Data Characterization of 4 Axis Shadow Robot Arm Integrated with Flex Sensor Mechanism

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Abstract. Robotic arms have seen widespread use in various industries in the recent years. However, most robotic arms are controlled to move in a predetermined path. The goal of this study is to develop a wirelessly controlled robotic arm which is able to mimic the user’s movements. The arm enables easier programming of robotic arms and increases ease of use of such arms. Methods of collecting the anthropometric measurements of the human body to be translated to digital data have been investigated. Integration of flex sensor for the fingertips movements were used to mimic by detecting the bending moment from the user. As for elbow detection, variable resistor was used to detect the changes by converting the changes of angle at the elbow structure to resistance value. Both of the data were mapped accordingly to the exoskeleton arm receiver by using wireless Bluetooth to ensure all structure move accurately with even slight changes done by the user. The optimization and filtering of the recorded data was also conducted in the study to develop a robotic arm that is able to mimic the human arm motion to the highest accuracy possible.

1. Introduction

The use of robotics arms in various industries have given rise to a large number of methods and developments in robotics technology. Throughout the development of robotic technology, there have been an increased interest in developing humanoid robots. Humanoid robots are robots with anthropometric body plans and human like senses [1]. These efforts are motivated by the desire to create robots that are able to mimic human motion and work in close cooperation with humans. Compared to high-ly specialized industrial robots which can perform industrial tasks such as welding, pick and place etc. with high accuracy consistently, humanoid robots cater to a different set of needs. These robots are designed to be used for general purpose and is meant to be robust and easy to use. The applications for such robots can be in situations which are of high risk but require humans to complete a task such as fire rescue of in high heat/radiation environments.

To develop a humanoid robotic arm capable of mimicking the finger and elbow motions, the methods of collecting the anthropometric measurements and movements are of critical importance. Current techniques involve using MEMS sensors such as gyroscopes and accelerometer chips to track user movement. The aim of this study is to explore the possibility and feasibility of employing simpler and lower costs solutions in tracking movement. The main goal is to achieve readings with similar accuracies.
with these low-cost measuring techniques as the electronic techniques. Therefore, the circuitry set-up and coding required to achieve high accuracy was investigated.

The design of the arm is also crucial as it has to mimic all the motions of the human fingers and elbows and thus requires a total of 4-degrees of freedom. The ability for the actuators to move the arm to the desired position as detected by sensors were also investigated. Current technologies such as the robotic arm shown in [2] uses pneumatic muscles to achieve accurate movement. This study will employ a lower cost solution which is servo motors which are able to rotate with 1-degree accuracy and are highly consistent and repeatable as well. Several tests and simulations in software will have to be conducted to ensure the arm has the full range of motions a human arm has and also to verify that the sensors are able to generate the desired output.

2. Methodology
The conceptual design and programming development have been fulfilled by the integration of two main software which are Solid-Works and Arduino software (IDE). Both software had specific function where SolidWorks software is focused on achieving the optimized design and creating simulation for movement of the 4-axis robotic arm. For this project, Arduino Uno microcontroller has been selected to detect the voltage changes across flex sensor and then convert the input data into mechanical movement at the robotic arm. The methodology is specified into following stages:

- Stage 1: Conceptual design of robotic arm and the controller
- Stage 2: Prototype fabrication
- Stage 3: Programming Input and Output

2.1. Conceptual Design
The design for the robotic arm was intended to mimic the mobility of a human arm. The exoskeleton suit from ‘Ironman’ has the mobility of a human body and the robotic arm was mainly inspired by that [6]. Most of the parts of the robotic arm are curvature in shape which aided in increase in strength as curve shape has better load distribution compared to flat shape [7]. The strength of the design was further improved by designed the wrist in round-shaped to allowed the robot palm to support heavy load. The design for the fists was inspired by a robot called ‘Atom’ from the novel ‘Real-Steel’ which have two huge fingers and a thumb with approximately similar size to the fingers [8]. The robotic arm was designed in SolidWorks software and the design consisted of 47 parts.
Figure 1 to 4 represent the assembly drawing for the robotic arm. The finger was designed to have only 3 units due to the pick and place testing that we will conduct in future works. The purpose of the design is to mimic the movement of actual hand.

### 2.2 Prototype Fabrication

The robotic arm is attached to the user’s arm and is controlled by a microcontroller to replicate the mobility of the user’s arm. However, there is a limitation found on the robotic arm as it only has 2 fingers with a thumb. There is no wrist rotation, but the elbow can be bent up to a maximum of 173°. The robotic arm was fabricated with 3D printer with the PLA plastic and 15% density. The material was chosen to be PLA due to the easier printing which able to produce finer details. As the robotic arm is still a prototype, the density of the material chosen to be 15% density due to lower cost to produce. In addition, 15% density of printed material won’t affect the integrity of the structure. Since the future testing phase will be done by moving small object, 15% density won’t affect the results too.

The robotic arm has 3-degrees of freedom (DOF) at the shoulder part, 1 DOF at the elbow joint, 2 DOF at the thumb and 1 DOF for each finger. The fingers and thumb are both controlled by using SG90 servo which located at the forearm of the robotic arm. The fingertips and the tip of the thumb are tied with 0.1mm diameter fishing rope and 0.7mm diameter elastic cord while the other end for each fishing rope are tied with SG90 servo and the elastic cord tied with the interior part of the palm of the robotic arm.

SG90 servo was chosen to control the fingers and thumbs due to the small size of the motor which able to fit 3 of it in the forearm. Besides, the torque of each servo motor is 2.5kg.cm which is a decent torque for the grip of the robotic arm. The servo motor to control the movement of the elbow joint is directly placed in the elbow joint itself to maximize the force of the motor. The motor chosen for the elbow joint was MG996R with the torque of 10kg.cm which is optimal torque for the elbow joint to withstand heavy load. The movements of the shoulder joint required 3 servo motors, MG946R with torque of 13kg.cm, which is considered higher than MG996R as the shoulder joint has to carry higher weight from the robotic arm itself as compared to the elbow joint. The servo motors used for shoulder joint were placed in the bicep, shoulder and the stand or support of the robotic arm. The forearm, bicep and triceps of the robotic arm are in curvature shape mainly at the edge and has minor flat surface to increase the strength of the arm, thus allows it to increase the load limit carried by the robotic arm.
Figure 5 to 8 represent the fabricated parts of the robotic arm. The robotic arm consists of 3 joints for two fingers as to mimic index finger and middle finger. The thumb finger will only have 2 joints as illustrated inside the figure.

### 2.3 Data Transmitter Communication Programming

Robotic arm and fingers (servomotors) were set to be controlled wirelessly by flex sensors through two Bluetooth modules. The first Bluetooth module was set as master device and second Blue-tooth module set as slave device [9]. The slave device (servomotors) must always executing the instruction given by the master device (flex sensors). Coding and circuit connection between two Blue-tooth modules on two separate Arduino Uno board must be well-configured in order to run the communication with minimum delay. Coding below shows configuration of data sender communication.

#### Master device

```c
int finger1 = A0;
int finger2 = A1;
int finger3 = A2;
int elbow = A3;
int fpos1, fpos2, fpos3, epos;
int state =0;

void setup() {
  Serial.begin(9600);
  pinMode(A0, INPUT);
  pinMode(A1, INPUT);
  pinMode(A2, INPUT);
  pinMode(A3, INPUT);
}
void loop()
```
5

if(Serial.available() > 0)
{
    state = Serial.read();
}

fpos1 = analogRead(finger1);
fpos2 = analogRead(finger2);
fpos3 = analogRead(finger3);
epos = analogRead(elbow);
fpos1 = map(fpos1, 0, 1023, 0, 180);
fpos2 = map(fpos2, 0, 1023, 0, 180);
fpos3 = map(fpos3, 0, 1023, 0, 180);
epos = map(epos, 0, 1023, 0, 180);
delay(100);

3. Results and Discussion

Analysis on the simulations and variations of voltage reading in mapping the value to the correct response mechanism. The micro-controller will send the data wirelessly to the shadow robotic arm to create similar movement done by the user.

3.1. Sensor Calibration Output

Servo motors only can be rotated at the desired angle based on the bending movement of the flex sensors. The range value of the flex sensor is from 0-1023 and the range value of servo motor is from 0-180. In master device, map() function is used to analyse and calculate the input data from flex sensor. The collected data will be converted into rotation angle as output and sent to slave device through Bluetooth communication. Once slave device is receiving the data, the servo motors will be started to rotate based on the calculated angle given by the flex sensor.

During calibrating, initial values for both flex sensors and servo motors were set at 0 respectively, assuming fingers, elbow and shoulder were initially at straight position. Any variations in value of flex sensors will be reflected to the value of servo motors. While both flex sensors and servo motors have reached maximum value of 1023 and 180 respectively. This shown fingers, elbow and shoulder were at maximum bending position. Based on the calibration, these predetermined values were matched correctly. Any errors found during calibration were solved accordingly.

3.2. Data Receiver Communication Programming

Slave device will be controlled accordingly based on the instruction given by the master device. Coding below shows configuration of data receiver communication.

3.2.1. Slave Device

#include <Servo.h>
Servo servo1, servo2, servo3, servo4;
int s1=3, s2=5, s3=6, s4=9;
int fpos1, fpos2, fpos3, epos;
int state= 0;

void setup()
{
    servo1.attach(s1);
    servo2.attach(s2);
servo3.attach(s3);  
servo4.attach(s4);  
//Set Servo write at 0 initially  
servo1.write(0);  
servo2.write(0);  
servo3.write(0);  
servo4.write(0);  
//delay(100);  
}  

void loop()  
{  
  if(Serial.available() > 0)  
  {  
    state = Serial.read();  
  }  
  servo1.write(fpos1);  
  servo2.write(fpos2);  
  servo3.write(fpos3);  
  servo4.write(epos);  
}  

3.3. Voltage Output Reading  
The mapping between flex sensor and servo motor is very crucial to obtain the most accurate deflection. The servo motor was attached to the robotic arm to control the movement for each finger.

Table 1. Result for flex sensor and servo motor voltage reading when all fingers are fold

| Transmitter | Receiver |
|-------------|----------|
| Finger 1    | Finger 1 |
| Finger 2    | Finger 2 |
| Finger 3    | Finger 3 |
| Elbow       | Elbow    |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |
| 0           | 0        |


Table 2. Result for flex sensor and servo motor voltage reading when elbow is fold and the rests are open.

| Transmitter | Receiver |
|-------------|----------|
| **Finger 1** | **Finger 1** |
| 153         | 152      |
| 154         | 153      |
| 152         | 151      |
| 152         | 152      |
| 153         | 153      |
| 150         | 154      |
| 152         | 152      |
| 153         | 153      |
| 153         | 154      |
| 152         | 153      |
| 154         | 151      |
| 152         | 152      |
| 151         | 151      |
| 153         | 152      |
| 154         | 153      |

Table 3. Result for flex sensor and servo motor voltage reading when elbow is open by 2 degree in angle.

| Transmitter | Receiver |
|-------------|----------|
| **Finger 1** | **Finger 1** |
| 154         | 153      |
| 154         | 154      |
| 152         | 153      |
| 153         | 154      |
| 152         | 154      |
| 151         | 153      |
| 153         | 150      |
| 154         | 153      |
| 151         | 154      |
| 152         | 152      |
| 153         | 154      |
| 150         | 151      |
| 154         | 154      |
| 153         | 155      |
| 153         | 153      |
| 153         | 153      |
| 153         | 153      |
After implementation of the coding, the voltage reading start from 0 and operate in live feed up to the voltage value of 179 when the bending mechanism is applied at maximum angle as shown in Table 1 to 4. The result shows reliable data obtained where the difference value between transmitter and receiver is less than 5.

The mapping between transmitter and receiver are important to ensure that the bending movement created can mimic perfectly onto the robotic arm. Four mechanism including the flex and gyro mechanism were integrated in one hand structure to detect the changes of the angle and the rotation of the 4 axis arm. The value is mapped to the movement on the servo motor to match the moving part of the sender mechanism. Hence, the receiving structure will move in similar accuracy as the sending structure.

| Transmitter | Receiver |
|-------------|----------|
| **Finger 1**  | **Finger 1**  |
| 173          | 172       |
| 174          | 171       |
| 174          | 172       |
| 175          | 174       |
| 175          | 175       |
| 177          | 172       |
| 172          | 171       |
| 174          | 173       |
| 174          | 174       |
| 175          | 175       |
| 175          | 176       |
| 177          | 171       |
| 173          | 173       |
| 170          | 171       |
| 174          | 174       |
| 174          | 175       |
| 175          | 175       |
| 176          | 171       |
| 173          | 173       |
| 174          | 174       |
| 175          | 175       |
| 177          | 172       |
| 170          | 171       |
| 174          | 174       |
| 174          | 175       |
| 175          | 175       |
| 176          | 171       |

3.4. Characterization of Voltage changes in Different Angle

The next stage of the experimentation is to map the changes of voltage in transmitter and receiver of the robotic. The turnout of this stage is to verify the accuracy of the mechanism in capturing the slight changes of movement of the robotic arm as shown in Table 5 and 6.

The result also indicates that the accuracy is at 100% where the mapping between transmitter and receiver voltage are the same. The trend of the voltage changes needs to be refine where slight inconsistency voltage trend occurred from 120 to 180 degree angle of bending. This happened may due to the inconsistent placement of the flex sensor at the robotic structure which causes inaccurate trend at higher degree of bending.
Table 5. Result for transmitting voltage from 0 to 180-degree angle

| Degree | Finger 1 | Finger 2 | Finger 3 | Elbow |
|--------|----------|----------|----------|-------|
| 0      | 14       | 11       | 16       | 0     |
| 10     | 21       | 24       | 27       | 5     |
| 20     | 37       | 34       | 29       | 9     |
| 30     | 40       | 42       | 36       | 12    |
| 40     | 60       | 50       | 46       | 28    |
| 50     | 59       | 57       | 60       | 49    |
| 60     | 69       | 56       | 80       | 61    |
| 70     | 74       | 61       | 84       | 76    |
| 80     | 89       | 58       | 98       | 85    |
| 90     | 102      | 98       | 100      | 96    |
| 100    | 105      | 99       | 88       | 110   |
| 110    | 120      | 118      | 100      | 115   |
| 120    | 124      | 121      | 110      | 119   |
| 130    | 116      | 107      | 117      | 131   |
| 140    | 126      | 136      | 122      | 138   |
| 150    | 125      | 133      | 130      | 141   |
| 160    | 128      | 146      | 136      | 146   |
| 170    | 133      | 146      | 138      | 148   |
| 180    | 144      | 158      | 156      | 184   |

Table 6. Result for receiving voltage from 0 to 180-degree angle

| Degree | Finger 1 | Finger 2 | Finger 3 | Elbow |
|--------|----------|----------|----------|-------|
| 0      | 14       | 11       | 16       | 0     |
| 10     | 21       | 24       | 27       | 5     |
| 20     | 37       | 34       | 29       | 9     |
| 30     | 40       | 42       | 36       | 12    |
| 40     | 60       | 50       | 46       | 28    |
| 50     | 59       | 57       | 60       | 49    |
| 60     | 69       | 56       | 80       | 61    |
| 70     | 74       | 61       | 84       | 76    |
| 80     | 89       | 58       | 98       | 85    |
| 90     | 102      | 98       | 100      | 96    |
| 100    | 105      | 99       | 88       | 110   |
| 110    | 120      | 118      | 100      | 115   |
| 120    | 124      | 121      | 110      | 119   |
| 130    | 116      | 107      | 117      | 131   |
| 140    | 126      | 136      | 122      | 138   |
| 150    | 125      | 133      | 130      | 141   |
| 160    | 128      | 146      | 136      | 146   |
| 170    | 133      | 146      | 138      | 148   |
| 180    | 144      | 158      | 156      | 184   |
4. Conclusion
The mapping shows the flex sensor bending mechanism are mapped accordingly. Hence, the servo motor will capture the changes of the voltage reading accurately to exhibit even slight changes of movement.
The work will be refined in future paper to comprehend the pick and place testing phase.

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