# Design and Development of a Five-Fingered Master-Slave Robotic Hand by Using Solenoid and Pressure Sensors Comparator Technology

Solenoid Actuation System


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***Abstract*— Robotics technology, especially in the robotic hand development, is very important to perform various tasks that are considered too risky or fatal to be performed by a human being. This technology is also important to assist human being physiological rehabilitation. There are numerous designs of robotic hand, but the five-fingered robotic hand design is the most dexterous robotic hand design due to its similar appearance with a human hand. In general, the fingers' motions are driven or actuated by geared motors or other types of emerging technologies and controlled by microcontrollers or computers that received instructions from sensors or user inputs. However, the motions are yet to be driven or actuated by solenoids and controlled by using pressure sensor comparator method due to the solenoid technology limited applications and the controller novelty approach. Nevertheless, solenoids are known for their fast reaction time and strong holding force that are useful to perform high speed motions and strong grasping actions. The controller novelty approach is also expected to provide good motions' accuracy and response. Therefore, the synergy of this idea can introduce a new master-slave robotic hand design called SPCT (Solenoid-Pressure-Comparator-Technology) Robotic Hand. For this particular paper, the focus will be on the slave component design and solenoid actuation system. It can be seen that the design has potential for further developments.**



***Keywords*— robotics; robotic hand; five-fingered robotic hand; solenoid.**


## I. Introduction

A technology that consists of design, construction, operation, development and application of robots is known as robotics [1]. Even the technology that involves the computer systems for control, sensory feedback and information processing for robots is known as robotics. These technologies are very crucial to perform various 'master-slave' or remote tasks that cannot be achieved by humans due to certain hazardous elements or safety issues such as performing dangerous manufacturing processes, handling biohazard elements, disarming bombs, post-disaster search and rescue missions, etc. There are many robotic components that are involved to perform these tasks but the most prominent component is the robot's hand since it has more degrees of freedom (DOF) compared to the other components.

There are various types of robotic hand designs but the five-fingered robotic hand design has the highest number of DOF. This is due to the fact that a five-fingered robotic hand is designed to be more dexterous compared to the other robotic hand designs because it has similar motions and appearance of a human hand. These motions are usually driven or actuated by geared electric motors [2]-[7] [11], but other emerging technological developments of prime movers are also applied to generate these motions such as shape-memory alloy [8] [9], pneumatic actuators [10] [11] and hydraulic actuators [12] [13]. However, recent technological developments of a five-fingered robotic hand have yet to explore the option of generating the motions by using solenoid technology. The main reason for this particular occurrence is the common perceptions or understandings on the solenoid applications.

Solenoids are commonly utilised as main prime movers for valve control [14] [15] and switching [16] [17] applications due to the large force that the solenoids can produce at short stroke length whilst having a low reaction time. This characteristic is very ideal to provide strong grasping strength and fast speed motions for the robotic hand but this characteristic is not suitable for generating a wide range of motions for the robotic hand because of the limited displacement. Nevertheless, the developments of solenoid designs have improved over the past few years with multistage coils and new plunger designs [18]. These improvements allow the solenoid to have a longer displacement while maintaining a decent, same or higher amount of force.

In the aspect of controlling (master), the user generally controls the robotic hand's (slave) motions by using microcontrollers with preset motion settings [19] [20], visual monitoring [21] [22], haptic feedback [23] [24] and CyberGlove [25]-[27]. However, the robotic's hand motion can also be controlled by a novel approach of master-slave pressures comparator technique.

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Due to the absent and also the synergy of these two particular methods of generating and controlling the robotic hand's motions, this paper will introduce a new master-slave robotic hand design called SPCT (Solenoid-Pressure-Comparator-Technology) Robotic Hand. The design will only cover the slave component of SPCT Robotic Hand along with its solenoid actuation system.

## II. Slave Component Design

### *A. Five-Fingered Hand Design*

The five-fingered hand design is shown in Figure 1 and Figure 2 for palm and back hand view respectively. Meanwhile, Figure 3 shows the side view of the index finger. It is important to note that the inset pictures in Figure 1 highlights the high tension string guide ways.

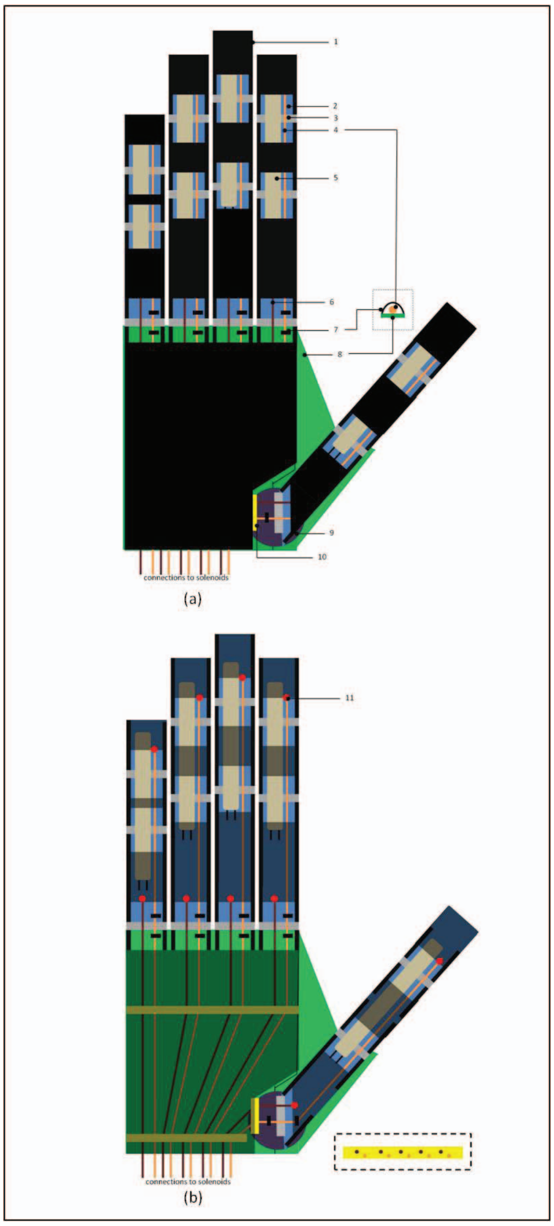


Fig. 1. (a) Palm view of the hand design and its (b) uncovered version to illustrate the high tension strings connections.

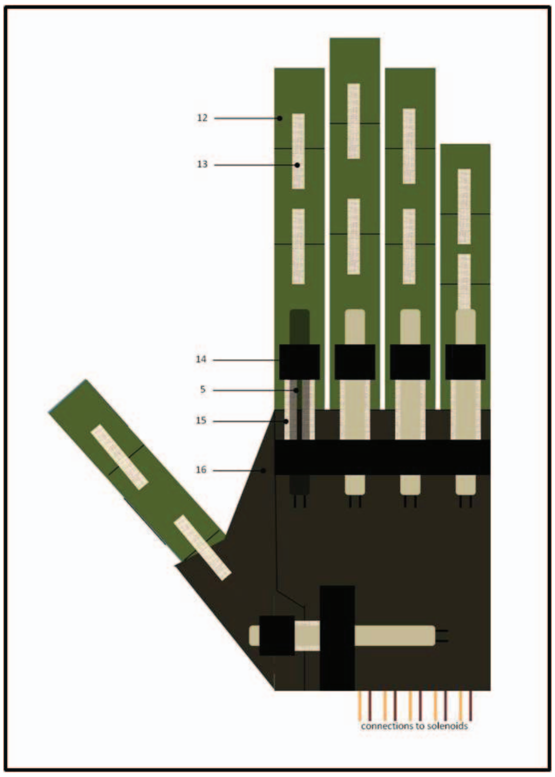


Fig. 2. Back hand view of the hand design.

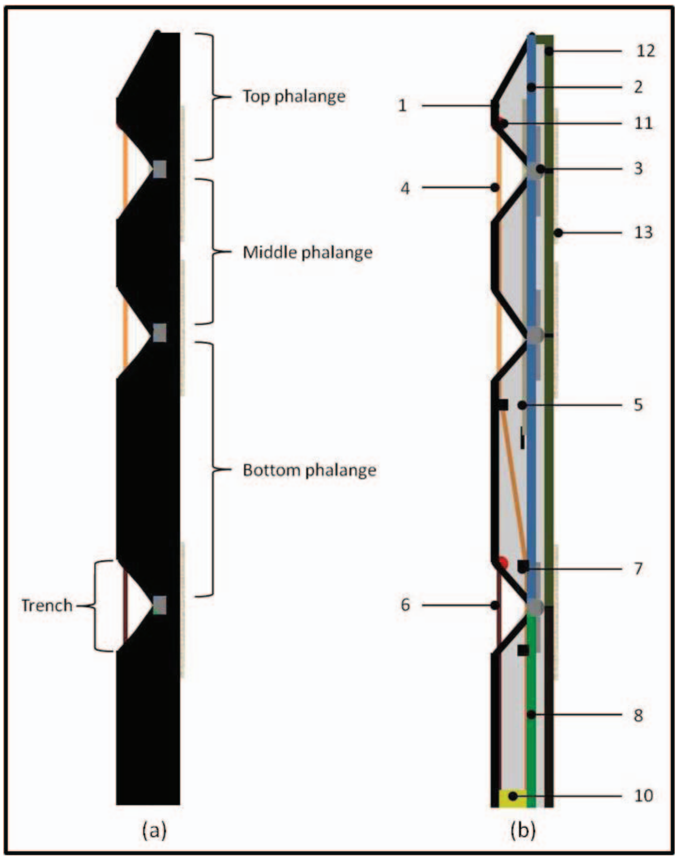


Fig. 3. (a) Side view of the index finger and its (b) uncovered version to illustrate the high tension strings connections

The labels are described in Table 1, which also explains the functions for each component.

Table 1. Labels for Figure 1, Figure 2 and Figure 3.

| No | Description | Function |
|---|---|---|
| 1 | Palm/Bottom plane | The palm surface area that interacts directly with objects. |
| 2 | Centre plane (fingers) | The central rotation axis for the fingers' motion where the hinges and bend sensors for double phalanges actuation are placed. |
| 3 | Hinge | Mechanical bearing that connects two phalanges and acts like a joint. |
| 4 | High tension string (double phalanges) | Connected to a solenoid to move the top and middle phalange from a single actuation. |
| 5 | Bend sensor | Connected to the microcontroller to determine the finger angular position. |
| 6 | High tension string (Single phalange) | Connected to a solenoid to move the bottom phalange from a single actuation. |
| 7 | Arc-shaped guide way | Guiding the high tension strings (double phalanges) towards the intended solenoids without crossing other high tension strings. |
| 8 | Centre plane | The central surface area that houses the guide ways, hinges and spiral torsion spring. |
| 9 | Spiral torsion spring | Provides a flexible movement for the thumb during operation. |
| 10 | Rectangular-shaped guide way | Guiding the high tension strings towards the intended solenoids without crossing each other. |
| 11 | Arc-shaped locker | Lock the high tension string to create motion during actuation. |
| 12 | Top/Back hand plane (fingers) | The back hand that houses the bend sensors for single phalange actuation and elastic fabric band. |
| 13 | Elastic fabric band | Returns the fingers towards the initial position when the solenoids are turned off. |
| 14 | Bend sensor placer | Places the bend sensor on the surface without sticking the sensor permanently to allow the fingers to bend. |
| 15 | Dual elastic fabric bands | Has double stretching force to prevent the bottom phalange to move when the top and middle phalanges are moving. |
| 16 | Top/Back hand plane | The back hand that houses the bend sensors for single phalange actuation and elastic fabric band. |

*B. Solenoid Actuator Connections*

The solenoid actuator, as shown in Figure 4, is used to create the fingers' motions by pulling the high tension strings through the plunger. In this particular robotic hand design, there are ten solenoids; five large solenoids and five small solenoids. The large solenoid is used to move two phalanges simultaneously and the small solenoid is used to move a single phalange. The solenoid actuators design is depicted in Figure 5 and Figure 6 for bottom and front view respectively.

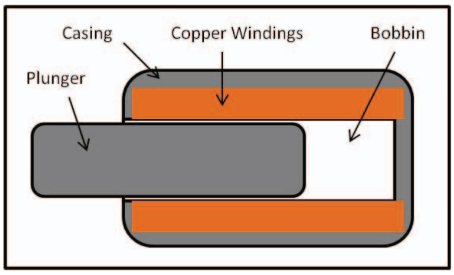


Fig. 4. Solenoid actuator.

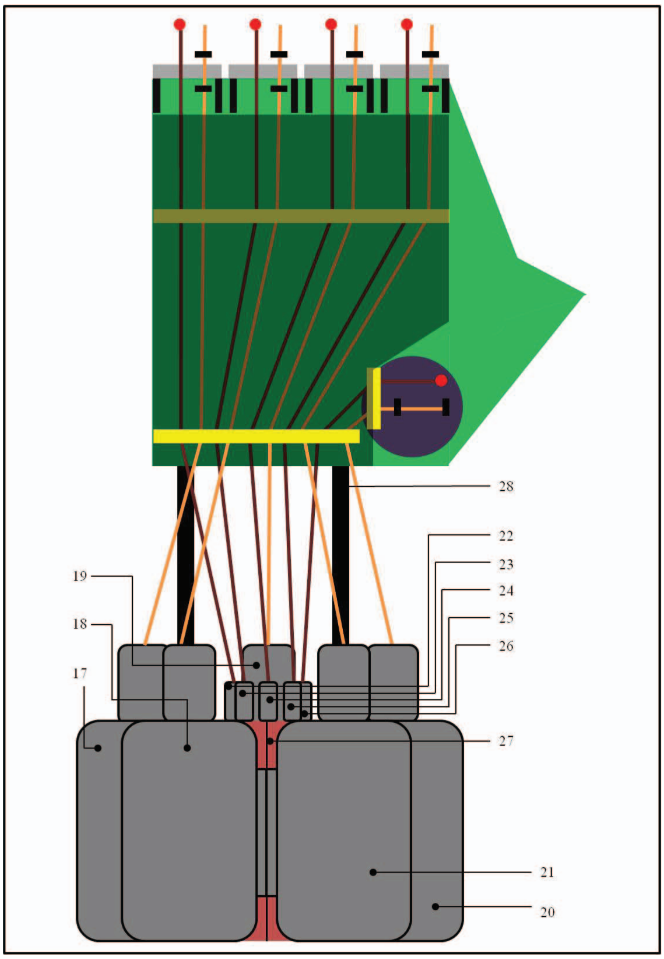


Fig. 5. Bottom view of the actuation system.

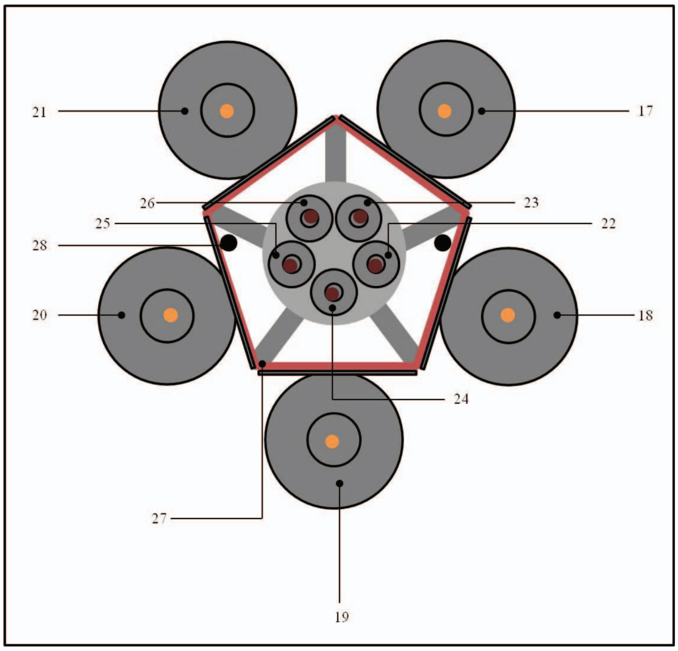


Fig. 6. Front view of the actuation system.

The labels are described in Table 2, which also explained the functions for each component.

Table 2. Labels for Figure 5 and Figure 6.

| No | Description | Function |
|---|---|---|
| 17 | Solenoid actuator (double phalanges - small finger) | Pulls the high tension string to move the small finger top and middle phalanges. |
| 18 | Solenoid actuator (double phalanges - ring finger) | Pulls the high tension string to move the ring Finger top and middle phalanges. |
| 19 | Solenoid actuator (double phalanges - middle finger) | Pulls the high tension string to move the middle finger top and middle phalanges. |
| 20 | Solenoid actuator (double phalanges - index finger) | Pulls the high tension string to move the index finger top and middle phalanges. |
| 21 | Solenoid actuator (double phalanges - thumb finger) | Pulls the high tension string to move the thumb finger top and middle phalanges. |
| 22 | Solenoid actuator (single phalange - small finger) | Pulls the high tension string to move the small finger bottom phalange. |
| 23 | Solenoid actuator (single phalange - ring finger) | Pulls the high tension string to move the ring finger bottom phalange. |
| 24 | Solenoid actuator (single phalange - middle finger) | Pulls the high tension string to move the middle finger bottom phalange. |
| 25 | Solenoid actuator (single phalange - index finger) | Pulls the high tension string to move the index finger bottom phalange. |
| 26 | Solenoid actuator (single phalange - thumb finger) | Pulls the high tension string to move the thumb finger bottom phalange. |
| 27 | Solenoids housing | Container that houses the solenoids. |
| 28 | Connecting rod | Connect or hold the solenoid housing and the hand together. |

## III. Solenoid Actuation System Operation

The solenoid actuators can generate the fingers' motions through a combination of string-hinge mechanism. In order to generate the hand's motions by using solenoids, the proposed mechanism is based on under-actuated muscle-tendon-joints connection. The plunger, which is the moveable part of the solenoid, will provide a pulling force on a string (tendon) to rotate hinges (joints). The pulling forces will then cause the hinges at the fingers' joints to rotate via the string, which will subsequently move the fingers into grasping position. The finger will return back to its original position through elastic cloth bands mechanism that are connected to the joints once the plunger does not provide a pulling force on the string anymore. Each finger requires two solenoids to operate (under-actuated) and since solenoids are known for having low reaction time and large force at short stroke length, the robotic hand can produce fast speed motions and strong grasping strength.

As mentioned earlier, a single finger requires two solenoids to create a full hooking or grasping action. Initially, the position of the finger is shown in Figure 3. When the solenoid for double phalanges is actuated, it will pull the high tension string to move the top and middle phalanges. These phalanges will move because the high tension string is tighten to the arc-shaped locker and this action or motion is shown in Figure 7.

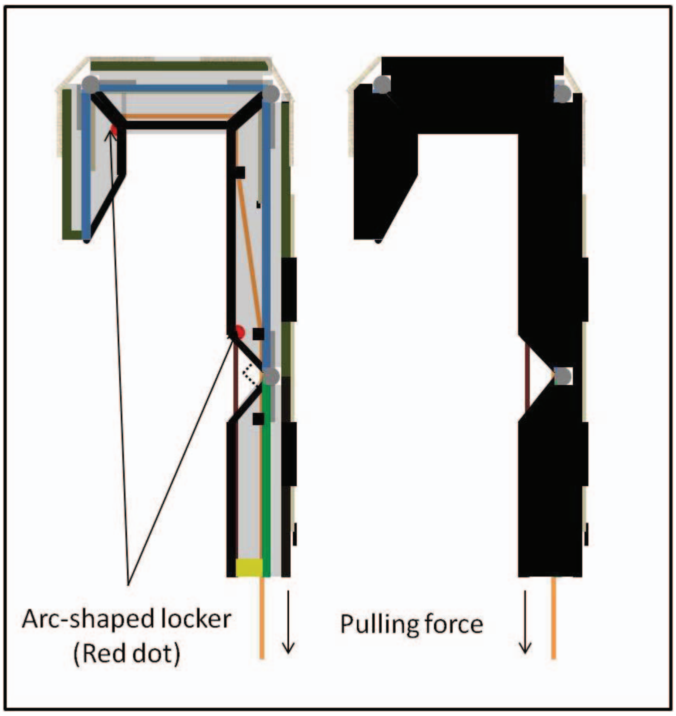


Fig. 7. Side view of the index finger during actuation to move the top and middle phalanges.

When the solenoids for double phalanges and single phalange are actuated, the top, middle and bottom phalanges will move as shown in Figure 8. Again, these phalanges will move because the strings are tighten to the arc-shaped lockers. It is important to take note that the high tension string for the double phalanges will slightly tighten at this position because the string is located near to the hinge's pivot.

Since a solenoid has a short stroke length, the distance between the palm/bottom plane and centre plane must be kept at a small value in accordance to the maximum stroke length of the solenoid. If the distance is too large, the 90° angle illustrated in Figure 7 and Figure 8 cannot be achieved. The slope angle at the trench must also be set to a proper value in order to create a 90° angle by ensuring the angle at the 'V' shape of the trench to be 90°. Detailed information on this matter will be discussed in another paper as the research and development progresses.

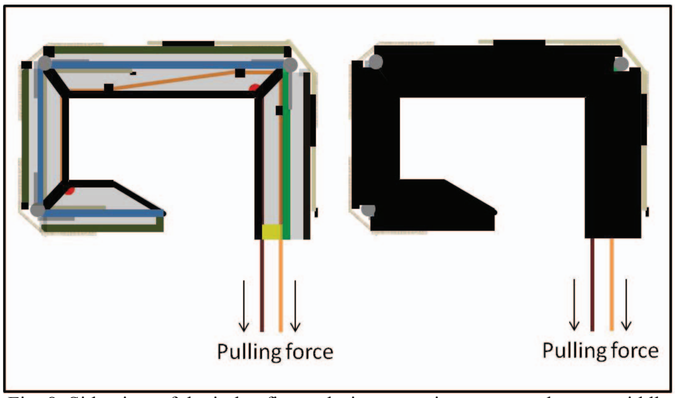


Fig. 8. Side view of the index finger during actuation to move the top, middle and bottom phalanges to create a hooking or grabbing action.

## IV. Conclusion

Based on the presented SPCT Robotic Hand slave components design, it can be concluded that the solenoid actuators have the ability to create decent fingers' motions that are fast, responsive and has strong grasping strength. However, the design is still in its initial stage and requires further research and developments to gauge its true potentials. This can be done via in-depth calculations, simulations and experimentations. Nevertheless, the idea to the introductory design is deemed feasible and practical for future studies.

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