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Research paper

Initial Development of a Master-Slave Controller for a Five-Fingered Robotic Hand Design by Using Pressure Sensors Comparator Technique

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Abstract

There are numerous robotic hand designs but the five-fingered robotic hand design is the most dexterous robotic hand design due to its similar appearance and motions with the human hands. The five-fingered robotic hands are commonly controlled or governed through a master-slave system that can be accomplished by using simple preset motions or other complicated and advanced technologies. However, a five-fingered robotics hand can also be controlled by a novel approach known as pressure sensors comparator technique. This technique compares the values from the pressure sensors that are strategically located at the glove (master) and robotic hand (slave). If the values differ, the actuators will generate motions accordingly. The initial finding based on the master and slave prototypes showed that applying this technique is very challenging due to the humans' physiological diversity. Nevertheless, a solution was proposed for further studies and future developments by introducing an offset.

Keywords: *robotics; robotic hand; five-fingered robotic hand; master-slave; pressure sensor; flex sensor; bend sensor.*

1. Introduction

1.1. Overview

Robotics is a technology that consists of processes or actions that are involved in designing, constructing, operating and developing robots [1]. The technology also includes the computer systems for controlling, sensory feedback and information processing of robots. These technologies are very important in performing a wide range of tasks that are very difficult or impossible to be executed solely by humans due to various 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 several robotic components involved to perform these tasks but the most utilised component is the robot's hand because it has more degrees of freedom (DOF) compared to the other components.

Robotic hand is available in a wide range of designs but the five-fingered robotic hand design has the highest number of DOF. This is because a five-fingered robotic hand is designed to be more dexterous compared to the other robotic hand designs as it imitates a human hand in term of appearances and motions.

A five-fingered robotic hand can be controlled through various methods but the master-slave controller scheme is considered to be the most widely used system. In a master-slave system, the user can control the robotic hand by using microcontrollers with preset motion settings [2] [3], visual monitoring [4] [5], haptic feedback [5] [7] and CyberGlove [8]-[10]. However, the robotics hand can also be controlled by a novel approach known as pressure sensors comparator technique. The pressure sensors comparator technique utilises microcontrollers to compare the values of pressure at each joints of the robotic hand fingers with the values of pressure at each joints of a specially designed glove. If the pressure sensor's value at one joints of the robotic hand finger is not the same as the pressure sensor's value at the similar joints of the glove, the microcontroller will activate the actuators to move the finger. This comparing technique allows the robotic hand to move rigorously according to the glove motions as long as the pressure sensors have similar characteristics.

1.2 Pressure Sensor Applications in Robotics

Pressure sensors are widely used for various domestic, industrial, agricultural, manufacturing and even military applications. Thus, pressure sensors are also widely used in robotics applications due to its importance and existence in each sector. However, pressure sensors were never used to regulate motions between the glove and robotic fingers meticulously. This is because these sensors are typically used for angle positioning and tactile sensing that are placed at strategic locations.

1.2.1 Angle Positioning

The types of pressure sensors that are usually used for positioning are flex sensor and bend sensor. These sensors have similar fundamental concept; the resistant of the sensors will increase as the flexing or bending angle increases. The changes are linearly proportional but the resistance at 0° angle has a tolerance value of ±30%, which is quite high and not suitable for sensitive or precision applications when the sensor is at relaxed position.

The sensors can be integrated with a glove or robotic fingers to perform various tasks by indentifying the flexing or bending angle. If the sensors are integrated with a glove, the output angles can be used to translate gestures [11] [12] or control the actuators to move the fingers according to the glove's motions [13] - [15]. The later application is generally used in rehabilitation for hand impaired patients. The sensors can also placed on the skin directly based on the recent development [16] but this type of sensor has lower sensitivity and higher relaxation settling time as compared to flex and bends sensors [17]. In the aspect of integrated sensors within robotic fingers, the main function is for validity test to ensure the motions are within the expected range [18] [19].

1.2.2 Tactile Sensing

Tactile sensing is an action that processes information from physical interaction with the surrounding environment through the biological sense of touching. Tactile sensor is a type of pressure sensor that is either made from piezoresistive, piezoelectric, capacitive and elastoresistive materials. The sensors are usually arranged in arrays to achieve optimum sensing.
The sensors are normally used in robotics to prevent assist robot from injuring the user [20], controlling the grasping strength of a robotic hand or fingers [21] - [27], obstacle detection [28], integration with haptic devices to provide feedback to the user [29] [30], thin sheet manipulation [31] and object recognition/identification [32]. Based on these applications, it can be concluded that the main function of the sensor is to prevent failures and damages to the handled objects and the robotic hand itself.

1.3 Pressure Sensors Comparator Technique

As stated before, pressure sensors were never used to strictly regulate motions between the glove and robotic fingers because these sensors are usually used for positioning and sensing. Therefore, this paper will firstly introduce the pressure sensor comparator technique by looking at the master and slave components, and the proposed comparator system. The prototype master and slave sensors' resistances will then be measured to determine the actual outputs when both components are making similar finger's action.

2. Master and Slave Designs

The glove and robotic hand are designed in accordance to a master and slave relationship respectively by using flex sensors (a pressure based sensor) and the solenoid actuated five-fingered robotic hand design (developed by the authors) as reference [33]. This particular relationship will force the robotic hand to strictly adhere to the glove's movements. Therefore, some duplicated structural designs were introduced to ensure proper instructional processing and executions from both parts.

2.1. Master Components

The master components design is shown in Figure 1, Figure 2 and Figure 3 for the top, base and perspective views respectively. It can be seen that the master or glove attachment design is partially based on the top part of a solenoid actuated five-fingered robotic hand's fingers and backhand. This design is modular and can be attached to any commercially available or handmade gloves. It is not shown clearly in the figures but it is important to highlight that the phalanges and backhand components are not connected to one another. These components can be freely arranged and attached to an existing glove for better flexibility and optimised sensors' positioning.

2.2. Slave Components

The slave components design is shown in Figure 4, Figure 5 and Figure 6 for the palm, backhand and perspective views respectively. It is important to highlight that the slave or hand design is the actual solenoid actuated five-fingered robotic hand design. This similar base design selection is important to reduce deviations in the pressure sensor's readings that might occur when the finger moves due to inconsistent structural design. There is always a possibility that the pressure sensor will bend inappropriately when the structural design is not consistent.

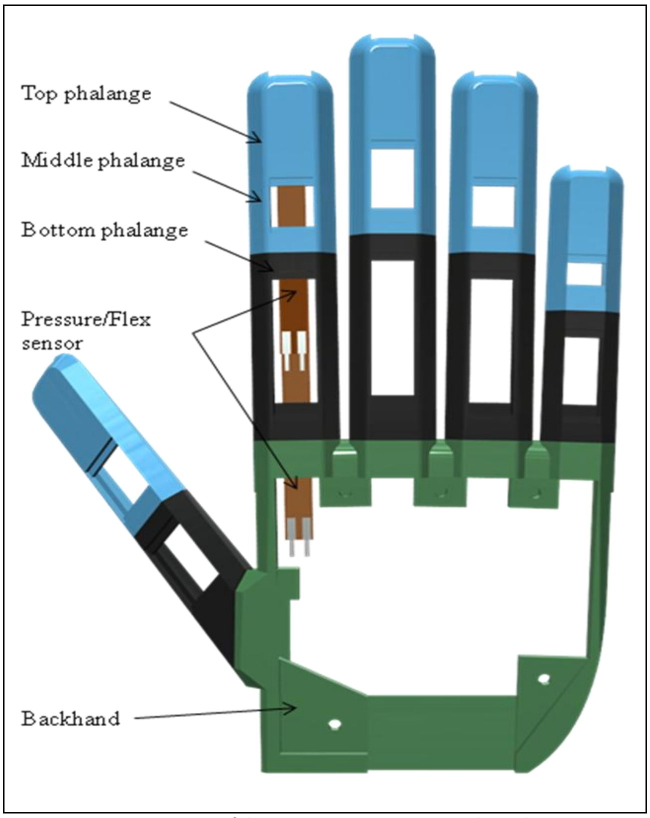

Fig. 1: Top view of the master components or glove design.

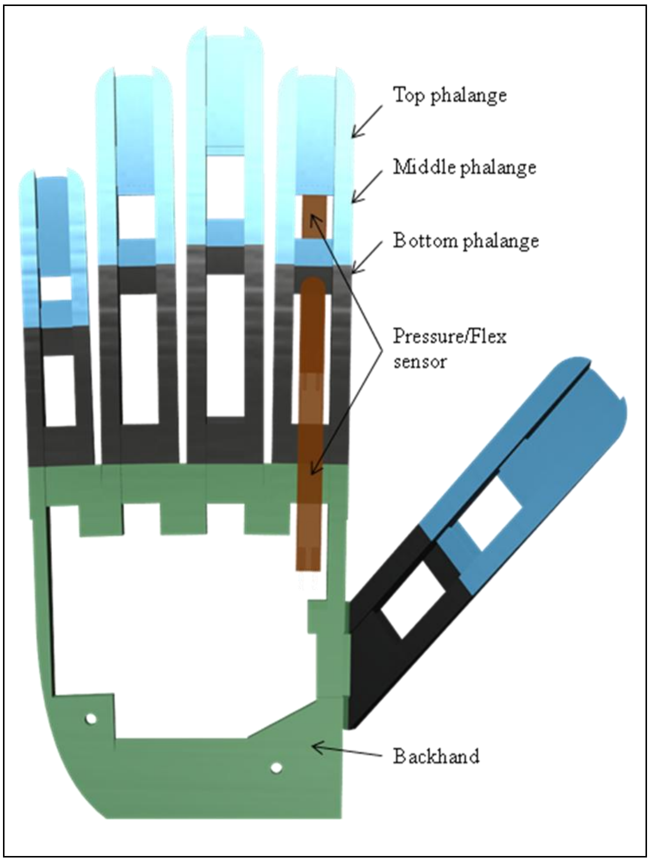

Fig. 2: Base view of the master components or glove design.

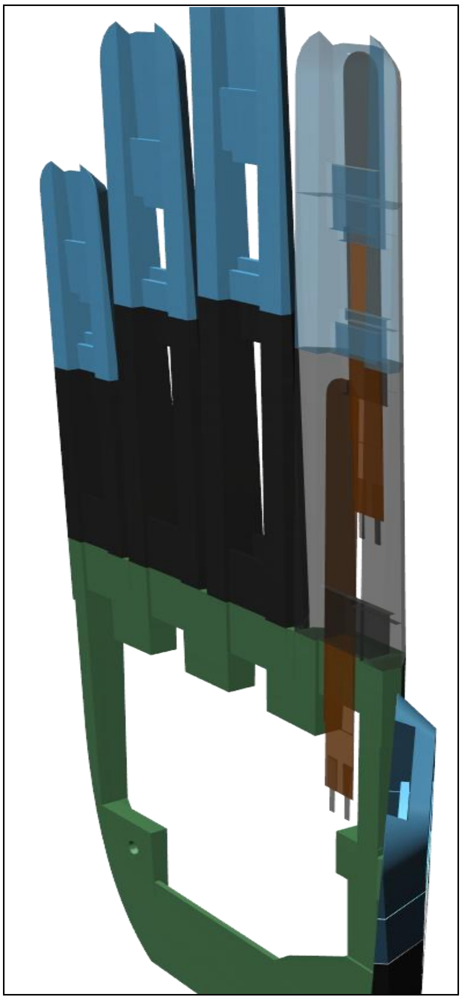

Fig. 3: Perspective view of the master components or glove design to emphasise the sensors placement.

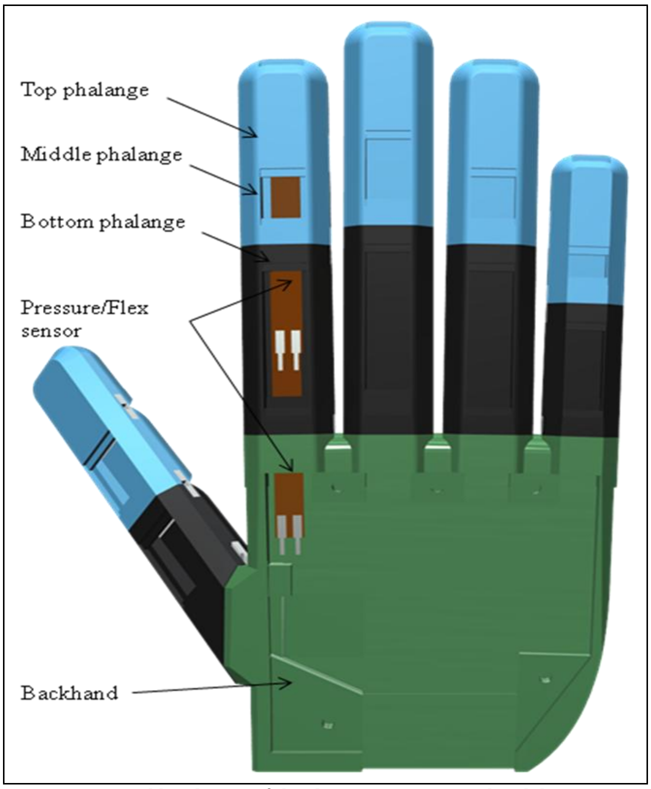

Fig. 5: Backhand view of the slave components or hand design.

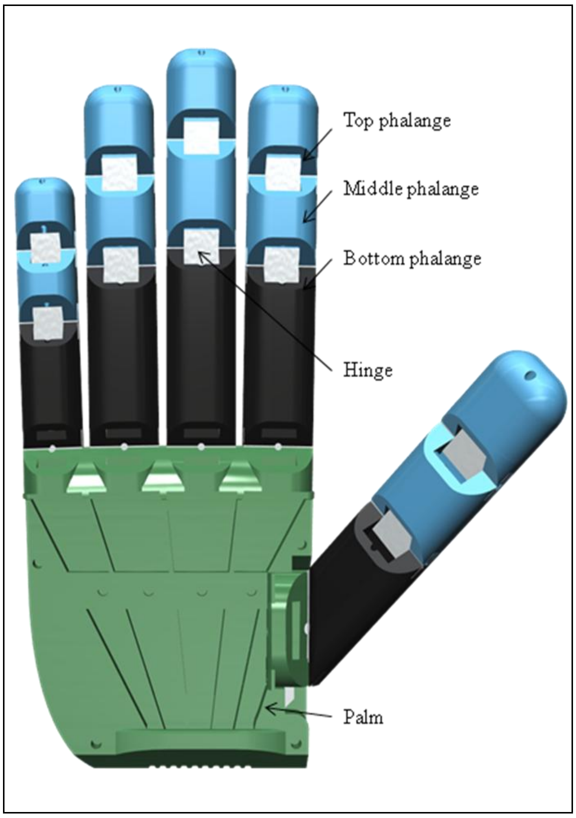

Fig. 4: Palm view of the slave components or hand design.

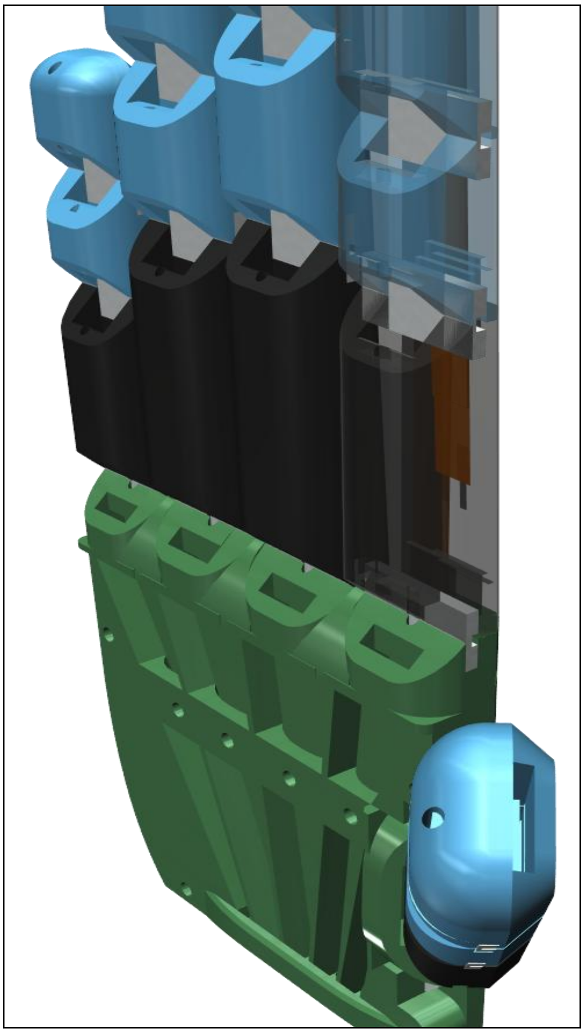

Fig. 6: Perspective view of the slave components or hand design to emphasise the sensors placement.

3. Pressure Sensors Comparator System

The pressure sensors comparator system, which is shown in Figure 7, is based on a closed loop system that regulates the actuators' movements by comparing the master and slave sensors' values. Essentially, the actuator for one finger will move as long as the sensor reading from a specific finger at the master is not similar with the sensor reading from a specific finger at the slave. It is important to note that the specified finger from both components must be similar i.e. index finger with index finger.

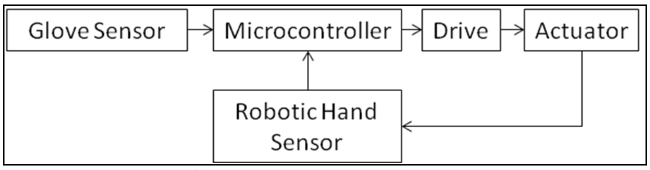

Fig. 7: The pressure sensors comparator system.

The recursive process can be clearly explained by using one finger and one pressure sensor, each from the master and slave as example. Initially, the microcontroller will read the values from the master and slave sensors. The value for each sensor will vary when the bending or flexing angle of the sensor varies because the sensor's resistance will increase linearly as the bending or flexing angle increases. Then, the microcontroller will use the values to compute an output to the drive through a control function (will not be discussed in this paper) that consists of calculations and logic functions. The drive will set a suitable voltage at the actuator that causes the finger to move into curling position (Figure 8 (a)) when the master sensor's value is larger than the slave sensor's value or straighten position (Figure 8 (b)) when the slave sensor's value is larger than the master sensor's value. Since the slave sensor's value will also change when the actuator moves due to the sensor's location within the finger, the actuator will keep on moving until both sensors' values are similar. This recursive process will cause the robotic hand to follow the glove's movements. A flowchart is shown in Figure 9 to provide a simple illustration on this recursive process.

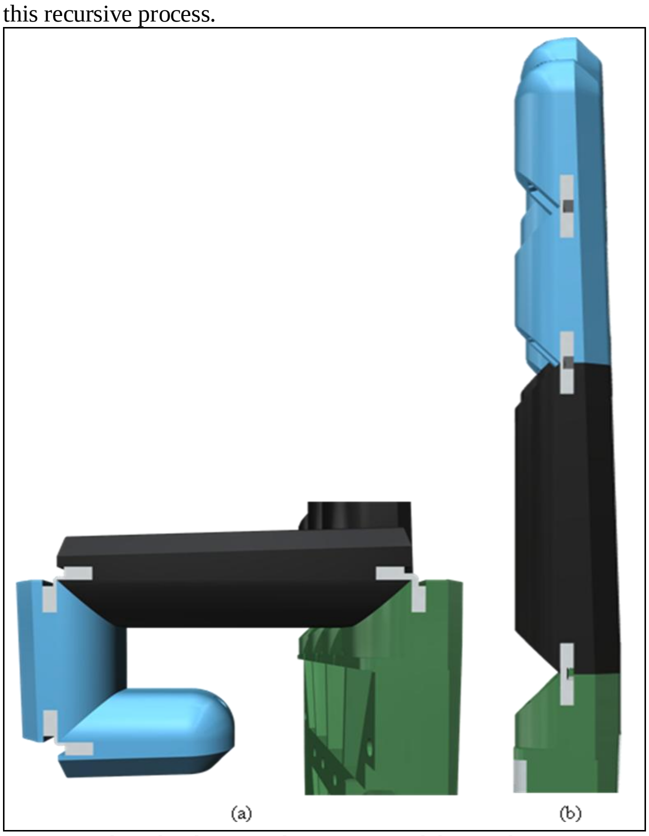

Fig. 8: Robotic hand in (a) curling position and (b) straighten position.

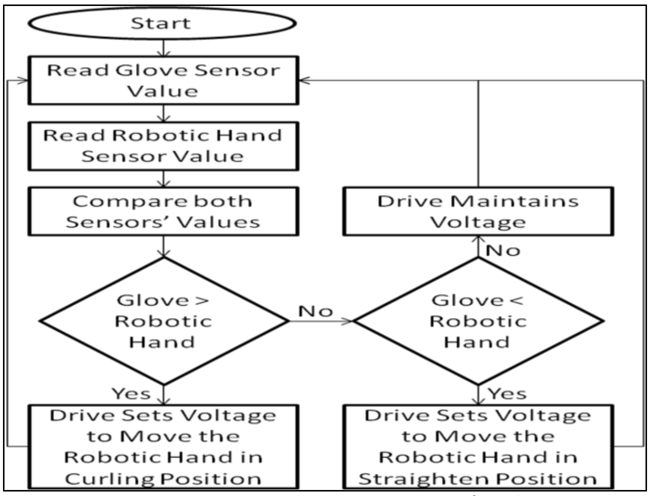

Fig. 9: Pressure sensors comparator system flowchart.

4. Master and Slave Sensors Readings

The pressure sensors used for the master and slave are similar but the values vary by ±30% due to the manufacturing tolerance based on the datasheet. Therefore, it is important to measure the pressure sensors from the actual master and slave prototypes in the initial development to determine whether the readings from both components vary greatly when making similar actions. Both prototypes were 3D printed based on the design in Section 2 to ensure consistency when the finger motions and resistance values of the pressure sensors are compared.

3.1. Master Prototype

The master prototype is shown in Figure 10. It is important to note that the angle between the fingers is now slightly larger as compared to the original design due the glove's design. Even though the modular design allows flexibility in placing the master components, the pressure sensors might be shifted from its original position when the finger moves because the human's backhand is not flat. These particular shifting actions might prevent the pressure sensors from bending in one direction.

Fig. 10: Master prototype components.

3.2. Slave Prototype

The master prototype is shown in Figure 11, Figure 12 and Figure 13 for the palm, backhand and side views respectively. Notice that the master component is similar to the slave's backhand shape.

Fig. 11: Slave prototype palm view.

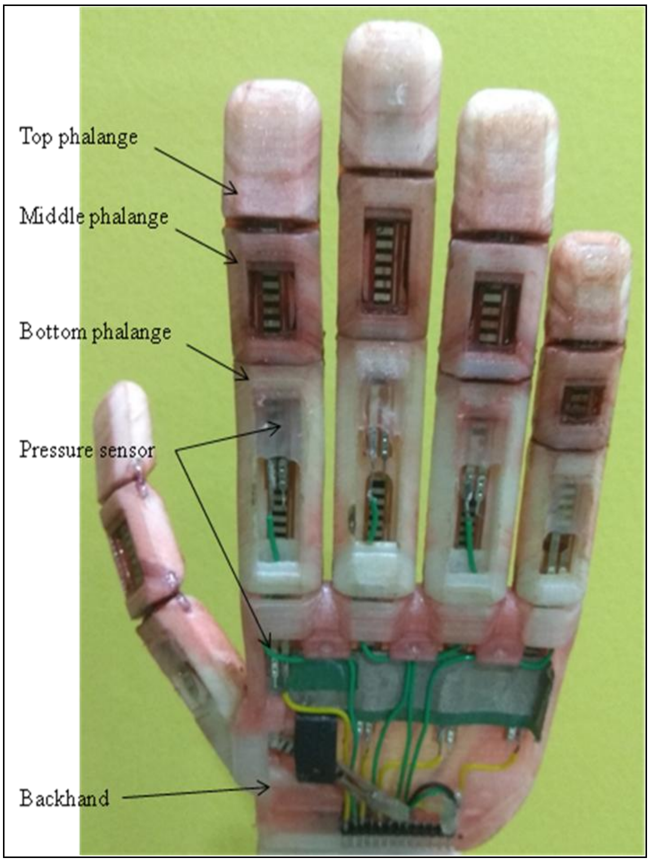

Fig. 12: Slave prototype backhand view.

Fig. 13: Slave prototype side view.

3.3. Sensors Reading

Figure 14 illustrates the index fingers' angular position for both master and slave prototypes.

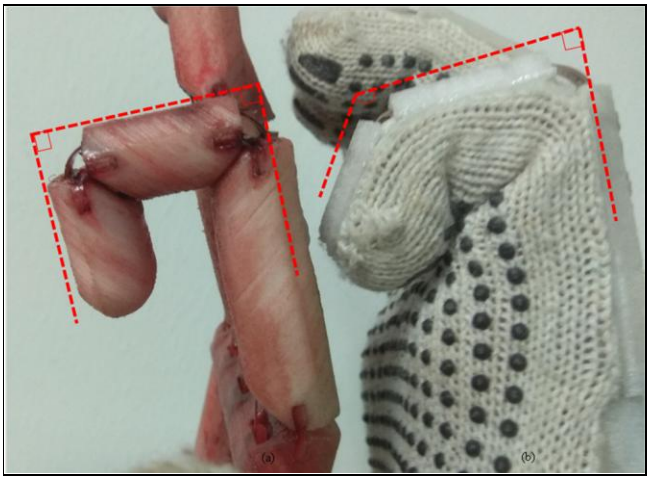

Fig. 14: The (a) slave prototype and (b) master prototype demonstrate a hooking gesture through the index finger. The red dashes lines indicate the angular positions.

Based on Figure 14, it can be seen that the angular position for the slave prototype and master prototype is not the same when both prototypes are making a hooking gesture. The slave component can make 90° bending between top-middle phalange and middle-bottom phalange but the master component can only make a 90° bending between mid-bottom phalange only. Since the angular position is not similar, the resistance values of the pressure sensors are not identical or close to each other too. The readings showed that the master's pressure sensor outputs a value of 70 kΩ whereas the slave's pressure sensor outputs a value of 121.6 kΩ (bending angle and resistance is directly proportional). This particular problem cannot be avoided because each human has different physiological conditions or appearances. Therefore, an offset should be introduced to solve the sensor's tolerance value and the angular variation between the master and slave problem.

One possible method is to normalise the sensor's value at the master or slave component by deducting the higher value with the lower value to get the offset when the finger is in straighten position. From this point onwards, the higher value readings will be deducted by the offset. For example, if the current master sensor's value is 20 kΩ and has a higher sensor's value than the slave component during straighten position with a calculated offset of 10 kΩ, then the actual value is 10 kΩ. This method can only be applied if the sensor changes linearly most of the time and this method must obtain the offset every time the microcontroller reboots. Another possible method of offset is to use variable resistors that can set the output readings for the master and slave to be similar when the microcontroller read the values at straighten or curling position. The variable resistors will also act as a memory for the offset calibration every time the power to the microcontroller is turned off.

5. Conclusion

Designing a master-slave controller for a five-fingered robotic hand design by using pressure sensors comparator method is possible but there are a lot of inconsistencies because the sensor's tolerance varies individually and the human's hand and fingers appeared in various physiological forms. However, the development is still in its early stage and introducing an offset to the technique or system might solve the problem. Therefore, further studies are required for further developments.

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