and G. Hirzinger, “A Five-fingered Underactuated Prosthetic Hand System,” in Proceedings of the 2006 IEEE International Conference on Mechatronics and Automation, 2006, pp. 1453 - 1458.

[3] M. T. Mason and J. K. Salisbury, Robot Hands and the Mechanics of Manipulation. Cambridge, Mass: The MIT Press, 1985.

[4] S. C. Jacobsen, J. E. Wood, D. F. Knutti, and K. B. Biggers, “The UTAH/M.I.T. Dextrous Hand: Work in Progress,” Int. J. Robot. Res., vol. 3, no. 4, pp. 21 - 50, Dec. 1984.

[5] G. Figliolini and P. Rea, “Overall design of Ca.U.M.Ha. robotic hand for harvesting horticulture products,” Robotica, vol. 24, no. 03, pp. 329 - 331, 2006.

[6] S. Hirose and Y. Umetani, “The development of soft gripper for the versatile robot hand,” Mech. Mach. Theory, vol. 13, no. 3, pp. 351 - 359, 1978.

[7] G. Figliolini and M. Ceccarelli, “A novel articulated mechanism mimicking the motion of index fingers,” Robotica, vol. 20, no. 01, pp. 13 - 22, 2002.

[8] IH2: Prensilia Srl. [Online]. Available: http://www. prensilia.com/

[9] Harada Hand: Harada Electric Industry Inc. [Online]. http://www.h-e-i.co.jp/Products/e_m_g/ph_sh_2_00 4.html

[10] H2 Hand: Meka. [Online]. Available: https://mekabot dev.com/m3doc/html/index.htm

[11] D. A. Keymeulen, “Investigation of the Harada robot hand for space,” presented at the IEEE RAS Internation Conference on Humanoid Robots, University International Conference Center, Tokyo, 2001.

[12] Dexterous Hand: Shadow Robot Company Ltd. [Online]. http://www.shadowrobot.com/products/dexterous-hand/

[13] Actuated Sheffield Hand: Elumotion Ltd. [Online]. http://www.elumotion.com/roboarm.html

[14]M. Kaneko, M. Higashimori, R. Takenaka, A. Namiki, and M. Ishikawa, “The 100 G capturing robot – too fast to see,” IEEEASME Trans. Mechatron., vol. 8, no. 1, pp. 37–44, Mar. 2003.

[15] S. Kawamura, H. Kino, and C. Won, “High-speed manipulation by using parallel wire-driven robots,” Robotica, vol. 18, no. 01, pp. 13–21, 2000.

[16] G. L. Smidt, “Biomechanical analysis of knee flexion and extension,” J. Biomech., vol. 6, no. 1, pp. 79–92, Jan. 1973. 15

[17] G. T. Lin, W. P. Cooney, P. C. Amadio, and K. N. An, “Mechanical properties of human pulleys,” J. Hand Surg. Edinb. Scotl., vol. 15, no. 4, pp. 429–434, Nov. 1990. 16

[18]H. In and K. Cho, “Concept of variable transmission for tendon driven mechanism,” in 2013 10th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), 2013, pp. 15–16. 17

[19] M. Kaneko, T. Yamashita, and K. Tanie, “Basic considerations on transmission characteristics for tendon drive robots,” in , Fifth International Conference on Advanced Robotics, 1991. “Robots in Unstructured Environments”, 91 ICAR, 1991, pp. 827–832 vol.1.

[20] J.-B. Sheu, J.-J. Huang, and J.-J. Lee, “Kinematic synthesis of tendon-driven robotic manipulators using singular value decomposition,” Robotica, vol. 28, no. 01, pp. 1 - 10, 2010.

[21] L.-W. T. Jyh-Jone Lee, “The Structural Synthesis of Tendon-Driven Manipulators Having a Pseudotriangular Structure Matrix,” Int. J. Robot. Res. - IJRR, vol. 10, no. 3, pp. 255 - 262, 1991.

[22] H. Kobayashi and R. Ozawa, “Adaptive neural network control of tendon-driven mechanisms with elastic tendons,” Automatica, vol. 39, no. 9, pp. 1509 - 1519, Sep. 2003.

국문 초록

자동형 가변 동력전달장치를 이용한 로봇손의 개발

본 논문은 자동형 가변 동력전달장치를 이용하여 힘줄 구동 로봇손의 사용성을 향상하는 한 가지 방법을 제시하고 있다. 이 연구의 개념은 실제 사람손의 특성에서 착안한 메커니즘으로, 사람의 손의 풀리에 의해서 필요에 따라서 힘줄의 모멘트 암을 자동으로 변화시키면서 힘줄의 수축 속도와 작용하는 장력의 크기에 비해서 빠른 회전 혹은 강한 회전력을 발생 시키는 특징을 모사하였다. 이러한 특징을 모사하기 위해서 본 역구에서 적용한 자동형 가변 동력전달장치는 사람의 손의 풀리의 역할과 같이 힘줄 와이어의 경로를 자동으로 변하도록 만들어주는 장치이다.

자동형 가변 동력전달장치는 와이어에 작용하는 장력의 크기에 따라서 탄성체의 길이가 변하여 관절의 모멘트 암이 변하는 특징을 이용한다. 힘줄 와이어에 작은 장력이 작용하면 모멘트 암이 짧게 유지되고, 힘줄 와이어에 큰 장력이 작용하면 모멘트 암이 길어지게 된다. 따라서 힘줄 와이어에 큰 장력이 작용하지 않는 일반적인 관절의 회전 시에는 모멘트 암이 짧아서 관절이 빠르게 회전하게 되고, 관절의 회전을 장애물이 막게 되면 힘줄에 큰 장력이 작용하여 모멘트 암이 증가하게 되어 큰 모멘트가 발생하게 된다.

좁은 구조의 로봇손에 자동형 가변 동력전달장치를 적용하기 위해서 여러 가지 디자인을 시도하여 적합한 메커니즘을 개발하였다. 제작된 스프링 티입 자동형 가변 동력전달장치를 탑제한 관절을 실험을 통하여 빠른 회전과 강한 모멘트를 선택적으로 구현할 수 있다는 것을 확인하였다. 그리고 로봇손에 적용할 자동형 동력 전달장치의 변수 값을 정하기 위해

서 변수에 대한 고찰을 진행하였다. 자동형 동력 전달장치의 변수에 대한 고찰을 바탕으로 제작된 로봇손을 기존의 힘줄구동 로봇인 Meka사의 H2 hand와 비교 해본 결과 약 20%의 전원으로 40%의 사용성을 보이는 것을 확인하였다.

힘줄구동 메커니즘에서 힘줄의 구동력을 증가시키지 않고도 보다 빠르게 회전하면서 큰 힘을 낼 수 있는 동력전달장치를 개발한 데에 본 연구의 의의가 있다고 하겠다.

주요어: 자동형 가변 동력전달장치, 힘줄구동, 로봇손, 파지력, 파지속도, 가변형 모멘트 암, 힘줄 와이어

학번: 2012-23191