Mimicking the Movements of the Human Hand using Leap Motion Sensor for Different Users

Maritoni M. Alano, Joseph B. Olleres, Ma. Dolores R. Rico, Jettro A. Satsatin, Jonalyn M. Solomo, Roselito E. Tolentino

Abstract— The researchers considered the disadvantage of using a Cyber gloves sensor that was always needed a calibration for mimicking a robotic hand. It is simply because human hand dimensions are not standard. For every person that would use the glove to operate a teleportation, there would be a different hand configuration to be able to perform the various tasks. Individual calibration is needed because each human hand has his personal calibration. Therefore, the researchers use Leap Motion sensor with the aid of a professional, high-precision, and fast motion tracking system which is designed to be placed on a physical desktop, facing upward to track human hands and fingers and then the researchers employed vector dot product method for the algorithm in order to acquire data in controlling a robotic hand to mimic the movements of the human hand for different users.

Index Terms— Leap Motion sensor, Mimicking, Robotic hand, Scalar product

I. INTRODUCTION

Mimicking a robot is one of the hottest and latest research topics today and an important application for the robotic systems. The Robots can be helpful as possible and be able to assist humans in their everyday activities. In this regard, one of the most important parts of our human body is the hands and is replicated as robotic hands. The human hand is very complex and highly articulated. In this concern, the field of robotics has explored the creation of a robotic hand that mimics human hand. In case of a sensitized glove, it is very expensive and user intrusive but it's not a problem. The works discussed different methods and approaches in calibrating a sensorized glove to be able to mimic a human hand movement. The data retrieved from the sensorized glove is being transmitted to the robotic hand for controlling [3].

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But this study was always needed a calibration. It is simply because human hand dimensions are not standard [3]. For every person that would use the glove to operate a teleportation, there would be a different hand configuration to be able to perform the various tasks.

To be able to solve this problem in the existing works, the researchers use Leap Motion sensor [1] that is a small USB peripheral device which is designed to be placed on a physical desktop, facing upward that works by projecting infrared light upward from the device and detecting reflections using monochromatic infrared cameras to track human hands and fingers that will acquire coordinates from the human hand. Using this coordinates, the researchers obtained joint angles by using an algorithm. In this algorithm, joint coordinates acquired from the sensor is being transformed into vectors. Using vector analysis, the vector orientation of each finger bone is acquired. The angle between these vectors was obtained and used to control the robotic hand movement.

With the availability of this sensor device, the true mimicking of a robotic hand can be made possible. The goal of this study is to use the Leap Motion sensor to control the movements of the robotic hand by mimicking the human hand for different users. This study also aims to impart additional idea on several fields where these innovative systems can be operative and be beneficial such as in medical application, domestic application, industrial application and for the application of accessing dangerous areas and handling explosives agents from the distance; but like other studies, this also have its delimitations to be taken out.

II. METHODOLOGY

Figure 1 shows how the system works. It consists of human hand movement, acquiring joint-coordinates of the human hand, acquiring finger-joints angle, and robotic hand movement. First, as the human hand's movement is in a close proximity above the Leap Motion sensor at a certain distance, the controller operates and identifies the hands position, digits of fingers, and the orientation of each finger bone. The Leap Motion sensor acquires joint coordinates of human hand tracked. Then, by using the given joint coordinates, the researchers obtained finger-joint angles by using Vector Multiplication (Dot Product). In this algorithm, joint coordinates acquired from the sensor is being transformed into vectors. Using vector analysis, the vector orientation of each finger bone is acquired. The angles between these vectors was obtained and then inputted into the robotic hand for its movement.

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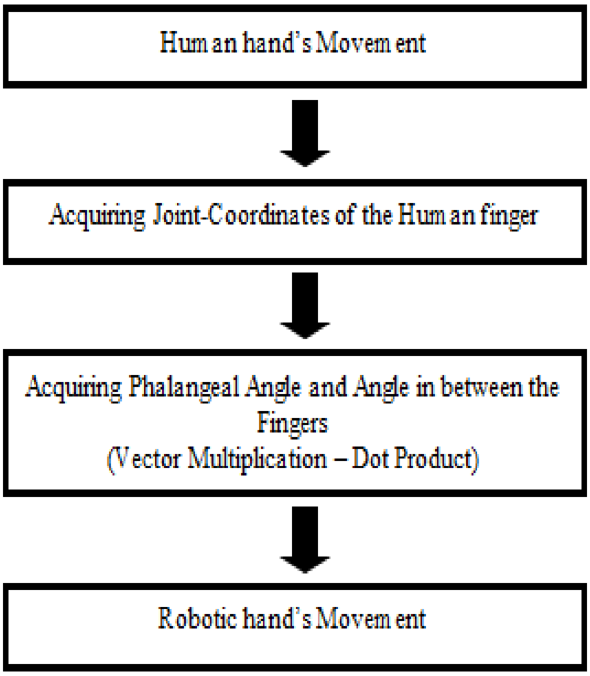


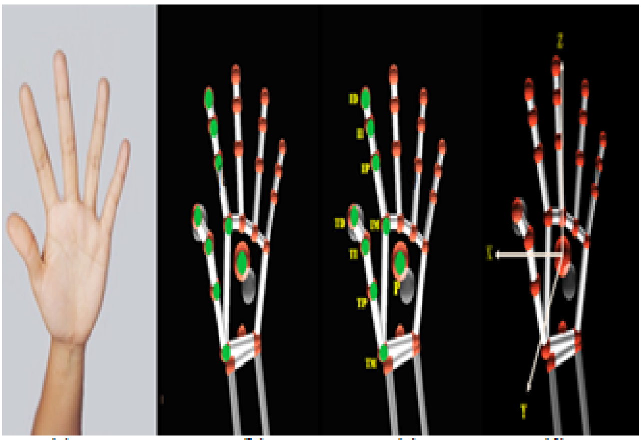
Figure 1. System Block Diagram

A. Output Data for Every Process in Acquiring the Angle of each Phalanges and the Angle in between the Fingers.

1. Acquiring Joint Coordinates of the Human Finger

First, to be able to acquire the angles created by the algorithm with respect to the angles created by the human fingers such as the angle of each phalanges and the angle in between the finger, the researchers use Leap Motion sensor SDK's skeletal tracking feature that focuses on tracking a human's fingers in the space above the device to obtain the 3D skeletal joint coordinates. Through the use of Visual Studio 2012, the researchers created a C# code to acquire the values of the joint coordinates. Then, by integrating the C# code into Lab VIEW the researchers are able to use the coordinates for finger-joint angles computation.

Then, the researchers make the center of the Palm as the origin for the X-axis that is toward to the thumb since the researcher used the left hand, the X-axis will be negative X-axis, the Z-axis is from the palm to the middle finger and Y-axis is perpendicular to X-axis and Z- axis.

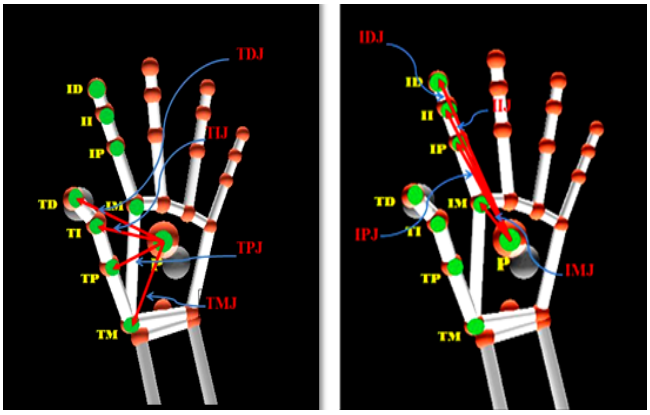


(a) (b) (c) (d)

Figure 2. Tracking of the hand (a) The user (b) 3D Skeletal joint of the user (c) Required joints and (d) Setting the Palm as origin

2. Acquiring of Vectors

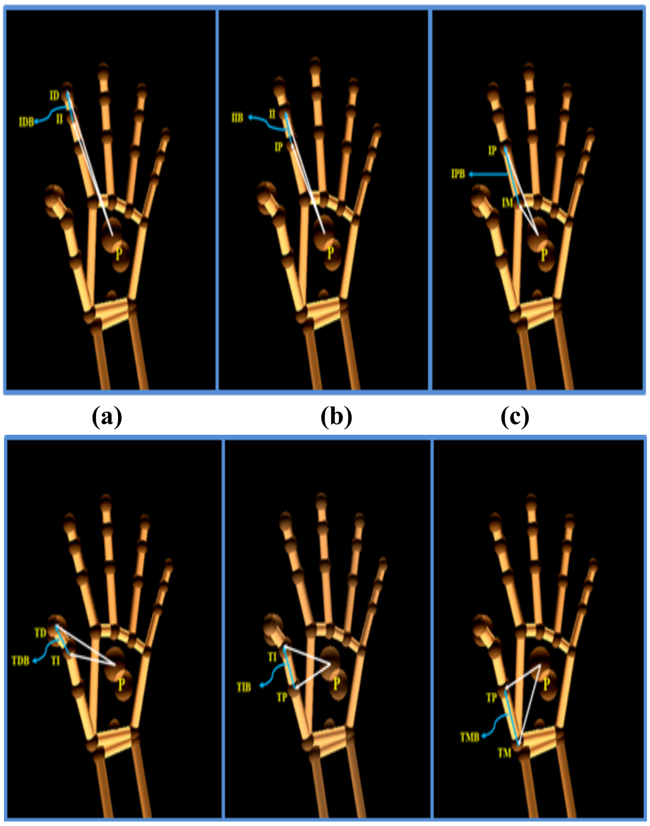
After acquiring the coordinates of the selected joints, it is use to create vectors, **TDJ, TIJ, TPJ, TMJ** for thumb **IDJ, IIJ, IPJ** and **IMJ** for index, respectively from the Palm joint. The researchers use the concept of vector sum to acquire these vectors.



(a) (b)

Figure 3. (a)Vectors created in Thumb (b)Vectors created in Index Finger

Then, the researchers performed vector addition to get the Vector of each bone of the finger named as **TDB**, **TIB**, and **TMB** for the Thumb finger and **IDB**, **IIB**, and **IPB** for Index finger.



(a) (b) (c)

(d) (e) (f)

Figure 4. Vector Bone of hand (a) Vector TDB (b) Vector TIB (c) Vector TMB (d)Vector IDB (e) Vector IIB (f) Vector IPB

The researchers normalize each vector to acquire only the direction of the vector. This step reduces the calculations to be done later. Normalizing a vector results to a unit vectors, a unit vectors are the vectors having a magnitude of one and that

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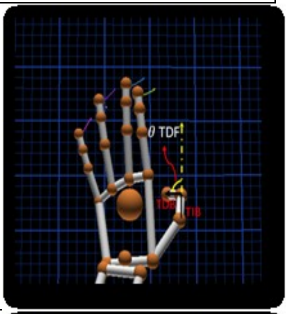
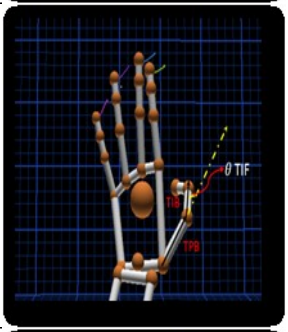
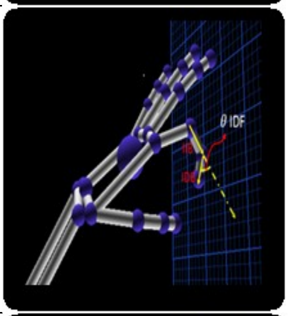
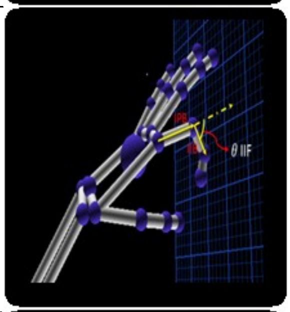
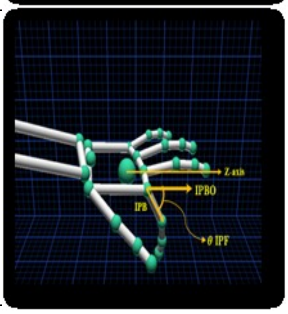
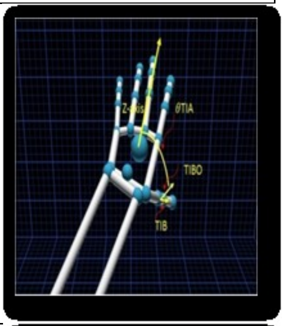
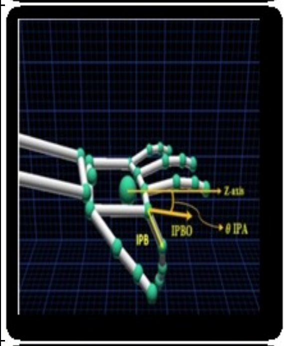
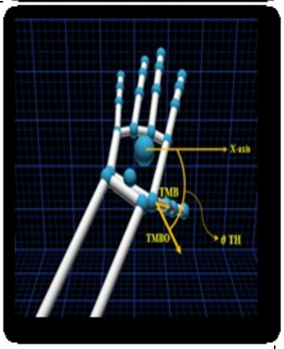
denotes the direction of the given vector components.

3. Acquiring Phalange Angle and Angle in between the Fingers (Vector Multiplication - Dot Product)

After acquiring the vectors, the researchers apply the concept of scalar product (also called *dot product*) to acquire the phalangeal angles and the angles in between the fingers. Since the researchers normalized the vector, they know that their magnitude is one. Therefore, the researchers acquired the equations and figures of every required angle as shown on the table below.

Table I. Angle Acquisition for Index and Thumb Movements

Required Angle	Equation	Figure
Thumb Distal Flexion Angle	$\theta_{TDF} = cos^{-1}(\bar{T}I\bar{B} \cdot \bar{T}D\bar{B})$	
Thumb Intermediate Flexion Angle	$\theta_{TIF} = cos^{-1}(\bar{T}M\bar{B} \cdot \bar{T}I\bar{B})$	
Index Distal Flexion Angle	$\theta_{IDF} = cos^{-1}(\bar{I}I\bar{B} \cdot \bar{I}D\bar{B})$	
Index Intermediate Flexion Angle	$\theta_{IIF} = cos^{-1}(\bar{I}P\bar{B} \cdot \bar{I}I\bar{B})$	
Index Proximal Flexion Angle	$\theta_{IPF} = cos^{-1}(\bar{I}P\bar{B}\bar{O} \cdot \bar{I}P\bar{B})$	
Thumb Intermediate Abduction Angle	$\theta_{TIA} = cos^{-1}(\bar{T}I\bar{B}\bar{O} \cdot k)$	
Index Proximal Abduction Angle	$\theta_{IPA} = cos^{-1}(\bar{I}P\bar{B}\bar{O} \cdot k)$	
Thumb Hyperextension Angle	$\theta_{TH} = cos^{-1}(\overline{TMBO} \cdot -\hat{\imath})$	

4. ***Creating a Wearable Sensor***

The researchers assessed the performance of the prototype with respect to the actual value of the human hand's movement to prove whether the prototype could still attain the same phalangeal angle and the angle in between the fingers even while varying in different movement.

In order to acquire actual phalangeal angle and the angle in between the fingers from the user, the researchers have made a wearable sensor which comprises of trimmer sensor mounted on a 1-DOF mechanical joint. The trimmer then sends analog signal as data into the Aceduino microcontroller. The collected analog signal data are interpreted by the microcontroller and is sent through serial communication into a computer for the LabVIEW to process. The data are to be converted into angular values, in which these values are inputted into LabVIEW's waveform chart feature. Communication between the LabVIEW and the microcontroller is possible through LabVIEW Interface for Arduino (LIFA).

In controlling the robotic hand, the researchers used a servo motor [2] as an actuator mounted on its joint, and a Leap Motion sensor as a computer vision sensor. The servo motor is connected on the microcontroller, and is controlled through LIFA. The servo motor's angular movement is based on the calculated angle.

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B. Response of the System

To evaluate if there is a significant difference between the angle of each phalanges of the human finger to the angle of each phalanges of the robotic finger, and the angle in between the fingers of the human hand to the angle in between the fingers of the robotic hand with respect to different users, the researchers perform the Z-test using the recorded actual and prototype angles as data.

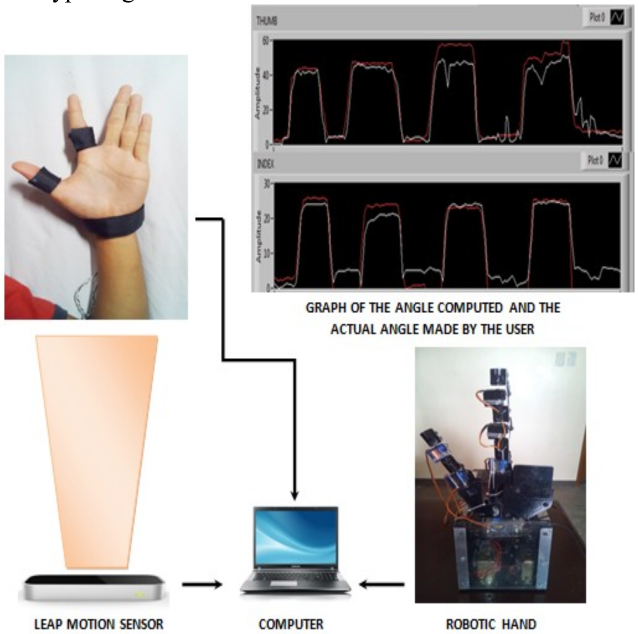

Figure 5. Set-up of the Robotic hand and the User's hand

Angular data from the robotic fingers and the user is acquired and plotted using NI LabVIEW. The plotted response of the system is then extracted into an Excel Worksheet where the evaluation of the data will be made. To evaluate the response, the proponents applied z-test using the acquired user and robotic fingers' angle. In Z-test, it is necessary to define the null hypothesis (H_o)that there is no significant difference among the samples being compared, and alternative hypothesis (H_a)which is used in case (H_o) is rejected.

To know the critical value, the significance level (α) is set to the standard value of 5%. Setting this significance value will create a confidence of 95% (100% - α), the area of the curve as the critical value will be .975 (1 – (α/2)/100%). Knowing the area, the proponents used the Z-test table and found the critical value 1.96.

The researchers will obtain the z value by using the Z-test equation below:

$$z = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \quad (1)$$

Where:

z = z-test result
$\bar{X}_1$ = mean of the 1st group
$\bar{X}_2$=mean of the 2nd group
n_1=no. of samples in the 1st group
n_2=no. of samples in the 2nd group
σ_1=standard deviation of the 1st group
σ_2=standard deviation of the 2nd group

III. RESULTS AND DISCUSSION

A. Angles Created by the Algorithm and Angles Created by the Human Fingers

From the fingers' movement made by five different users, the researchers obtained 3D coordinates pertaining to the distal phalange, intermediate phalange, proximal phalange of the index finger of the user; and distal phalange, intermediate phalange and metacarpal phalange of the thumb finger of the user. After acquiring the coordinates, the researchers performed addition of vectors to acquire the required vectors and applied the concept of scalar product (also called *dot product*) to acquire the angles made by the user's hand.

The researchers made a table for step by step of acquiring the angle of each phalanges and angle in between the fingers. The table for the 3D coordinates, vectors and the angles are shown below.

1. Angles of Left Index

Table II. The resulting angles compared to the computed angles of each users' index for Distal and Intermediate flexion and its angle difference and averages

Index						
User	Distal Flexion			Intermediate Flexion		
	Actual	Computed	Difference	Actual	Computed	Difference
1	60	60.2138	-0.2138	80	80.0358	-0.0358
2	60	60.161	-0.161	80	79.3712	0.6288
3	60	61.7301	-1.7301	80	79.3169	0.6831
4	60	62.5075	-2.5075	80	81.7128	-1.7128
5	60	60.9629	-0.9629	80	80.8697	-0.8697
Mean	60	61.11506	-1.11506	80	80.26128	-0.26128

Table III. The resulting angles compared to the computed angles of each users' index for Proximal flexion and Abduction and its angle difference and averages

Index						
User	Proximal Flexion			Abduction		
	Actual	Computed	Difference	Actual	Computed	Difference
1	80	80.0221	-0.0221	24	24.0034	-0.0034
2	80	79.8757	0.1243	24	24.436	-0.436
3	80	80.0347	-0.0347	24	24.3148	-0.3148
4	80	80.3078	-0.3078	24	24.5588	-0.5588
5	80	80.0936	-0.0936	24	24.4308	-0.4308
Mean	80	80.06678	-0.06678	24	24.34876	-0.34876

Table II and III, shows the resulting angles of each phalanges of the index from five different users with actual angles of each phalanges and the difference of actual and the resulting angle from each phalanges. The table shows the average of the resulting angles and its average difference for each movement. The researchers observed that for every user, the robotic hand can mimic the movement of the users' hand

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effectively. On the other hand, user four (4) has the largest angle difference value compared to the other four, specifically in distal angle, because user four (4) does not have a capability to do a 60 degrees angle with respect to distal phalange compared to the other user. This problem affects the computation of angles with respect to the bending of his/her fingers.

2. Angles of Left Thumb

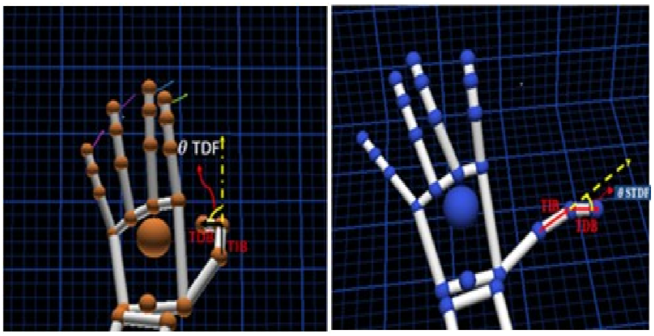
Table IV. The resulting angles compared to the computed angles of each users' thumb for Distal and Intermediate flexion and its angle difference and averages

Thumb						
User	Distal Flexion			Intermediate Flexion		
	Actual	Computed	Difference	Actual	Computed	Difference
1	70	70.2756	-0.2756	40	40.5218	-0.5218
2	70	71.4129	-1.4129	40	39.182	0.818
3	70	69.0548	0.9452	40	40.7832	-0.7832
4	70	69.3502	0.6498	40	41.0032	-1.0032
5	70	69.1327	0.8673	40	40.2138	-0.2138
Mean	70	69.84524	0.15476	40	40.3408	-0.3408

Table V. The resulting angles compared to the computed angles of each users' thumb for Abduction and Hyperextension and its angle difference and averages

Thumb						
User	Abduction			Hyperextension		
	Actual	Computed	Difference	Actual	Computed	Difference
1	70	70.1694	-0.1694	85	85.1757	-0.1757
2	70	70.6354	-0.6354	85	85.2931	-0.2931
3	70	70.0874	-0.0874	85	85.0912	-0.0912
4	70	70.7993	-0.7993	85	85.777	-0.777
5	70	70.2208	-0.2208	85	85.1459	-0.1459
Mean	70	70.38246	-0.38246	85	85.29658	-0.29658

Table IV and V, shows the resulting angles of each phalanges of the thumb from five different users with actual angles of each phalanges and the difference of actual and the resulting angle from each phalanges. The table shows the average of the resulting angles and its average difference for each movement. The researchers observed that for every user, the robotic hand can mimic the movement of the users' hand effectively. On the other hand, user two (2) has the largest angle difference value compared to the other four, specifically in distal angle, because the posture of the thumb finger of the user two (2) has unintentionally made an overstretch. This unintentional movement made by the user two (2) affects the computation of the distal angle. This over stretched movement that shown on Figure 6, produced a large difference between the actual angle and the resulting angle.

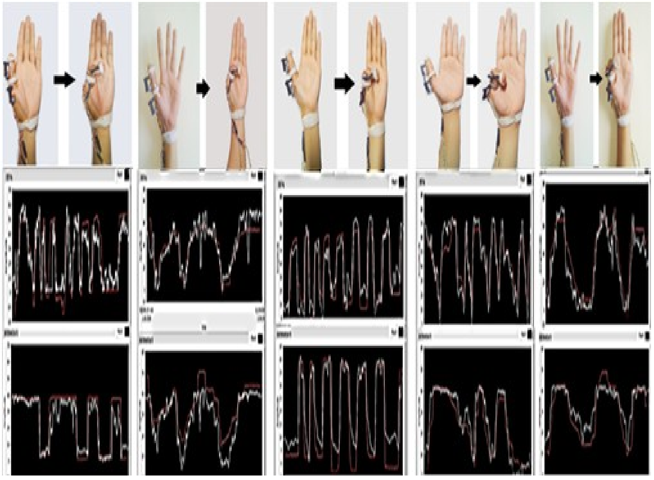


(a) (b)

Figure 6. Thumb Distal Flexion (a) proper position (b) over stretched position

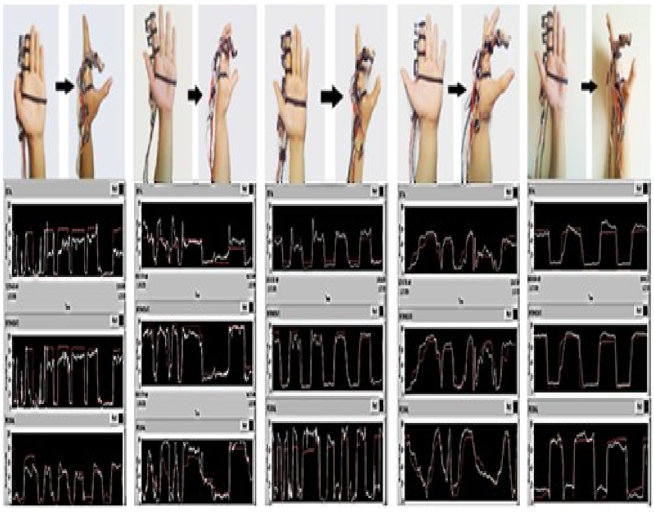
B. Evaluating the Angles Made by Five Different Users and the Angles Measured from the Robotic Hand

The researchers conducted experiment to evaluate the angles made by five different users and the angles measure from the robotic hand.



(a) (b) (c) (d) (e)

Figure 7. Graph of the thumb angles made by the users and robotic hand for the flexion movement: (a) User 1 (b) User 2 (c) User 3 (d) User 4 (e) User 5



(a) (b) (c) (d) (e)

Figure 8. Graph of the index angles made by the users and robotic hand for flexion movement: (a) User 1 (b) User 2 (c) User 3 (d) User 4 (e) User 5

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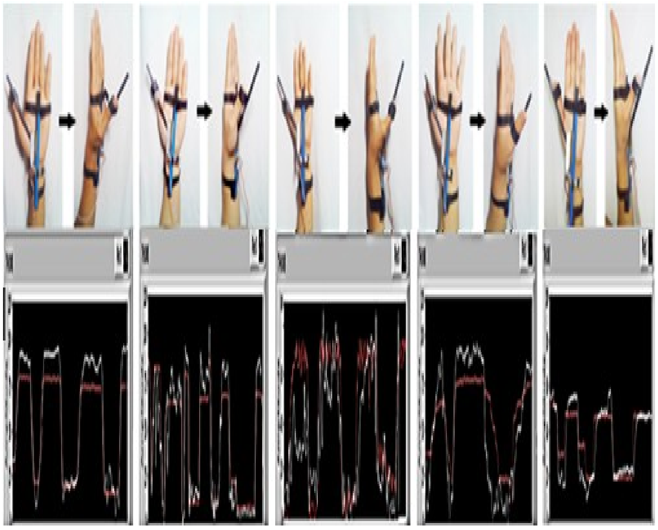
(a) (b) (c) (d) (e)

Figure 9. Graph of the angles made by the users and robotic hand for abduction and adduction movement: (a) User 1 (b) User 2 (c) User 3 (d) User 4 (e) User 5



(a) (b) (c) (d) (e)

Figure 10. Graph of the hyper-extension angles made by the users and robotic hand: (a) User 1 (b) User 2 (c) User 3 (d) User 4 (e) User 5

The Figure 7 shows the movement of the thumb for flexion, Figure 8 shows the movement of the index for flexion, Figure 9 shows the movement of both thumb and index for abduction, and Figure 10 shows the movement of thumb for hyperextension of five different users and below its corresponding response of the wearable device and the robotic hand prototype. The graph shows the angle being measured from the wearable device which is the red lines and the robotic hand which is the white lines by the program using Leap Motion sensor. The researchers observed the graph that the white line has more jitters than the red line. It simply indicates that the robotic hand has more noise than the wearable device. The researchers initiate that the noise being produced from the robotic hand was caused by detection of human joints. The Leap Motion sensor has the capability to detect human joints but does not have any filtering algorithm, so that, the response of the robotic hand was jittered.

The researchers will evaluate the angular data taken from the movement of five different users and the robotic hand. From the graph shown, the researchers extract the data being gathered from it and compare them using z-test.

Table VI. Z-test Evaluation of the various angular data from the Human Index finger and Robotic Index finger

	Index	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 1	Distal Angle	100	44.44	21.65	100	49.49	29.10	-1.39	Null Hypothesis is acceptable
	Intermediate Angle	100	19.47	26.91	100	24.31	29.65	-1.21	
	Proximal Angle	100	26.96	20.78	100	28.80	18.09	-0.67	
	Abduct Angle	100	13.74	8.17	100	12.04	6.77	1.61	
	Index	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 2	Distal Angle	100	30.73	15.36	100	27.13	16.30	1.61	Null Hypothesis is acceptable
	Intermediate Angle	100	22.46	17.50	100	22.96	17.76	-0.20	
	Proximal Angle	100	11.75	2.17	100	12.09	1.49	-1.29	
	Abduct Angle	100	13.30	9.76	100	15.66	10.81	-1.62	
	Index	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 3	Distal Angle	100	26.95	21.25	100	28.43	15.76	-0.56	Null Hypothesis is acceptable
	Intermediate Angle	100	39.06	31.98	100	39.59	33.49	-0.11	
	Proximal Angle	100	36.36	32.85	100	31.23	24.67	1.25	
	Abduct Angle	100	11.33	9.58	100	10.20	11.83	0.74	
	Index	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 4	Distal Angle	100	33.05	21.13	100	30.27	17.74	1.01	Null Hypothesis is acceptable
	Intermediate Angle	100	46.09	30.16	100	41.61	25.54	1.13	
	Proximal Angle	100	38.34	16.86	100	40.94	15.81	-1.12	
	Abduct Angle	100	9.86	6.24	100	11.28	6.06	-1.63	
	Index	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 5	Distal Angle	100	33.68	19.44	100	33.04	25.05	0.20	Null Hypothesis is acceptable
	Intermediate Angle	100	46.97	30.72	100	44.25	34.24	0.59	
	Proximal Angle	100	33.22	25.15	100	27.59	30.41	1.43	
	Abduct Angle	100	12.44	9.93	100	12.04	10.15	0.28	

Table VI shows the Z-test evaluation of the angular data gathered from the Human Left Index finger and Robotic Left Index finger. The researchers observed that for every user, the robotic hand can mimic the movement of the users' hand effectively. On the other hand, user 4 has the largest Z-value compared to the other four because user four (4) does not have a capability to do a required angle with respect to distal phalange compared to the user that affects the computation of angles with respect to the bending of his/her fingers. It simply indicates that user four (4) cannot fully do a mimicking effectively compared to the other four users. The table shows that the z-test result is within the range of -1.96 to +1.96. Thus, the Null Hypothesis of "There is no significant difference between the robotic fingers' angle and the actual user angle" is accepted. Therefore, the robotic hand angles are close to the actual user angles.

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Table VII. Z-test Evaluation of the various angular data from the Human Thumb finger and Robotic Thumb finger

	Thumb	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 1	Distal Angle	100	32.07	16.65	100	33.15	19.34	-0.42	Null Hypothesis is acceptable
	Intermediate Angle	100	26.04	12.78	100	28.31	16.75	-1.08	
	Abduct Angle	100	25.74	16.94	100	22.34	13.50	1.57	
	Hyperextension	100	60.05	34.45	100	53.04	27.08	1.60	
	Thumb	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 2	Distal Angle	100	49.89	15.36	100	47.33	7.38	1.50	Null Hypothesis is acceptable
	Intermediate Angle	100	32.04	12.19	100	34.85	12.15	-1.63	
	Abduct Angle	100	13.67	11.77	100	11.22	10.68	1.54	
	Hyperextension	100	50.38	25.59	100	56.41	27.50	-1.61	
	Thumb	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 3	Distal Angle	100	36.72	22.50	100	34.49	22.32	0.70	Null Hypothesis is acceptable
	Intermediate Angle	100	17.88	13.40	100	15.40	16.38	1.17	
	Abduct Angle	100	26.82	19.20	100	30.26	21.28	-1.20	
	Hyperextension	100	43.11	26.40	100	49.46	28.47	-1.63	
	Thumb	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 4	Distal Angle	100	39.61	16.69	100	42.47	11.71	-1.40	Null Hypothesis is acceptable
	Intermediate Angle	100	22.41	15.78	100	22.03	11.23	0.20	
	Abduct Angle	100	30.82	29.20	100	31.01	31.84	-0.04	
	Hyperextension	100	57.46	30.29	100	56.16	16.49	0.38	
	Thumb	Prototype Angle			Actual Angle			Z	Remarks
		n_1	$\bar{x}_1$	σ_1	n_2	$\bar{x}_2$	σ_2		
USER 5	Distal Angle	100	24.20	26.05	100	29.76	23.14	-1.60	Null Hypothesis is acceptable
	Intermediate Angle	100	29.60	11.94	100	26.73	13.04	1.63	
	Abduct Angle	100	42.96	19.81	100	38.51	25.93	1.36	
	Hyperextension	100	36.67	16.55	100	39.85	10.78	-1.61	

Table VII shows the Z-test evaluation of the angular data gathered from the Human Left Thumb finger and Robotic Left Thumb finger. The researchers observed that for every user, the robotic hand can mimic the movement of the users' hand effectively. On the other hand, user two (2) has the largest Z-value compared to the other four because the posture of the thumb finger of the user two (2) has unintentionally made an over stretch of his/her thumb phalanges. This unintentional movement made by the user two (2) affects the computation of each angle. It simply indicates that user 2 cannot fully do a mimicking effectively compared to the other four users. The table shows that the z-test result is within the range of -1.96 to +1.96. Thus, the Null Hypothesis of "There is no significant difference between the robotic fingers' angle and the actual user angle" is accepted. Therefore, the robotic hand angles are close to the actual user angles.

IV. CONCLUSION

The researchers developed a system to control the robotic hand using Leap Motion sensor. The main objective of this study is to control the robotic hand. Based from the data summarized, the acquired joint coordinates and the resulting vectors are different from five different users; however, the resulting angles are close to each other. The resulting angles for distal, intermediate, proximal, abduct and hyperextension angles have an average angle difference shown on Table II for index finger and Table III for thumb finger of different users. Based on the data gathered, there are some users that cause a large difference between the algorithm and the actual angle. Some reasons that the researchers observed is that some user does not have a capability to do a required angle with respect to distal phalange compared to the user. This problem affects the computation of angles with respect to the bending of his/her fingers. Furthermore, there is also some user that cause a large difference because of unintentionally made an over stretched of distal phalange with respect to intermediate phalange of the thumb. This unintentional movement made by the user also affects the computation of the distal angle. Instead of angle θ_{TDF} will need to get, unknown angle θ_{STDF} that shown on Figure 6 produced by over stretching of the distal phalange will acquire. This over stretched movement produced a large difference between the actual angle and the resulting angle. Overall, the result from the average angle difference suggests that the angles do not differ that much in five different users thus the algorithm proposed by the researchers was effective in acquiring the value of the user's hand angle.

Moreover, the z-test result for distal, intermediate, proximal, abduct and hyperextension angles are within the range of the critical values, thus the null hypothesis states that there is no significant difference between the robotic hand's angle and the actual user hand's angle is accepted. The data gathered from the graph are inconsistent indicating that there are jitters caused by insufficient filtering algorithm. The test and the graph shows that the response of the robotic hand is close to the response of the human hand thus, the proposed system can mimic the user's hand movements.

RECOMMENDATION

This section of the chapter will discuss the things to be considered for the further development of the proposed study. Based on the results of the conducted study, the researchers recommend to improve the proposed algorithm that will not depend on over stretched movement of the thumb distal phalange with respect to the thumb intermediate phalange for acquiring the angles from the movement made by the researchers. The researchers recommend applying filtering algorithm like Kalman's filter or Low pass filter that can improve the detection of the human hand to minimize the jitters because the Leap Motion sensor has the capability to detect human joints but doesn't have any filtering algorithm.

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