International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 18, Issue 4 (Jul.-Aug. 2022), PP. 09-16

Human-Robot Interaction: Virtual Simulation of Real-Time Gesture Recognition System using Continuous Hand Movement Tracking

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ABSTRACT: *Certain occupational environments pose major threats to human safety, potentially keeping their lives in danger and due to which various kinds of robots are designed to perform such complicated tasks. Robots were formerly guided by mechanical instruments, but with advent developments in Human-Computer Interaction, they are presently controlled by hand gestures and speech, which have introduced a new field in robotics, called Collaborative Robots. Among them, gesture recognition is the most sort after technology as it uses hand movements as input to perform the desired task. Thisarticlereports a novel system to detect the gestures in real time with continuous hand movement tracking via microprocessors and position sensors. The system consists of transmitting module and receiving module. The transmitting module is a glove comprising of an Arduino controller, flex sensors, MPU-6050 sensor, Bluetooth module and a power source. The method is virtually validated in MATLAB Simulink by simulation of robot arm through user hand movements via electro-mechanical sensors.Wireless communication and quick response time serves as the main feature of the suggested methodology.*

Date of Submission: 10-07-2022 Date of Acceptance: 25-07-2022

I. INTRODUCTION

Internet of things (IOT) is undergoing a phase of accelerated evolution. Automated technologies like robots are currently being implemented in almost all sectors be it medical, industrial, military and social service.Due to the increasing concern for human safety and to ensure protection for workers, various service robots are being progressively implemented in hazardous environments such nuclear power plants[1], industrial welding, deep sea exploration[2], bomb detection [3], and toxic waste collection [4], etc.

Earlier, robots were operated by physical devices such as joysticks and keyboards [5], but presently due to the substantial advancements in Artificial Intelligence and Deep Learning, Human-Computer Interaction (HCI) methods such asgestureand voice controlled are paving a new spectrum in the area of Collaborative Robots[6,7]. Hand gesture oriented computing is the most natural, efficient, and interactive approach in HCI as it entails immersive communication by mimicking human hand movements [8]. Computer Vision and Electro-mechanical sensors based dynamic tracking systems are some of the existing technologies in gesture recognition [9].

This paper focuses ondevelopment of a novel approach for real-time hand gesture recognition with continuous finger movement tracking using MEMS sensors. The proposed methodology is validated through the simulation of robot arm, controlleddirectly by the user via hand movements. The aim of the research is to augment human-machine interaction, and promote the need for wireless control of robot arm.

II. LITERATURE REVIEW

Several studies and approaches are currently in existence to mitigate the use of conventional keypad/joystick devices to operate the robot. As stated previously, artificial intelligence and machine learning have helped lay the groundwork for humans to control a robot directly, endorsing advanced human-robot interaction.Computer Vision is a branch of Artificial Intelligence, which involves advanced concepts, mainly machine learning image processing and neural networks.Sushmit et al.[10] designed a low cost gesture controlled robotic gripper to assist in industrial automation. The hand gestures performed by the user is captured by the camera and later image processing techniques were performed to use that as the input to control the robot. Similarly, Atre et al. [11] and Choudhary et al.[12] applied the computer vision technique to design the gesture controlled robot, with an aim to minimize response time between the hand gesture and motion robot. But there were certain limitations in complex environments such as low-light background, inappropriate lighting anddark skin tone.

Narayananet al.[13] proposed a scheme to control robotic arm using Leap Motion Controller and Arduino Uno.Unlike depth sensors, the Leap Motion Controller incorporates infrared optics and cameras to detect and record the movements. This sensor operated a 5 DOF robotic arm, using hand gestures, that were employed in bomb defusing operations.However constraints in the components employed hampered the system's efficiency and lowered its agility.Currently, this method is in development stage but assures to be a promising technology.

Another popular technique in gesture recognition is the use of Electromyography (EMG) Signals, which records the muscle movements. The integration of principles of EMG (using a Myo armband) and Depth Vision was developed by Zhou et al. [14] withthree level hierarchical k-medoids method to label the cluster of the collected data (1 to 10 Chinese number hand gestures) automatically by dividing the gestures layer by layer. A related study, also employing Myo armband to communicate three sign languages (thumbs up, thumbs down and relax) to control Softbank's Pepper Humanoid Robot was proposed by Kobylarz et al. [15] though Inductive and Supervised Transductive Transfer Learning with a short calibration of 15 seconds which yielded a data accuracy of 97%, when compared to 7 seconds that resulted in only 55% accuracy.

The application of Micro-electro-mechanical-system (MEMS) such as flex sensors to detect the fingers' movements and accelerometer to record the arm motion Jiang et al.[16] along with the Arduino microcontroller resulted in minimum response time and minimized the overall weight of the haptic glove, thereby proving its compactness.Additionally, Sihombing et al. [17] incorporated Fuzzy logic method and Bluetooth module to provide wireless transmission. MEMS sensors work on the principles of piezoelectric, capacitive, electromagnetic, and piezo-resistance [18].

This project seeks to address some unresolved issues raised by the literature review:

1. Computer vision is dependent on visual transmission of the gestures i.e. the user has to perform the actions in front of the camera within the focal area. It also requires proper light conditions for accurate recognition
   - This work eliminates the need for any external visual hardware and the gestures can be performed at the user's comfort.
   - The proposed methodology is independent of environmental conditions
2. Leap motion sensor is not efficient and exerts high cost due to its developing stage.
   - The components (MEMS sensors and Arduino microcontroller) used in the work serves to be an alternative to the Leap motion sensor as it is cheaper and more reliable.
3. EMG signalling technique depends on pre-recording the muscle movements and labelling it according to the appropriate gestures.
   - In the proposed work, the input is provided in real time via position sensors, by interfacing the sensor output directly to the mechanical system of the robot arm.
4. Fuzzy logic method entails complex programming and the system consists of wired connections.
   - In this work, Fuzzy Logic is not employed and the methodology focuses on wireless transmission of data.

III. METHODOLOGY

The system consists of two modules: transmitting and receiving module. The transmitting module is the glove, which will be put on by user in their hand. This module consists of MPU-6050 sensor, flex sensor, Arduino Mega, Bluetooth module and a 9V battery, all connected toa breadboard. MATLAB is the receiving module, where the robotic arm is simulated. Figure 1 shows the block diagram of methodology. A brief procedure of the working of methodology is explained below.

1. The user performs the required actions wearing the glove (transmitting module).
2. The sensors capture the gestures as analog input.
3. The Arduino reads the input from the sensors and transmits it to the MATLAB via Bluetooth module.
4. The robot arm is designed in CAD software and exported to the MATLAB Simulink.
5. The analog input from the transmitter module is converted into digital output, which is used to control and simulate the robot arm.

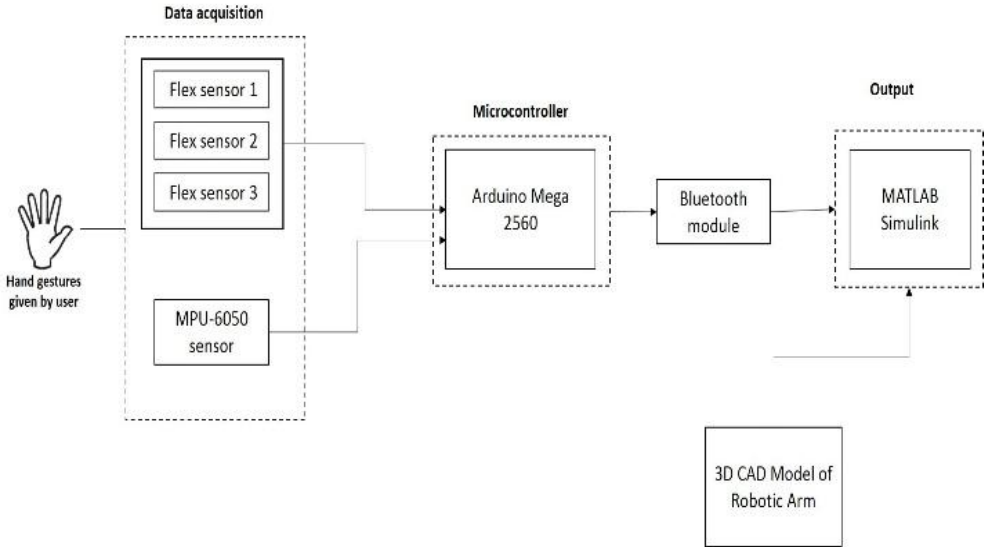
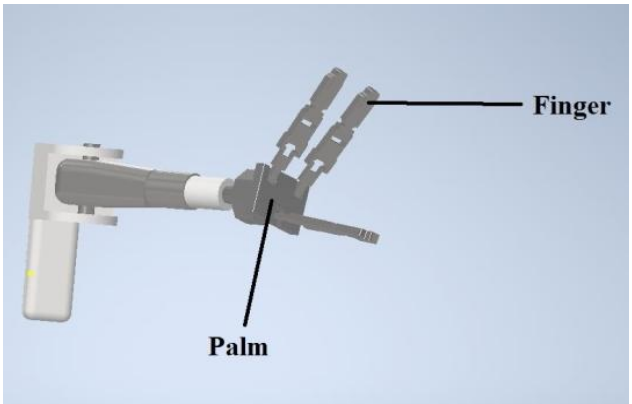


Figure 1: Methodology

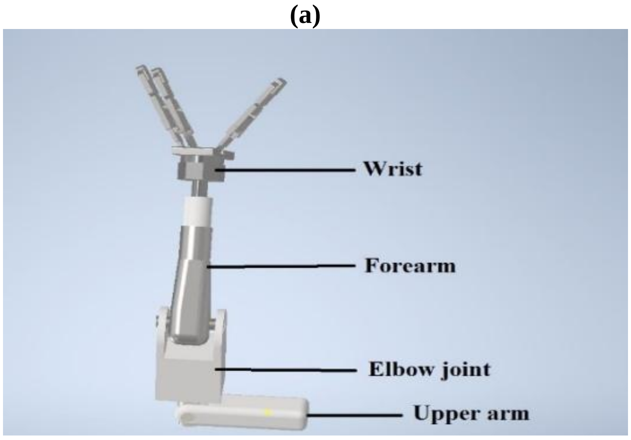
IV. EXPERIMENTAL PROCEDURE

4.1 Robotic Arm Design

The arm is made up of three grippers with one degree of freedom (DOF) each, which are fixed to a palm that is positioned on the forearm, and the entire part is mounted on a base. The palm and wrist are configured to rotate along the z-axis. The upper arm was grounded (fixed), and the forearm has one degree of freedom (DOF) for up – and – down motions. In CAD software, titanium was selected for the material, since they are applied in robotic design due to its low thermal conductivity, low density and elastic modulus, high strength, corrosion-resistance[19] and also light-weight.Figure 2 shows the 3D model of the robotic arm.



(a)



(b)

Figure 2:Robotic Arm - (a) Isometric view (b) Orthographic view

4.2 Glove design

Flex sensor is placed over the finger of the glove, Arduino Mega and MPU-6050 sensor is connected to a breadboard and the breadboard is placed over the rear side of glove. Figure 3 shows the schematic representation of glove design used in this project.

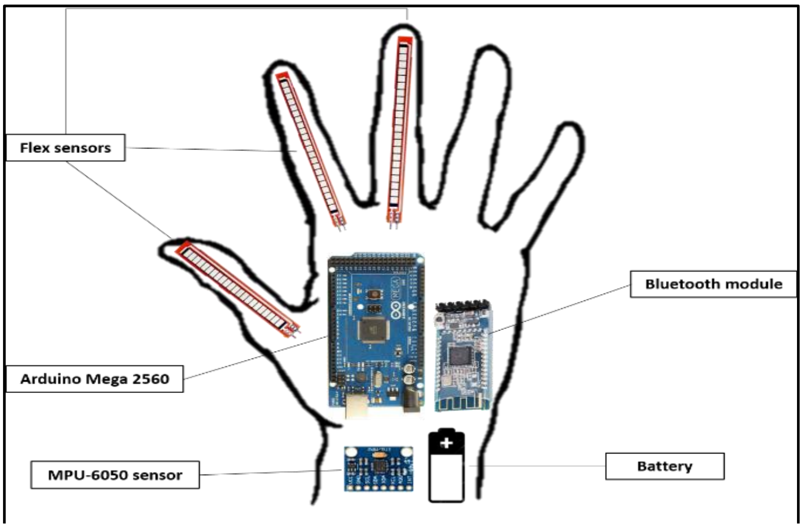


Figure 3: Experimental setup of glove (Transmitting module)

MPU-6050 sensortracks the orientation (accelerometer) and angular velocity (gyroscope) of the arm. It detects dynamic forces caused by movement and vibrations [20].Flex sensor is utilized in opening and closure of grippers on the robotic arm by recording the movement of fingers. It measures the amount of bending or deflection by detecting the variation in resistance of the sensor with reference to the resistor[21]by converting the bend change to electrical resistance, which is later provided as voltage output to the Simulink model.Arduino Mega 2560controls the signal processing and decision making functionsbased on the code provided. HC-05 bluetooth modulewas used for wireless transmission of the input data from Arduino to MATLAB.All the connections of sensors and Arduino were connected to the breadboard as it is efficient and supportssolder less connections. A battery was provided as the power source for microprocessor.

4.3 Data acquisition from Arduino

4.3.1 Calculating acceleration and angular velocity from MPU-6050

The sensor is placed on the rear hand of the user. Until then, the sensors on the glove are at rest. The Arduino measures the tilt of a section at the start of a trial employing accelerometer measurements obtained at 100 Hz. The angle is measured using the arctangent function. In contrast to the arcsine, this function is accurate for an indefinite number of inputs and is less vulnerable to noise [22].Referring**Hyunh et al. [23]**, equation (1) and (2) was formulated for calculating the total acceleration (α) and angular velocity (ω).

$$\alpha_{total} = \sqrt{(\alpha_x)^2 + \left(\alpha_y\right)^2 + (\alpha_z)^2} \qquad (1)$$

$$\omega_{total} = \sqrt{(\omega_x)^2 + (\omega_y)^2 + (\omega_z)^2} \qquad (2)$$

where $\alpha_x, \alpha_y, \alpha_z$ – angularaccelerations in X, Y and Z axes
$\omega_x, \omega_y, \omega_z$ – angular velocity in X, Y and Z axes

4.3.2 Roll, Pitch and Yaw Estimation

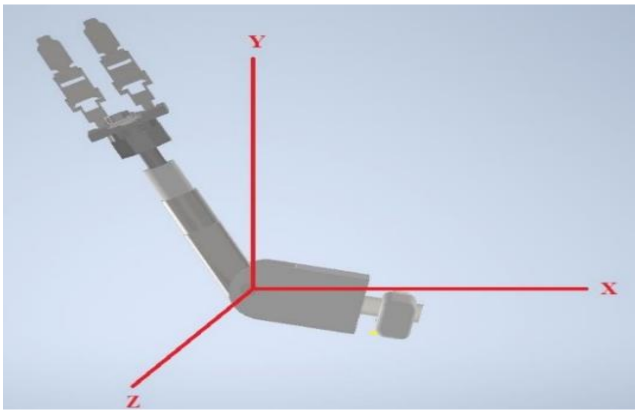
The motion of the MPU sensor is estimated from its roll, pitch and yaw transformation with respect to its reference point. Figure 4 shows the roll, pitch and yaw angles with respect to model and transformation matrix. Equations (3), (4) and (5) shows the transform matrix of roll, pitch and yaw about x, y and z axeswith reference to **Mark Pedley [24]**.

$$Roll = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\Psi & \sin\Psi \\ 0 & -\sin\Psi & \cos\Psi \end{pmatrix} \qquad (3)$$

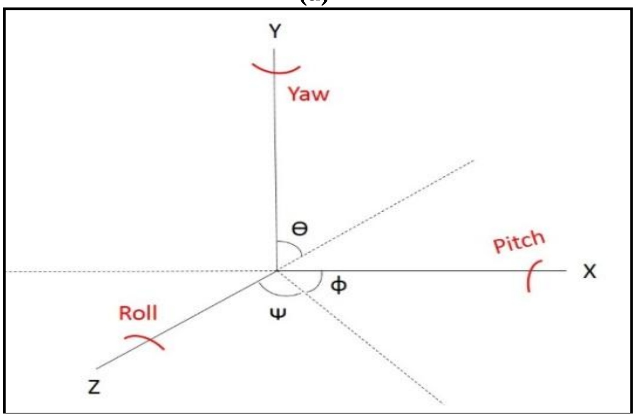
$$Pitch = \begin{pmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{pmatrix} (4)$$

$$Yaw = \begin{pmatrix} \cos\Theta & \sin\Theta & 0 \\ -\sin\Theta & \cos\Theta & 0 \\ 0 & 0 & 1 \end{pmatrix} (5)$$

The above equations 3, 4 and 5 are generally used to calculate the transformation of the body in the respective orientation and axis. These equations can then be combined in various orders to get the desired output. However, there were some errors in gyroscope readings because of an inaccurate null[25]in the initial tests conducted. So, we resolved them by adding the appropriate error value to the final output of the sensor reading.



(a)



(b)

Figure 4: Rotational angles with respect to (a) 3D model and (b) transformation matrix

4.3.3 Calculating resistance from Flex sensor

The flex sensor reads the resistance with respect to change in its bending angle. We used three flex sensors for our project, which were placed on thumb, index finger and middle finger respectively, to control three fingers of the robot arm. The flex sensor works on the principle of potentiometer that, when the resistance is changed, provides a voltage as an output[26]. This voltage is then used as input in Simulink to control the robot fingers. Three resistors are connected to three flex sensors, which are used as the reference resistance for flex sensors. The voltage can be calculated from the resistance using the equation (6), based on the work from **Abro et al.[27].**

$$V_f = V_p \left(\frac{R_f}{R_f + R_s}\right) (6)$$

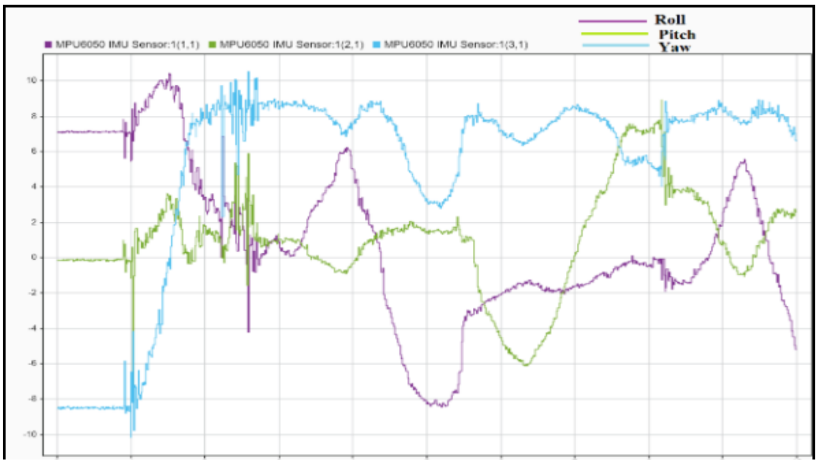
Where V_f is voltage output of flex sensor, V_p is power supplied voltage, R_f is the resistance of flex sensor and R_s is the resistance of the resistor.

VI. RESULTS AND DISCUSSION

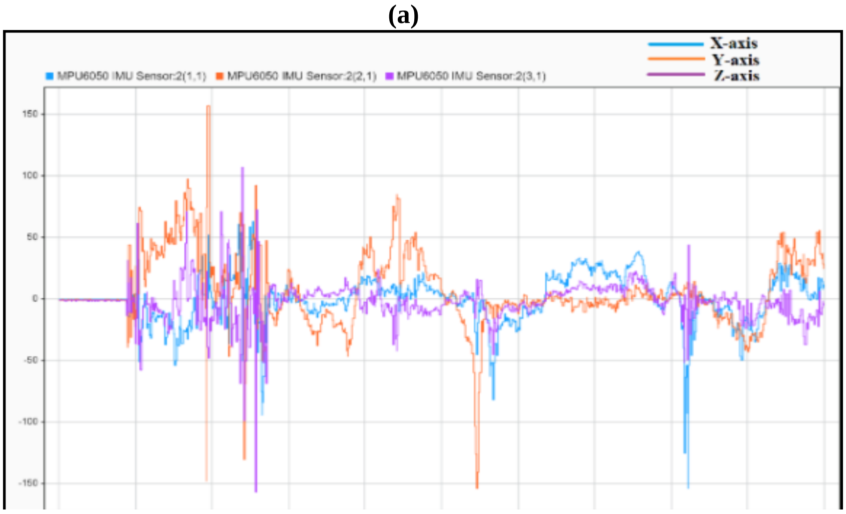
MATLAB Simulink was used to simulate the designed robot arm. We employed a straightforward approach, without the use of any robot toolbox, to replicate the robot model in Simulink, reducing complications and time-consuming programs. The proposed model was exported to SimMechanics (.xml) format and then imported into MATLAB Simulink. SimMechanics is a MATLAB plug-in that imports a 3D CAD model, loaded with structures, joints, assemblies, and mass which signifies that the model can be reproduced to investigate motions, spatial accelerations, and displacements of each structural component in mechanical joints, and simulate the 3D model's motion when taking individual object masses into account [28]. The analog input from the Arduino was converted to double data type using the *datatype* conversion toolbox.

Graph 5 shows the accelerometer (roll, pitch and yaw) and gyroscope sensors' (x, y and z-axes)input obtained from Arduino in MATLAB. The analog input from the MPU sensor is transformed into the matrix equations as shown in equation 1-6, to determine the required translational and rotational changes.

Similarly, the graph 6 represents the input acquired from the flex sensors. The graph shows the relationship between the voltage differences caused by the resistance change in flex sensor with respect to time. The voltage can be calculated from resistance as shown previously in equation 6. From the graph, it can be clearly understood from the variations that the flex sensor is sensitive even to small bends. This might be caused due to the weight of the fabric of glove, or even micro vibrations in user's fingers.



(a)



(b)

Figure 5: Graph of inputs acquired from (a) Accelerometer (b) Gyroscope

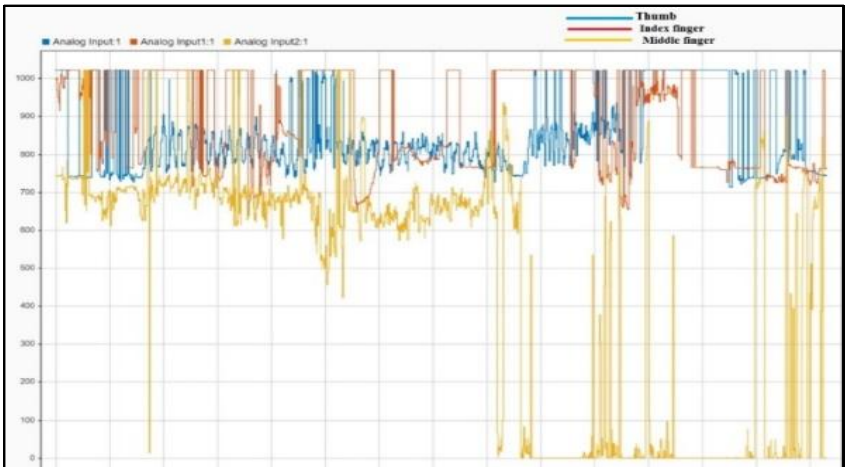
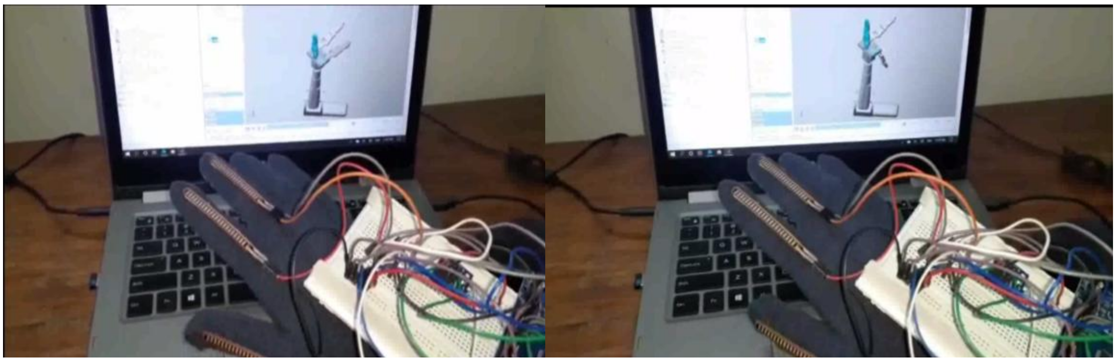
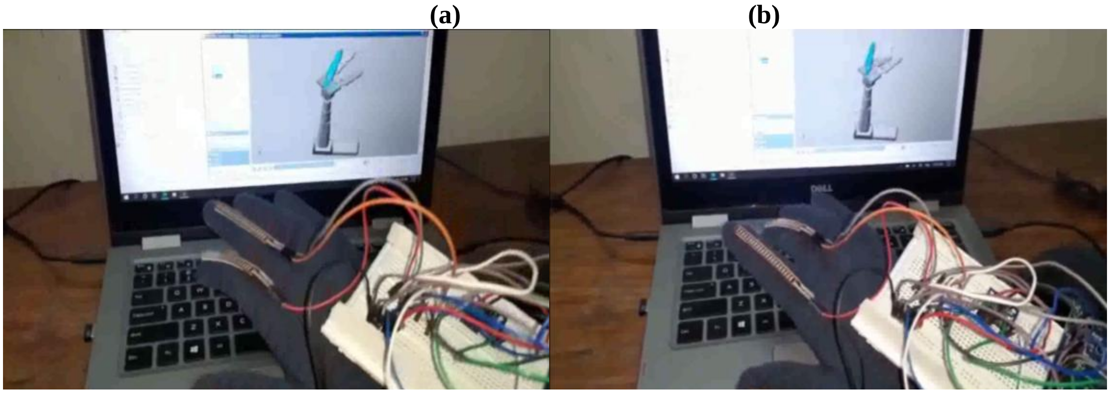


Figure 6: Flex sensor input acquired from thumb, index finger and middle finger

The kinematics of the robot arm was provided by rigid body transformation. The simulation showed negligible discrepancies due to excess noise signals from the sensors. Figure 7 shows the simulation result obtained. For clear understanding, (a) blue finger in robot model represents middle finger movement of user's hand, one gripper (index finger) of robot model is kept at stationary, (b) user's moves the thumb and the gripper adjacent to the stationary gripper is simulated.



(a) **(b)**



(c) **(d)**

Figure 7: Simulation result (a) No movement of fingers (b) User moves his thumb – blue color is indicated to represent thumb in robotic arm (c) User moves his index finger (d) User moves his middle finger

VII. CONCLUSION

The objectives of thearticleis fulfilled successfully. Noise and error corrections in the analog output from Arduino wereremedied, which brought down the response time of the system. The hand movements recorded by the sensors were efficiently converted to digital output which was then provided as input to the mechanical system in MATLAB. The primarygoalof the research was to minimize complex programming and introduce wireless communication. This paper demonstrates a modular approach in continuous and real-time gesture recognition system using hand movements. The methodology discussed in the article presents an alternative approach to traditional vision based recognition system.

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