Human Arm Movement Detection Using Low-Cost Sensors for Controlling Robotic Arm

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***Abstract*—This paper presents the development of a wearable device to detect the human arm movement for controlling the robotic arm remotely. The proposed system employs the simple and low-cost sensors consist of seven potentiometers and one flex sensor. A small size Arduino Nano microcontroller is employed as the processing unit to process the analog signal from the sensor into the digital value which is then sent to the robotic arm via the Bluetooth communication. The experimental results show that the system achieves good linearity between the human arm movement and the robotic arm movement. The average linearity error of the whole sensors that represents the deviation of sensor output from the ideal one is 2.20%. Since the sensors are simple and low cost, the error could be acceptable for the real implementation.**

***Index Terms*—Human Arm Detection; Robotic Arm; Potentiometer; Flex Sensor.**

I. INTRODUCTION

In robotic technology, a robotic arm is one type of robot that mimics the human arm. Due to the importance of human hand/arm in handling some tasks, the robot arm is very popular used in industries for replacing the human operator, especially to handle the dangerous tasks such as in the nuclear plant, toxic chemical reactors, or high-temperature environments. In such places, a tele-operated robot is commonly employed. In the tele-operated robot, a human operates the robot remotely. A common method to control the robot arm is by using buttons or joystick. But it is the inconvenient method. Therefore the new methods to detect the human arm are developed in [1-15] to provide a convenient method for controlling the robot.

The sensors to detect the human arm movement could be divided into several types, i.e. the potentiometer [1-3], [8-10], the flex sensor [4-6], [13], the inertial measurement unit (IMU) [7], [11-13], the accelerometer [8], [13], and the camera [15].

In [1], six potentiometers were employed to detect the movements of shoulder in the horizontal and vertical directions, the bending of elbow, the rotation of arm, the bending of wrist, and the gripping motion. They employed a low-cost Arduino Uno microcontroller to read the data from sensors and control the servo motors on the robotic arms. In [3], the potentiometer was used to detect the finger movement for controlling the robot. In [8], the sliding linear potentiometers were employed to the detect the bending of fingers.

The flex sensors were employed to detect the finger movements [4, 5], the shoulder, elbow, finger and wrist movements [6], [13]. The sensors are attached to the hand/arm, so that when the hand/arm is bent, the resistance of sensor will change proportionally to the bending degree.

In [7], the IMU sensors were placed in the hand, arm, and fingers for operating the robot remotely. In [11], the IMU-sensor network was employed to capture the hand movements. To overcome the problems of precision and drift in the IMU sensors, the Kalman filter was coupled with the sensor [12].

The method to track the hand movement using the image processing technique was proposed in [15]. They employed two cameras to detect the red band put on the arm for tracking the arm movement.

As discussed previously, the hand movement detection system using the potentiometer is the simple and low-cost method. However, it requires a good designing in the mechanical part, especially to convert the hand movement into the rotational motion. Further, the flex sensor provides the good method to detect the bending movement.

In this paper, we develop a wearable device by combining the potentiometer and flex sensor for detecting the arm movements with the simple mechanical construction. A small size Arduino Nano microcontroller and a Bluetooth module are installed on the wearable device to provide the wireless communication for controlling the robotic arm.

The rest of paper is organized as follows. Section 2 presents the proposed system. Section 3 presents the experimental results. The conclusion is covered in Section 4.

II. PROPOSED SYSTEM

A. Mechanical Part

The mechanical design of the wearable device is illustrated in Figure 1. It consists of four segments, i.e., shoulder segment, elbow segment, wrist segment, and finger segment. The shoulder segment is used to detect the movement of shoulder rotation in vertical and horizontal direction, the upper arm rotation. The elbow segment is used to detect the bending of elbow and the rotation of lower arm. The wrist segment is used to detect the rotation of wrist and the bending of wrist. The finger segment is used to detect the bending of finger.

The wearable device is worn by tying it on the arm and shoulder. The device is made from the aluminum material.

B. Sensors and Electronic Parts

Seven potentiometers and one flex sensor are employed to detect the hand movements. Three potentiometers called as **Shd-V Pot**, **Shd-H Pot**, and **Arm-Up Pot** are located in the shoulder segment as shown in Figure 2. The mechanical construction is designed so that when the shoulder swings in the vertical direction, it will rotate the **Shd-V Pot**. The **Shd-H Pot** will rotate when the shoulder swings in the horizontal direction, while the **Arm-Up Pot** will rotate when the upper arm is rotated.

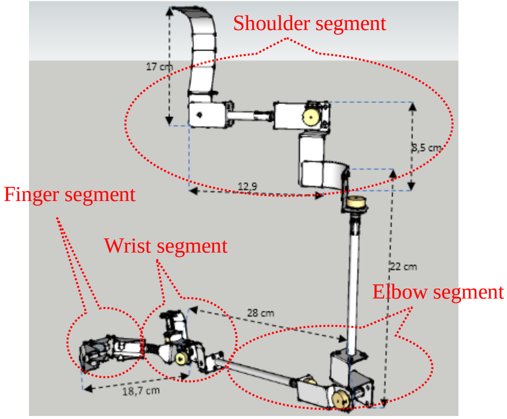

Figure 1: Mechanical design

Two potentiometers called **Elb-Rot Pot** and **Elb-Bend Pot** are located in the elbow segment as shown in Figure 3. The **Elb-Rot Pot** will rotate when the elbow is rotated. The **Elb-Bend Pot** will rotate when the elbow is bent.

Two potentiometers called **Wrt-Pitch Pot** and **Wrt-Yaw Pot** are located in the wrist segment as shown in Figure 4. The **Wrt-Pitch Pot** will rotate when the wrist is moved up and down (pitch movement). The **Wrt-Yaw Pot** will rotate when the wrist is moved left and right (yaw movement). It is noted that the up/down and left/right direction refer to the wrist position when the palm approaches the downside.

A flex sensor (**Flex Sens**) is attached along finger (center finger) as shown in Figure 4. Thus the **Flex Sens** will follow the bending of finger.

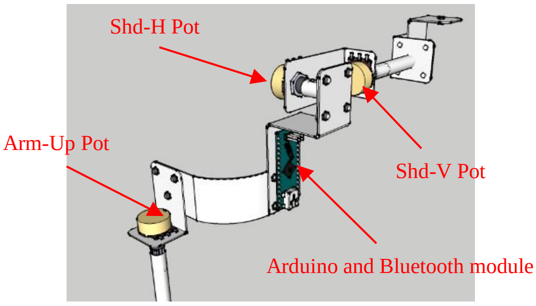

Figure 2: Potentiometers and electronic module on the shoulder segment

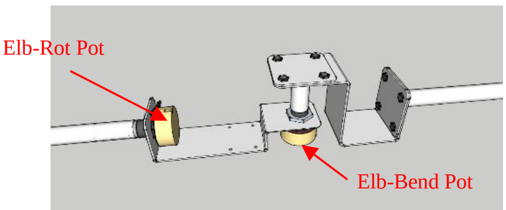

Figure 3: Potentiometers on the elbow segment

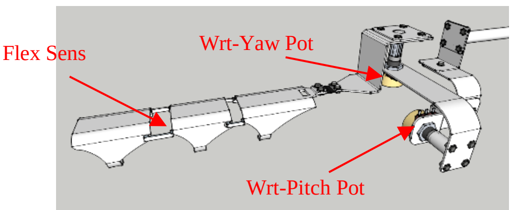

Figure 4: Potentiometers and flex sensor on the wrist and finger segments

The block diagram of the electronic system is depicted in Figure 5. The components in the wearable device are the sensors, a microcontroller and a Bluetooth module. While in the robotic arm, there are a microcontroller, a Bluetooth module, and the actuator (servo motors). In the wearable device, since the modules should be attached to the human arm, we choose the small size Arduino Nano and the HC-05 Bluetooth module. Using this arrangement, the wearable device could be worn freely by the user and no more cable is needed between the user and the controlled robotic arm.

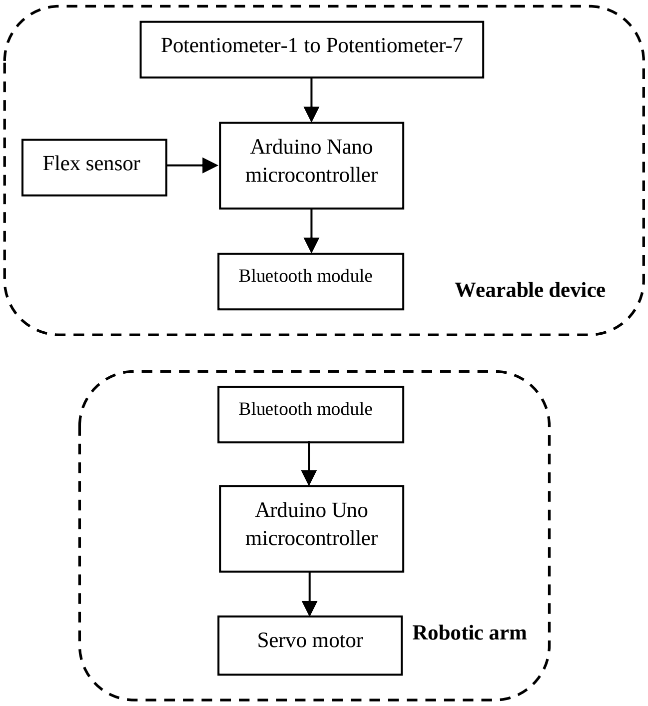

Figure 5: Block diagram of electronic system

The outputs of potentiometer and flex sensor are the resistances which are varied according to the angular position of the potentiometer and the bending degree of flex sensor. In this work, 100K Ohms potentiometers are used. Thus the resistance output varies from 0 Ohm to 100K Ohms, while the resistance output of flex sensor varies from 10K Ohms to 40K Ohms. Therefore, they could be treated as the voltage divider. The output of this voltage divider is converted into the digital signal by the built-in ADC on the Arduino Nano.

The program written in the Arduino Nano is very simple. It first converts the analog signals from the sensors into digital values. Since the resolution of ADC is 10 bits, the range of digital value is 0 – 1023. It then maps into 0 – 180, which represents the angle of servo motor in the robotic arm. These values are sent to the robotic arm via the Bluetooth module.

III. Experimental Results

The prototype of the proposed wearable device for detecting the human arm movement has been made as shown in Figure 6. To evaluate the proposed system, several experiments are conducted. In the first experiment, the relationship between the output voltages of the sensors and the rotation angles (bending angle) of the sensors are measured. The measurement is done by measuring the angle of the arm and the output voltage of the respective sensor as shown in Figure 7. In the second experiment, the relationship between the joint angles of controlled robotic arms and the rotation angles of the sensors (human arms) are measured. This measurement is used to examine the performance of our system in controlling the robot, i.e. how close the robotic arms follow the human arm movements. The measurement is done by measuring the angle of the arm and the angle of the respective robotic arm as shown in Figure 8. The experimental results are discussed in the following.

Figure 6: Prototype of proposed wearable device

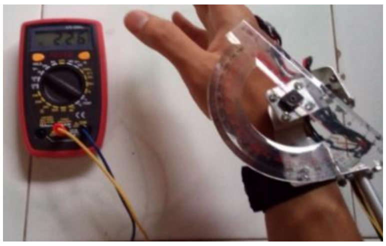

Figure 7: Measurement the arm angle and the output voltage of the sensor

Figure 8: Measurement the arm angle and the robotic angle

The measurement result of the output voltage versus bending angle of the flex sensor is shown in Figure 9. From the figure, it is obtained that the relationship between the output voltage and the bending angle is almost linear. The linearity error is 1.02% as given in Table 1.

The measurement results of the output voltage versus rotation angles of seven potentiometers are shown in Figure 10. In the figure, **Shd-V Pot**, **Shd-H Pot**, and **Elb-Bend Pot** have the positive relationship, i.e. the output voltage increases when the rotation angle increases. While **Arm-Up Pot**, **Elb-Rot Pot**, **Wrt- Yaw Pot**, and **Wrt- Pitch Pot** have the negative relationship, i.e. the output voltage decreases when the rotation angle increases. The relationships between the output voltages and the rotation angles of seven potentiometers are almost linear, where the linearity errors are given in Table 1.

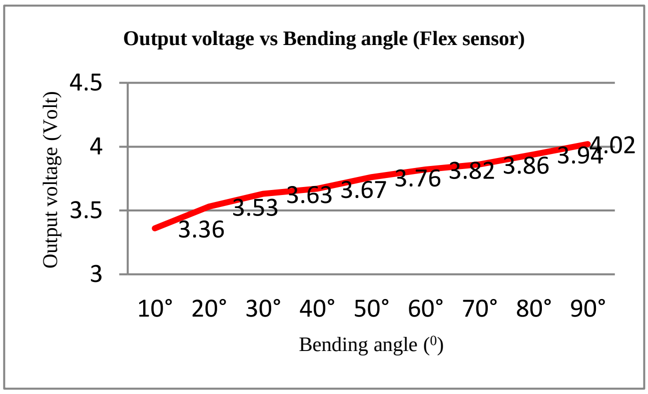

Figure 9: Output voltage versus flex sensor bending angle

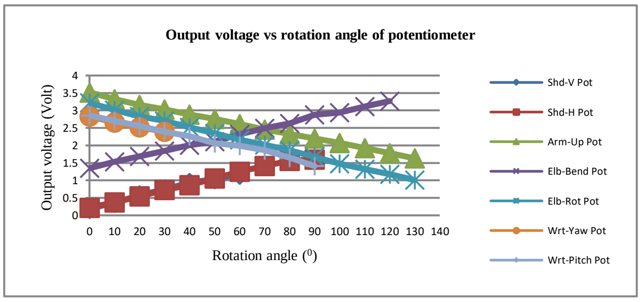

Figure 10: Output voltage versus rotation angle of potentiometer

Table 1
Linearity errors of potentiometers and flex sensor

No.	Sensor Name	Linearity Error
1	Flex sens	1.02%
2	Shd-V Pot	4.21%
3	Shd-H Pot	5.69%
4	Arm-Up Pot	2.47%
5	Elb-Bend Pot	0.82%
6	Elb-Rot Pot	0.96%
7	Wrt-Yaw Pot	0.39%
8	Wrt-Pitch Pot	2.05%
	Average	**2.20%**

The robotic arm to be controlled is shown in Figure 11. It is a 5 DOF robotic arm kit produced by Crust crawler [16]. The robot has a base, a shoulder, an elbow, a wrist, and a gripper. In the experiment, the **Elb-Rot Pot** is used to control the base, the **Shd-V** Pot is used to control the shoulder, the **Elb-Bend Pot** is used to the elbow, the **Wrt-Pitch Pot** is used to control the wrist, and the **Flex sens** is used to control the gripper.

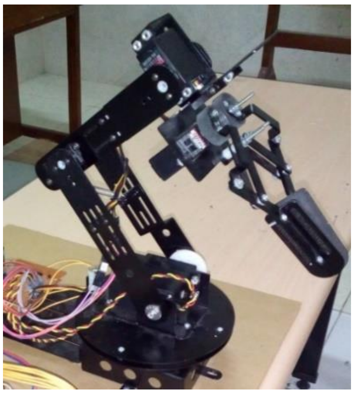

Figure 11: The controlled robotic arm

The relationship between the gripper movement and the bending angle of flex sensor is shown in Figure 12. It is noted that the gripper movement is a translation motion. As shown in the figure, the gripper movement is proportional to the bending angle of flex sensor.

Figure 13 shows the relationship between the arms movement and the respective rotation angle of the potentiometer in the wearable device. The good linearity is achieved in the base, wrist, and shoulder movements. However, for the shoulder movement, some points are not linear as shown in the figure. The results suggest that the proposed wearable device could be used to control the robotic arms in the linear fashion, so that the user or operator may control the robotic arm conveniently.

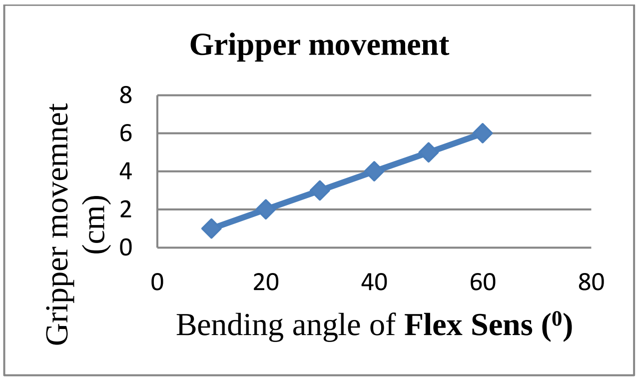

Figure 12: Gripper movement

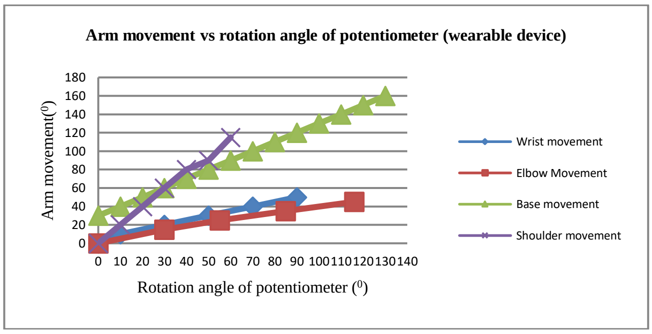

Figure 13: Arm movement

IV. CONCLUSION

A simple apparatus to detect the human arm movement is developed using the low-cost potentiometer and flex sensor. A lightweight mechanical structure is made to attach the sensors to the human arm. Even though the wearable device is simple, the experimental results provide a promising method to control the robotic arm effectively by moving the human arm naturally.

In future, some improvements will be carried out such as to add more arm movements, to detect more fingers motion. Further, the experiments with the other types of robotic arms will be addressed.

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