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Smartphone Sensor-based Development and Implementation of a Remotely Controlled Robot Arm

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Abstract—**As a result of advances in both technology and science, it is now possible to carry out essential processes such as lifting objects and moving them by remote control of an arm. In this sense, it is much easier for a person to engage in potentially dangerous activities without running the risk of getting hurt. This article presents the development and design of a robot arm that is controlled by a smartphone device using gyroscope sensors integrated inside. Smartphones with built-in gyroscope sensors are used to operate robot arms in a flexible and affordable manner. The robot arm's movement is effectively controlled by the gyroscope sensors, which include proximity, orientation, and accelerometer sensors, to get it to the required position. The developed prototype found to capable of handling a variety of objects with a smooth movement and transporting them based on the movement of a mobile phone. The control of the arm imitates the movements of a human being, which results in the reduction of the amount of time and effort required by a person to carry out a certain process.**

Keywords—Smartphone; Controlled; Robot Arm; Microcontroller; Sensor; Remotely; Human-Machine Interaction.

I. INTRODUCTION

A robot arm is a highly adaptable and precise mechanical device that can be used in a wide range of applications, including manufacturing and assembly, logistics, and beyond. The developments of robotics had revealed many applications such as industrial, services, household, and healthcare applications [1]-[5]. A robot arm is a piece of machinery that can be used in the industry building. The progression of various controllers with user-friendly interfaces facilitates the advancement of highly efficient control systems [5][6]. A computer or microcontroller is primarily used for movement control, an end-effector is used for specific task completion, and a number of connected segments with powered joints are all common components. A research carried on lively robot control systems. One interaction method controls mobile robots with sensor-equipped mitts. The technology utilized in these gloves may detect the hand's inclination or finger bending through the use of sensors. [7]-[10].

The development of robotic control gloves has greatly improved the lives of those with weak hands. These gloves use motion sensor technology and fingertip strength to help people execute specific tasks. Fuzzy logic and flex sensors on each finger are used in these gloves to control and enter commands for mobile robots. While some designs emphasize ease of assembly, inflexible connections might cause them to have significant dimensions and weight. Pneumatic actuator-equipped soft robotic gloves are more flexible, but they are less portable since they require large external supply systems. These developments generally improve function and provide support throughout the course of therapy and recuperation [11]-[23].

When carrying out certain tasks, such as any chemical operation, it is necessary to wear protective clothing and make certain that the environment around you is free of any hazardous materials. In addition, the immediate area must be thoroughly cleaned. On the other hand, when a robot arm becomes available, it will be kept in a secure location that is closed off from any potentially hazardous materials. Because it is operated from a remote location, there will be no need to wear protective clothing during any of the activities or procedures involved. As well, developed prototypes of robot arms aimed to transport heavy and difficult materials that are difficult to transport in a humane manner and, as a result, have saved human time and effort in the process. An Ethernet robot arm control system with Kinect V2 camera for hazardous locations is presented. The robot arm control and Ethernet connectivity are tested for object selection and placement. The finding of the presented research shows that the robot arm always follows the position of objects and the movements of the user effectively [24]. In such locations, the application of robot arms for rescue purposes has been increasingly constrained by numerous researchers due to the difficulties involved in reaching them [25]-[27].

Robots have improved healthcare by introducing advancements that enhance precision and accuracy [28][29]. The robot arms had recently applied to wider application including medical application in such condition where treatments to be remotely handled [30]. The advances of new technologies help to realize efficient automated applications [6][31]. Rapid advances in science and technology offer advantages for adopting integrated embedded microcontrollers in industrial operations [32]-[34].

Moreover, the needs for such robots to be implemented in to medical applications in which it mostly requires a high level of precision and accuracy [35]-[37]. An example of such highly risked conditions is the treatments of patients in the quarantined rooms during the COVID-19 pandemic [38][39]. Therefore, the need for such developed devices could highly help in delivering the proper healthcare in hospitals and other medical facilities smoothly and safely [40][41]. The constraints imposed by the COVID-19 pandemic necessitated the development of a robotic arm for online robotics practical courses in which both instructors and students were unable to visit laboratory facilities [42]. A 4-axis educational robotic arm with endoscopic display and many control mechanisms reduces COVID-19 transmission during swab tests. With its versatile manipulator and user-friendly design, this robot improves personalities safety and simplifies medical operations [43].

Accidental injuries caused by chemicals are quite common in a number of countries because of the high-risk environment that exists when working with chemicals. Robots are being utilized more frequently in manufacturing and research within chemical industries to minimize chemical exposure and ensure safety. Laboratories are utilizing robotic arms to organize chemical tubes in order to enhance researcher safety and productivity [44]. The recommendations for the use of robot arms were made in response to the fact that thirteen Saudi women were injured with chemical burns while participating in scientific experiments. The purpose of these recommendations was to provide prevention and reduction of the risk factor rate in Saudi Arabia [45].

A robot that performs floor cleaning duties is introduced, based on an effective path planning algorithm designed for floor cleaning. The results demonstrate completeness of coverage and highlight the algorithm's importance in floor cleaning applications [46]. Utilizing computer vision system, a multi-robotic arm system designed for sorting is developed to be integrated with a conveyor system for transporting goods. The slave robot transports the object depending on the size characteristic received from the master robot, ensuring it is positioned in the correct position. The experiment findings demonstrate the system's efficacy for usage in industrial processes to decrease the necessary time and enhance the production line's performance [47]. Using the image processing methodology A computer vision-based robotic arm has been designed to recognize color, form, and size. The proposed system can also detect geometrical shapes (circle, triangle, square, rectangle, pentagon, and star) and sizes (big, medium, and tiny) of objects by employing image processing tools in Python. Empirical results show that the developed robotic arm can detect colored items with 80% accuracy. It achieves great size and shape recognition precision in real time, with 100% accuracy [48].

In a research paper, a novel redundant dual-arm robot motion learning method was proposed. This method was based on human-arm coordination characteristics. In both cartesian and joint space, the design that was developed is capable of realizing human-like coordination motion when applied to a dual-arm robot. The reported method is evaluated on a genuine redundant dual-arm robot platform in order to ensure its effectiveness. A series of experiments are carried out with two different tasks, namely carrying and pouring, and the results demonstrate that the robot is capable of successfully reproducing the human-arm motion tasks that have been demonstrated. Additionally, the dual-arm robot possesses coordinated motion characteristics that are similar to those of humans, which improves the smoothness and naturalness of robotic dual-arm manipulations [49].

For the purpose of selectively monitoring and managing human muscle fatigue in human-robot co-manipulation approaches, a method is proposed which is based on a machine learning technique to be used to learn the complex relation between individual human muscle forces, arm configuration, and arm endpoint force. The estimated muscle forces are then utilized in the process of determining the levels of fatigue experienced by each individual muscle. By making the robot safer and more ergonomic, the model has the potential to significantly increase its applicability in situations that are based in the real world. Experiments were carried out with two collaborative tasks (polishing and drilling) under a variety of conditions in order to carry out functional validation of the proposed method [50]. A multi-modal learning and control paradigm is presented for managing a supernumerary robotic limb. This wearable robotic arm is intended to improve the user's manipulation skills and extend their reach to new heights. The testing findings show that the hand position prediction error is 1.99 cm ± 1.39 cm. In addition, the design was examined in a human-robot collaborative sorting job using a user study with seven participants. The results indicate the usefulness of the proposed design control framework [51].

Utilizing a human pose estimation framework and human-machine interaction to determine the position of a humanoid arm in real time. The presented design utilized a Kinect depth sensor in conjunction with the MediaPipe framework in order to acquire three-dimensional position data of skeletal joints in humans. The outcomes demonstrate that the MediaPipe framework produces joint angles with the smallest standard error when compared to Kinect-based approaches [52].

An innovative approach to kinematic mapping is presented in order to enable the robotic arm to fulfill demands for real-time motion data. In order to effectively resolve the index space, which includes all mapping information and indexes [53].

A planar parallel manipulator which has two degrees of freedom and is utilized in the process of MEMS bonding as well as the assembly of electronic devices. In order to fulfill the requirements of the MEMS industry, the next step is to construct a control system by utilizing a motion control card and a motor driver amplifier. In regardless of this, the results of the experiments demonstrate that the robot is capable of functioning in real time with high speed and high acceleration, and it also demonstrates a satisfactory response to trajectory generation [1]. An automated robot navigation system designed for object retrieval by suggesting a mechanism that substitutes keys and remote controllers with operator commands. The concept introduces a "MEMS and Voice Controlled Robotic Arm with Gesture" to improve accuracy and efficiency in industrial settings. The system comprises a robotic hand, a platform, and an accelerometer, and it is wirelessly operated via cost-effective ZigBee signals [54]. Utilizing manual gestures to control robotic arms is efficient and simple. A design utilizes a smartphone and gyro accelerometer to evaluate gesture control is presented in reference study [55]. The study examines techniques for detecting gestures and use MEMS accelerometer data to regulate robot movement. Arduinos capture acceleration data based on position from accelerometer signals.

The inverse kinematics method was used to design a small-scale three degree of freedom (3-DOF) robot arm for a pick and place mission. The suggested mechanical robotic arm system was developed in Solidworks and employs four servo motors as actuators. Furthermore, Arduino Mega 2560 is the microcontroller that uses the inverse kinematic method to move the robot based on the coordinates of the destination pick and place. Conclusively, the results showed that the robot arm can pick and place according to the target coordinates with an average deviation of roughly 3% [56]. A binary integer linear programming (BILP) model optimizes shoe piece selection and placement in a mold to save time and decision-making. The presented technique was tested using 500 trays and two 3-piece unit shoe models, one for validation and one for training. The results show that BILP can plan task motion in complex environments with many pathways and arm collisions. The model works for shoes with different assembly numbers, proving its versatility [57]. The study outlines the process of creating and assembling a pick-and-place robot that is utilized for the purpose of transferring workpieces to and from a shaping machine. Additionally, the robot adjusts the machine's vice by tightening and loosening it during these operations. The system is comprised of two components: one utilizes a motor-driven chain and sprocket drive to adjust the vice, while the other employs a robotic arm to handle the workpiece. These devices collaborate to mechanize the operation of sequentially loading and unloading components [58].

A study presenting a multi-robotic arm system and a stereo vision system implemented to sort things in the correct position based on size and shape parameters [47]. The presented design comprises of one master and three slave robots linked to three microcontroller-controlled conveyor belts. Instead of reconstructing the complete disparity map, the stereo vision system is designed to detect the 3D coordinates of the object. The 3D coordinates of the item are then determined using the pinhole camera model's formula. The results showed that the intended design successfully picked up the objects and placed them on a conveyor branch at the correct position based on their shape. The experimental findings demonstrate the usefulness of the system, which may be utilized in industrial operations to reduce necessary time and increase production line performance.

Based on the aforementioned scope of different designs of robot arms; a robot arm was developed in which can be controlled remotely using the sensors in a mobile phone and can perform any operation easily and safely. The main components and the generalized flow of operation of the proposed are clarified as in Fig. 1. With the help of this arm, the safety factor could be realized. This arm ensures that the risk of damage to humans is kept to a minimum when performing any chemical process, making it simple and safe to carry out any operation without feeling threatened.

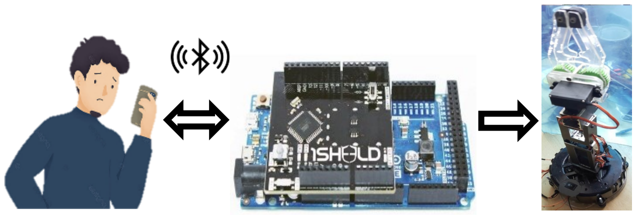

Fig. 1. The general block-diagram of the purposed system

Unlike many other robot arms, the proposed design does not include any external sensors to control the robot arm, as the operation of the arm is regulated by a 3D sensor built into the smartphone. This was achieved by using the 1Sheeld app to activate the smartphone device gyroscope integrated sensors, so the phone's movement is reflected into a robot's movement.

II. Hardware Implementation

The main components of the proposed robot arm and its control system are presented as follows:

A. *Arduino Mega 2560*

The Arduino mega microcontroller is equipped with 256 Kbyte of flash memory for code storage, 8 Kbyte of RAM, 16 analog I/O, and 54 digital I/O. It is employed in this project to interact with and drive the servomotors of the robot arm. It specifies the angles of the smartphone through the data which is captured from the sensors and sends the control instructions to the servomotors in order to execute the appropriate motions. Programming the Arduino microcontroller is accomplished through the use of the C++ programming language.

B. *The 1Sheeld*

The 1Sheeld is a device that enables connecting and controlling the Arduino microcontroller throughout a mobile app by utilizing all of the features of Android smartphones which including Wi-Fi, LCD screen, LEDs, switches, and accelerometer. Basically, 1Sheeld is made up of two components: the 1Sheeld app and the 1Sheeld module board. The 1Sheeld module, which is physically connecting to the Arduino microcontroller board, transfers data over Bluetooth between the Arduino microcontroller and any Android smartphone running the 1Sheeld app. 1Sheeld app was programed using Android software to control the robot arm remotely. Fig. 2 shows the 1Sheeld module and the 1Sheeld app.

1Sheeld module and 1Sheeld app are used in this project to transfer the signal from the orientation sensors and accelerometer based on the user's hand movement to determine the direction of movement. Furthermore, they are also used to transfer the signal from the proximity sensor based on the user's palm movement to control the end effector grippers to pick up objects.

Fig. 2. The 1Sheeld module and 1Sheeld app

C. Servomotor

Servomotor is a small and lightweight dc actuator that enables a precise shaft positioning through a gear and positional feedback control. Its shaft position is controlled by the width of the position control signal, which is a single pulse with an adjustable width. The MG996R servomotor is used to rotate the joints of the robot arm and to move the grippers of the end effector. The MG996R servomotor is shown as in Fig. 3.

Fig. 3. The MG996R servomotor

D. The Robot Base

The base of the robot is the bottom part of the robot where the robot arm is attached. The base must be somewhat robust in order to maintain the robot's stability while the arm is gathering objects. Besides, the base is made from a strong aluminum, and the servomotor can be mounted to it using the pre-drilled holes and connectors. The assembled robot base, the mounted servomotor, and the bearing that permits the base to rotate are shown in Fig. 4.


Fig. 4. The base of the robot arm

E. U-shaped Aluminum Frames

The frames are developed to support the majority of servomotors. They are robust, lightweight, and have a number of holes. When combined with an appropriate servomotor it can be combined with other frames to build a joint that can rotate 180°. Moreover, the top and bottom frames enable the robot to rotate along the shaft to form a revolute joint. Fig. 5 shows some of the U-shaped aluminum frames and the methods of combined to form a revolute joint.

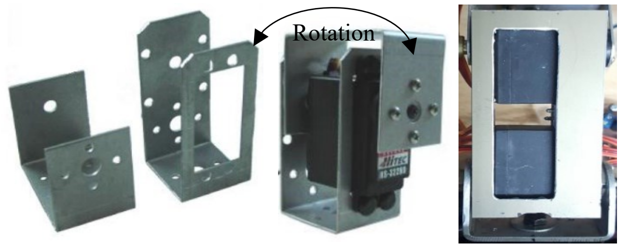

Fig. 5. Servomotor mounted in the top and bottom of the U-shaped frames

F. End-Effector Gripper

The construction of the end-effector gripper ensures that it is only use one servomotor and conforms to a simple mechanical gear design. The gear is turns when servomotor is turned on, which allowing the gripper to stretch or compress. Fig. 6 illustrates how the gripper is assembled together from multiple elements.

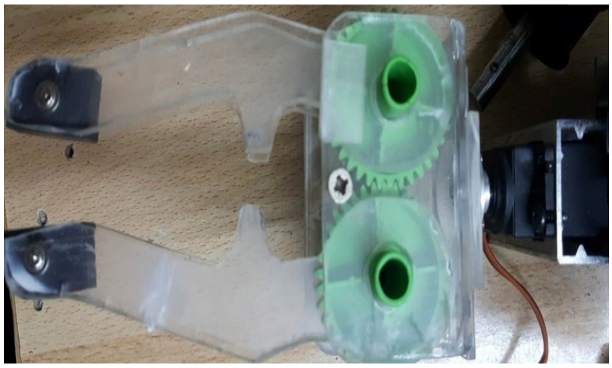
Fig. 6. Assembled end-effector gripper

G. Power Supply

A Buck-converter XL4016 is used to supply power to the complete electronic circuits in the robot arm system. It used to convert 220V rms to 12V dc, then the regulator step-down the voltage to 5V dc in order to feed the servomotors.

III. Robot Arm Design

The goal of the developed robot arm's implementation is to reduce the risks to people. The prototype robot arm is intended to be controlled remotely, which could reduce the risks to people while carrying out chemical experiments or moving heavy objects. The robot arm is made up of a series of U-shaped aluminum frames connected together by revolute joints driven by servomotors. The end-effector is located at the end of the robot arm and consists of two grippers that move to pick up objects.

The 1Sheeld app takes directions from the sensors available in the smartphone, and based on the information collected from accelerometer and orientation sensors, the

1Sheeld app instructs the Arduino controller to send control signals to servomotors. Each servo receives signals from the Arduino microcontroller and responds by moving to the desired direction in three directions of X, Y, and Z. The proximity sensor that is built into the phone can be activated by the 1Sheeld app. Besides, the proximity sensor provides the instruction to the microcontroller to move the end effector gripper in order to pick up objects when the user moves their palm closer or farther to the phone.

The main limitation of this design is the difficulty to control the robot arm from a long distance because the 1Sheeld app uses Bluetooth to transfer the signal from the phone. On the other hand, several requirements are taken into account when designing the robot arm. These included the employing small servomotors to control the arm's angle of movement, the use of light metals like aluminum in the building of the frames, the use of solid iron in the development of the arm's base for stability, and the use of smartphone sensors rather than separate sensors in order to reduce the cost. Fig. 7 shows the final planned mechanical design for a 5-DOF fixed articulated robot arm which consists of a base, two revolute joints, and an end-effector. Fig. 8 indicates a detailed representation of the mechanical design of the components that make up the prototype arm. Fig. 9 demonstrates the final implementation of 5-DOF articulated robot arm.

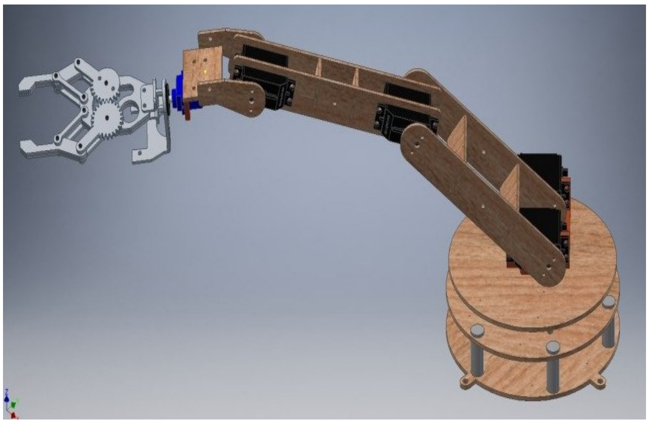

Fig. 7. Mechanical design of the planned robot arm

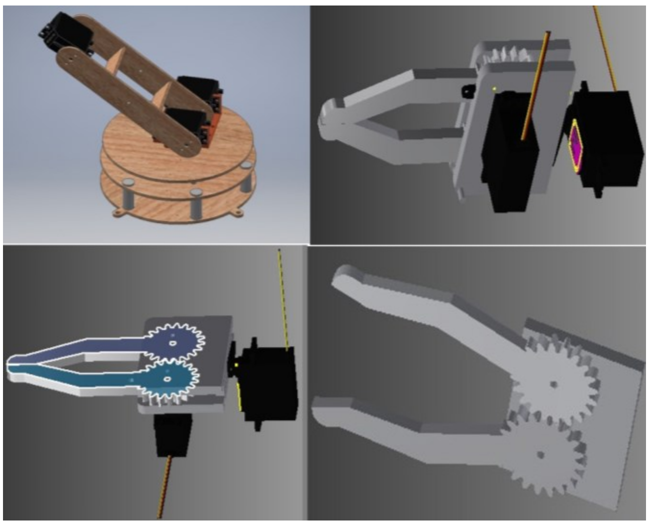

Fig. 8. Detailed mechanical design components of the robot arm

Fig. 9. The developed 5-DOF articulated robot arm

In electronic circuit, each output and input were identified, as well as the connections between the electronic components were clarified. The basic configuration of command transmission between sensors, Arduino microcontroller and servomotor has been achieved. Fig. 10 illustrates the electronic circuit of the developed system and its components. It displays that the smartphone connected to Arduino board via Bluetooth connection to pass the intended direction through sensors and Arduino microcontroller which transferring commands to servomotors [59]. Furthermore, it demonstrates that Bluetooth connects to the smartphone and Arduino microcontroller, so that the 1Sheeld app reads the smartphone's sensors signal to send the desired direction. Subsequently, the 1Sheeld app uses the Arduino microcontroller, which is directly connected to servomotors, in order to transmit orders to servomotors and that cause the robot arm to move in a manner that matches the smartphone movement.

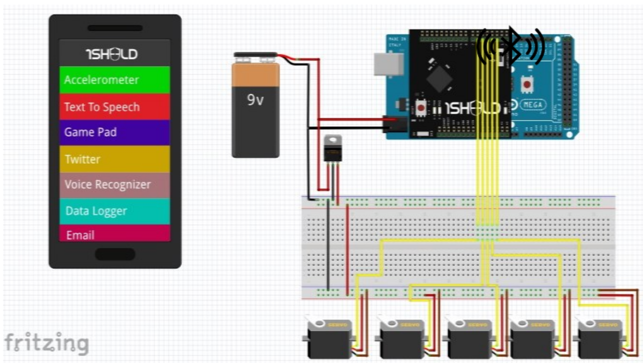

Fig. 10. Electronic circuit of the proposed system and its components

When the robot arm is operated, the 1Sheeld module establishes a Bluetooth connection with the 1Sheeld mobile app and then activates the arm's movement sensors. The accelerometer sensor sends data to the Arduino microcontroller, which causes the robot arm's servomotor to rotate around X and Y axis. The orientation sensor also sends data to Arduino microcontroller to drive the robot arm along the Z axis, and the proximity sensor sends data to the Arduino microcontroller to control the end effector grippers for holding objects.

IV. SOFTWARE IMPLEMENTATION

Once turning on the robot arm, launching the 1Sheeld app on the smartphone, the sensors are scanned, and the 1Sheeld app which connected over Bluetooth with the 1Sheeld module sends the captured data. Fig. 11(a) shows the user trying to activate the orientation and proximity sensors at 1Sheeld app. Fig. 11(b) shows the interface of activation of the accelerometer, orientation, and proximity sensors, as well as position and direction changes on the axes.

(a) (b)

Fig. 11. Sensors activation with position and direction changes on the axes

The flowchart of robot arm is shown as in Fig. 12. Using of the phone's sensors, the 1Sheeld app transmits signals to the 1Sheeld module. The servomotor is controlled to rotate on the X, Y, and Z axes through the Arduino microcontroller, which receives these signals from the 1Sheeld module.

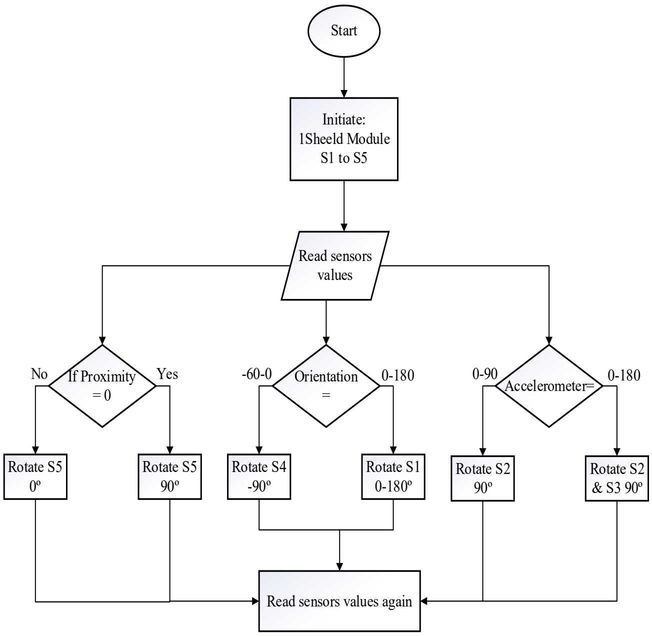

Fig. 12. Flowchart of the robot arm

The following orders of the signals that could be sent out by the sensors and implemented by servomotors:

1. If the orientation sensor sends a signal between 0 and 180, the Arduino microcontroller instructs servomotor1 (S1) to rotate 0-180°.
2. If the accelerometer sensor sends a signal between 0 and 90, the Arduino microcontroller instructs S2 to rotate 90°.
3. If the accelerometer sensor sends a signal between 0 and 180, the Arduino microcontroller instructs S2 and S3 to rotate 90° each.
4. If the orientation sensor sends a signal between -60 and 0, the Arduino microcontroller instructs S4 to rotate 90° (rotate hand right).
5. If the orientation sensor sends a signal between 0 and 60, the Arduino microcontroller instructs S4 to rotate -90° (rotate hand left).
6. If the proximity sensor sends a signal of 0 or 8, the Arduino microcontroller instructs S5 to open or close the grippers.

Table I shows the signal captured by smartphone sensors, which leads to the actions that must be taken by servomotors to move the robot arm to desired position.

TABLE I. SMARTPHONE SENSORS AND RESULTED ACTION

Sensor	Signal	Actuated motor	Resulted action
Orientation sensor	0-180	S1 base	(0-180°)
Accelerometer sensor	0-90	S2 shoulder	0-90°)
Accelerometer sensor	0-180	S3 elbow	(0-90°)
Orientation sensor	0-60 or - 60-0	S4 wrist	(-90 or 90°)
Proximity sensor	0 or 8	S5 grippers	(open or close)

V. RESULT AND DISCUSSION

The developed prototype of the robot arm is tested for gripper's movement, and the movement in different moving positions. The user's palm movements control the grippers of the robot arm end-effector, where they open and close to pick up objects. Instantly as the user's palm moves away from the mobile phone's screen, the proximity sensor = 8 causes S5 activate to close the grippers. Meanwhile, as the user's palm gets close the proximity sensor = 0 causes S5 activate to open the grippers, the desired outcome of these movements is illustrated in Fig. 13.

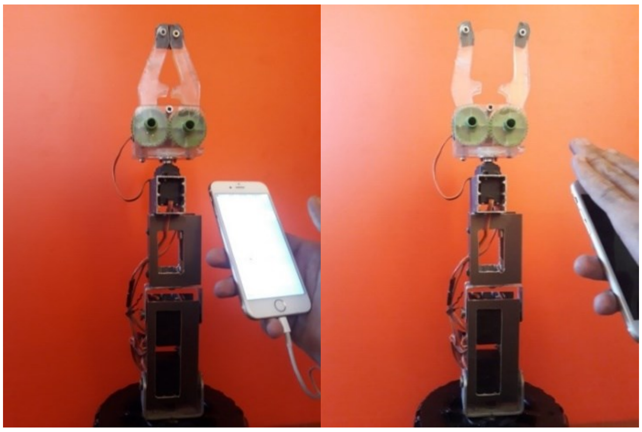

Fig. 13. The end-effector gripper's movement

If the user rotates the mobile phone between 0-180° along the Z axis in order to rotate the robot arm from the base. The orientation sensor transmits that angle to Arduino, which then activates S1. Fig. 14 shows the rotation of the robot arm to the right and to left along the Z axis.

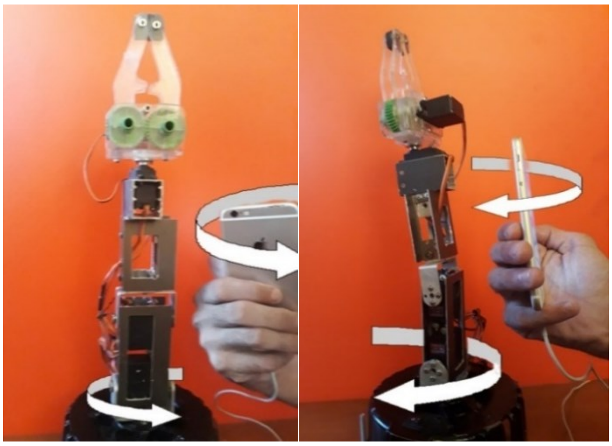

Fig. 14. The robot arm rotates to the right and to the left along the Z axis

In the event that the user moves the mobile phone up or down horizontally between 0 and 180°, the robot arm moves up or down. The accelerometer sensor transmits the captured angle to Arduino which activates S2 and S3. Fig. 15 shows the robot arm moves up and down with horizontal end effector.

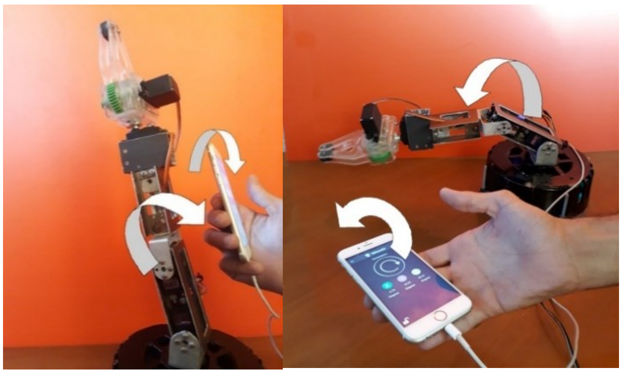

Fig. 15. The robot arm moves up and down with horizontal end effector

In case the user moves the mobile phone up or down vertically between 0 and 180° in order to move the robot arm up or down. The accelerometer and orientation sensors transmit that angle to the Arduino, which then activates S2, S3 and S4. Fig. 16 shows the robot arm moves up and down with vertical end effector.

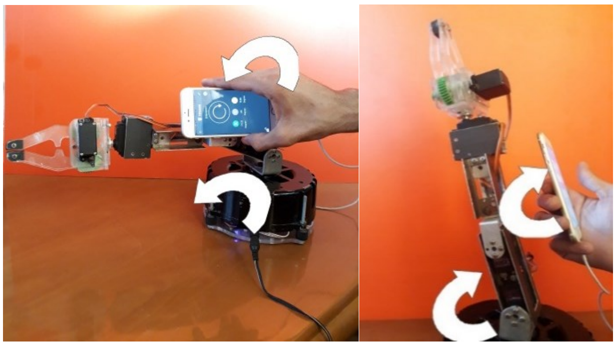

Fig. 16. The robot arm moves up and down with vertical end effector

Now, while the user rotates the mobile phone to the right and left along the X axis, the end effector moves to the right and to the left. The orientation sensors transmit the captured angle data to the Arduino, which then activates S4. Fig. 17 shows the end effector rotates to the right and to left along the X axis.

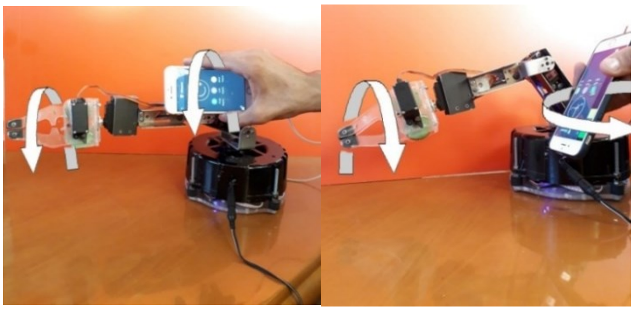

Fig. 17. End-effector rotates to the right and to left along the X axis

The communication with other devices can be made easier by incorporating a commonly used commercial controller into the presented proposed design. In addition to utilizing the widely used Internet of Things technology (IoT), multiple tasks can be performed by robots [60][61]. In addition to taking advantage of the proposed design through the smartphone application which could be a further improvement to the device in the future [62][63]. With the ability to control the robot arm with a smartphone, it becomes much more convenient to employ the robot in applications that include hazardous environments.

VI. CONCLUSION

In this paper, an articulated robot arm with 5-DOF is developed and implemented. The design of the mechanical structure and electronic control system integrated with an Arduino microcontroller and Android 1Sheeld app is presented. The 1Sheeld app activated the smartphone's gyroscope sensors to detect the change in orientation and direction of the mobile phone caused by the user. The 1Sheeld app and 1Sheeld module connect the smartphone to the Arduino via Bluetooth. Even though Bluetooth restricts the robot's control range, this is intentional. The user of this robot must be in close vicinity to the work site, but they are prohibited from coming into direct contact with hazardous areas. As a result, data regarded to the phone's orientation and direction changes are sent to the Arduino to remotely move the robot arm in response to the phone's alignment. This study demonstrates significant improvements in the area of human-machine interaction, as well as the success of implementing mobile phones with automated systems. The outcomes of the test experiments demonstrate that a smartphone can be utilized to remotely control the robot arm in variety moving positions. Furthermore, it may open the door for other applications or industries, such as remotely healthcare assistance, manufacturing or education.

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