CONTROLING MOVEMENTS OF A ROBOTIC ARM THROUGH CAPTURING AND REPLICATING MOTION OF HUMAN ARM

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ABSTRACT

Robotic arms are widely used in industrial environments to increase efficiency and accuracy. However, training these to follow a complicated sequence of movements to achieve a specific task could be very challenging. As an alternative, this paper presents a design that control the movements of a robotic arm by capturing motion in a human arm and replication that motion in a robotic arm in real-time. This is particular useful to gain high lifting capabilities or reach and operate in hostile environments. The motion of the human arm was modeled with four joints moving in vertical and horizontal planes over limited ranges, and is captured using a wearable structure constructed of insulated lightweight acrylic material. The captured motion is processed by a control unit and use to control the movement of an electro-mechanical arm, constructed with aluminum and wood. The resulting motor control signals are recorded to re-create the movement sequence off-line, giving the capability to train a robotic arm to follow a pre-defined set of fine movements, repeatedly if necessary. The user can toggle between real-time and recorded movement replication modes.

***Key words*:** Movement Replication, Robot Arm, Motor-drive, Motor control, Capture motion sequence

1. INTRODUCTION

Robotic arms are increasingly used in industrial environments to enhance productivity and efficiency. In addition, these are capable of operating over long periods of time, repeating the same movement with good accuracy and operating at high speeds and high lifting capabilities. However, programming a robotic device to follow a complicated sequence to movements is very challenging. Instead, a unit can be designed to learn a sequence of movements, through manually moving the robotic arm itself or using some other human machine interface.

In this paper, we present a design that controls the movements of a robotic arm by capturing motion in a human arm and replication that motion in real-time. The motion of the human arm was modeled with four joints moving in vertical and horizontal planes over limited ranges, and is captured using a wearable structure constructed of insulated lightweight acrylic material.

The user inputs the physical movements to an arm shaped unit fitted with sensors at every joint, each corresponding joint movements are converted into the digital domain and processed through a control unit. These captured movements are replicated in real-time in the electro-mechanical arm, where each joint in maneuvered by a servo motor. In conjunction with this a motor control signals recording unit records the digital pulses such that when the digital pulse stream is played back it emulates the exact movement of the learned motion sequence. This approach eliminates the need for an expert programmer and gives the freedom for a trainer to work in any kind of environment, in addition the unit can work in real time and off-line which enhances the versatility of the robot arm to be used for a variety of applications.

The rest of the paper is organized as follows. The section 2 presents the design of the motion capturing unit and the electro-mechanical arm. Section 3 presents the motion sequence recording of the robot arm. Section 4 describes the conclusion of the research and finally section 5 presents the references used in the research.

2. DESIGN AND IMPLEMENTATION

Our design is mainly divided into three units. First unit is the Motion Capturing Unit. This unit is used to capture motion sequence of the human arm. Second unit is the Control Unit & User Interface with Power Supply. This is the unit responsible for the basic controlling of the Mechanical Robot Arm and the conversion of the current. Third unit is the Electro Mechanical Robot Arm and this is the main part of our project. By using the servo motors it will replicate movements of the human hand. Figure 1 shows the diagram of basic transition and unit contents.

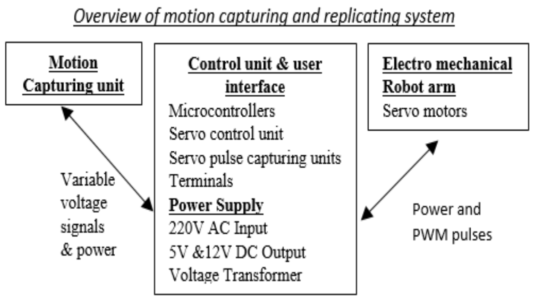

Figure 1: Overview of Motion Capturing and Replicating System

2.1 Motion Replication Unit

In this unit we are using a motion capturing wearable structure as show in Figure 2 to replicate the motion sequence of the human arm.

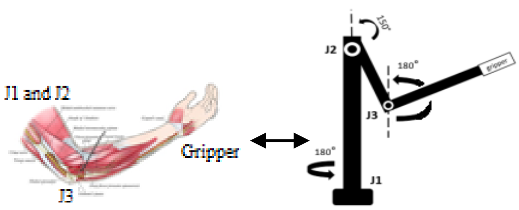

Figure 2: Motion Capturing Wearable Structure side by side comparison with Human Arm

The motion capturing unit has four variable resistors, each positioned at joints J1, J2, J3 and gripper, so each joint should have a theoretical capturing capability of 270^0 but due to motor rotation limitations we only allowed maximum 180 degrees for joint freedom. As shown in figure 2 human arm had been matched accordingly to the motion capturing wearable structure. In here the joints J1 and J2 taken separately to represent the human shoulder movement because the design will be more complex if its shown by a single joint. Table 1 presents the motor rotation capability at each joint in the motion capturing unit.

Table1:

Capture/Replicating Ability of the Motors Used

Joint Reference	Correspondin g Motor	Capture/Replicating Ability
J1	M1	180° of rotation – horizontal plane
J2	M2	150° of rotation – vertical plane
J3	M3	180° of rotation – vertical plane
Gripper	M4	Only horizontal gripping capability

To assist the coding process we made a rudimentary device with a variable resistor and a 360° protractor then we used the analog to digital converter and the UART module of the PIC to get the range of converted values with varying angle. The plot between the angle and the voltage is shown in the Figure 3.

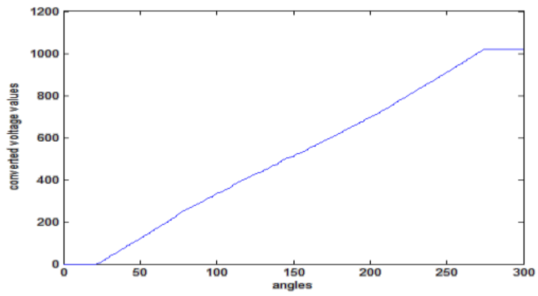

Figure 3: The plot of variable voltage bits varying with angle

2.2 Mechanical Robot Arm

The mechanical arm has a wooden base where a vertical aluminum pedestal is attached to a servo motor through a bearing razor as shown in figure 4. 2D diagram of this is shown in figure 5 also.

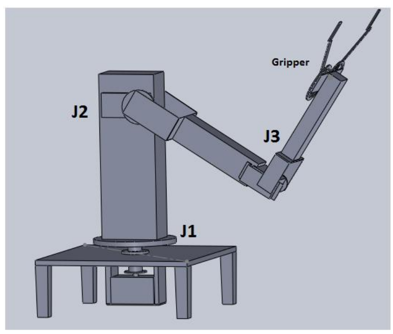

Figure 4: Mechanical Robot Arm Unit

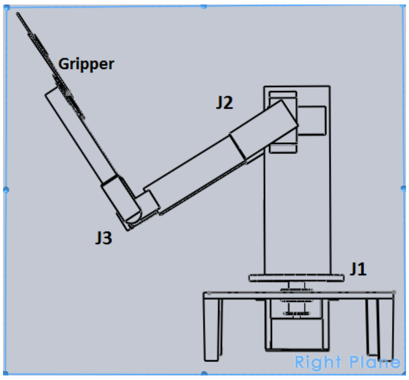

Figure 5: Mechanical Robot Arm Unit 2D View

The gripper section is shown in figure 6 below uses two rubber padded claws which are hinged to two nylon cogwheels meshed together , one of the cogs are attached to the spline of a servo motor. So accordingly two cogs will rotate to get the required grip from the rubber padded claws.

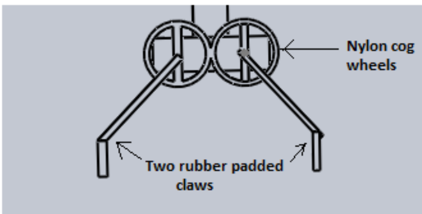

Figure 6: Mechanical Robot Arm Unit

Since we used servo motors with limited torque selecting the dimensions of the robotic arm was difficult so we had an imaginary target lifting load of 500g and did the calculations starting from the gripper section all the way down to the base of the arm. Torque calculations are based on the following equations.

Gripper

$$F = \mu R \text{ [Eq. 01]}$$

F = Friction between rubber gripper and plastic

μ = Coefficient of friction between rubber and plastic

R = Normal force

$$T = 2ml \text{ [Eq. 02]}$$

T = Torque of the gripper

l = Gripper length

m = Mass of the target lifting object

Motor at joint J1

$$T_{J1} = m_l m_a m_{m1} x_1 \text{ [Eq. 03]}$$

T_{J1} = Torque required at joint J1

m_l = Weight of the load

m_a = Weight of the arm

m_{m1} = Weight of motor on J1

x_1 = Distance of centre of gravity from the armature

Motor at joint J2

$$T_{J2} = m_l m_b m_{m2} x_2 \text{ [Eq. 04]}$$

T_{J2} = Torque required at joint J2

m_l = Weight of the load

m_b = Weight of the elbow panel

m_{m2} = Weight of motor on J2

x_2 = Distance of centre of gravity from the armature

The same motor is used for joint J2 and joint J3 since the vertical pedestal does not change the torque so the same equation will be used for joint J3. Table 2 represents the calculated torque values for the each section using the above mentioned equations.

Table 2: Specific Torque Requirement for each joint

Joint	Torque(kgcm)
Gripper	0.7
J1	0.7494
J2	3.148
J3	3.148

Table 3 represents the information about the motors we planned to use in our project. Motor selection for each part will be based on this given data.

Table 3: Specifications of Each Motor That Are Using

Motor	Stall Torque at 4.8V(Kgcm)	Device Weight(g)
Tower pro sg90	1.8	9
Tower pro sg5010	8.0	38
Tower pro mg995	8.5	55

Table 4 represents the selected motors for each part of the arm according to the data given in Table 3.

Table 4: Selection of Motors Which Are Used For Each Joint

Joint	Motor
Gripper	Tower pro sg90
J1	Tower pro sg5010
J2	Tower pro mg995
J3	Tower pro mg995

The servo motor control unit has a microcontroller clocked at 40MHz , the analogue to digital converter module converts the varying voltages into digital values which acts as the limit for a loop which switches the state of a bit from 0 to 1 creating a square wave .

Variable voltage α loop switch's frequency. Switch's frequency α pulse width. Pulse width α servo's angular movement. By altering the switching delay time in the code we can fine tune the movements of the servo. All of our servos respond to a pulse width range of 600 – 2400us

3. MOTION SEQUENCE RECORDING

The servo pulse recording unit utilizes 4 entry level microcontrollers clocked at 20MHz which captures and writes the servo pulses using the CCP (capture and compare module) of the microcontroller and stores in its EPROM with a speed of the oscillator. When replicate mode is activated then uses the values to activate a similar loop switch as implemented on the servo motor control unit.

We discovered that instead of using a micro controller to record the servo pulses we can use a PC software for audio recording to record and play back the audio signal through an op-amp set to produce a peak voltage of 5volts but this method proved to be cumbersome and relatively expensive. We came up with two pulse recording techniques so at a point it became difficult to decide on which technique should be researched and applied further.

Since there is a maximum chance of all 4 motors working at the same time we designed our power supply to provide a peak current output of 5 amperes, it also facilitates four 5V main outputs, one 5V output and one 12V output. A 220V to 12V voltage step-down transformer was used and a bridge full wave rectifier with a smoothing capacitor was used. All motors can work on either 6V or 4.8V but we opted for 5V to reduce the complexity of the power supply. Table 5 describes the current and power consumption of the motors and the main units.

Table 05: Current and Power consumption of the motors and the units

Part	Supply Voltage	Peak Current	Peak Power
M1	5	1500	7500
M2	5	1500	7500
M3	5	1200	6000
M4	5	600	3000
Controller Unit	5	100.5	502.5
Capturing Unit	5	50	250

According to parameters in the Table 05 total peak power consumption assuming that all the components are working at full load is 24.753W.

4. CONCLUSION

This movement replication robotic unit holds the promise for easy and effective use. The remote and ergonomically shaped wearable structure enables the robot arm to be in one condition and the user in another condition and the angle response and pulse recording interval can be altered accordingly. Therefore this whole system can be used in many industrial applications where accuracy and ease of usage is required. This unit also can be further developed by changing the simple gripper into a more complex structure like human hand.

5. REFERENCES

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