A Novel Design of an ATmega32L Microcontroller Based Controller Circuit for the Motion Control of a Robot Arm Actuated by DC Motors

Enaiyat Ghani Ovy, Shakil Seeraji, S.M.Ferdous, Mohammad Rokonuzzaman

***Abstract*— Articulated robots are generally driven by electric motors where proper controlling signal with proper time synchronism are needed to have control over the movement of the robot. Electric motors employed for the motion control must be operated sequentially and with certain time duration. This paper discusses the motion control of an articulated robot which can be used for precise positioning having applications in various industries. Necessary conditions for the precise positioning of an articulated robotic arm are determined, and ways to control the hand based on these conditions are proposed. A controller circuit is designed which is based on ATmega32L microcontroller for controlling the motion of the motors. It ensures greater accuracy, better speed, flexibility, reduced circuit size and more economical operation than any other control circuit. The whole system is operated by three DC motors which are controlled by H bridge circuits. The controller circuit has been designed and implemented to control the three degrees of freedom of the articulated robot arm.**

***Index Terms*— ATmega32L Microcontroller, DC Servomotor, Seven Segment Display, Opto-coupler.**

I. INTRODUCTION

A robotic arm can be defined as a robot manipulator, usually programmable, with similar functions to a human arm. The links of such a manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. Robot arms are being used in today's world for several industrial automation processes. The precise control of each degree of freedom of a robot arm is a great challenge in implementing industrial work. Many significant researches are notable for controlling a robot arm.

Lygorouas et al. [1] developed a computer-controlled light-weight mechanical arm. This mechanical arm was a self-contained, autonomous system capable of executing high-level commands from a supervisory computer. The actuators of the joints were permanent magnet type dc motors driven by servo-amplifiers via Pulse Width Modulation. Aung [2] designed and implemented a controller circuit based on PIC microcontroller and H bridge circuit to control the motion of a Wheeled Mobile Robot (WMR). He used MATLAB software for the modeling of the total system. Silva [3] applied fuzzy logic at several hierarchical levels of a typical robotic control system. For controlling robotic manipulators, Moosavian [4] used transpose jacobian (TJ) control. Arciniegas et al. [5] developed neural network based adaptive control system to control the flexible robotic arm. Tseng [6] developed a DSP based instantaneous torque controller to control the manipulator. Rogers [7] designed a microcontroller circuit for interfacing joint sensor to control robotic arm. A simple structured linked model of the articulated limb was developed where the model is manipulated in simulation to 'pull' the end of the limb towards the desired destination position and orientation [8]. Hisham [9] developed a PIC 16F877 micro-controller based system where an articulated robot arm having six degrees of freedom was controlled [9]. In this present work, an ATmega32L microcontroller based controller circuit has been designed to control the three degrees of freedom of an articulated robot arm. The robot arm is actuated by the three DC servomotors. A seven segment display and set of LEDs are used for indication purpose. Push buttons are set to give the necessary input commands. Programming language C is used to program the microcontroller which is written in AVR STUDIO 4 software.

II. MECHANICAL SPECIFICATIONS

Degrees of freedom: 3
Repeatability: ±0.5 mm at the end of arm (fully extended)

A. Specification of the DC Servo Motor

- Volt : 12V

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• Current: 2A (for motors used to rotate first and second arm) & 4A (for motor to rotate the waist)

Table 1: Mechanical capabilities

Joint	Maximum Angle(degree)	Speed(RPM)
Base	360	1500
First arm	90	1500
Second arm	90	1500

III. Different Movements

Three different movements have been employed in this system. They can be titled like:

- Waist Movement
- First Arm Movement
- Second Arm Movement

A. *Waist Movement*

The waist of the robotic arm is controlled by the spur gear mechanism which is placed in the base of arm. The DC motor is directly coupled with a pinion having 20 teeth. The pinion is meshed with a gear having 258 teeth. Hence the speed of the motor is decreased by around 13 times and the torque is increased by the same ratio. The gear holds the total assembly on it so that the assembly can rotate according to the requirements.

Fig.1 First DC motor is used in the set up to rotate the base.

B. *First Arm Movement*

Another DC motor is coupled with a worm reducer, which has a reduction ratio of 40:1. The worm reducer will transmit the power to the shaft. This shaft is connected to the first (lower) arm. So if the shaft rotates then the first arm will rotate accordingly.

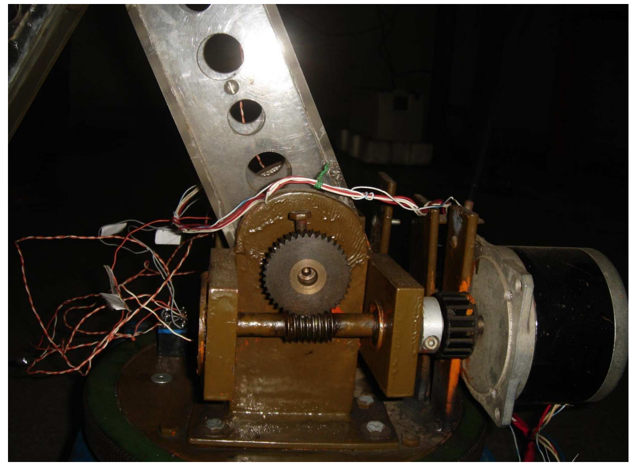


Fig.2 Second DC motor is used in the set up for moving the elbow up and down.

C. *Second Arm Movement*

A third DC motor is coupled with the second (upper) arm. This motor transmits the motion directly to the shaft which is connected to the second (upper) arm. This shaft rotates according to the rotation of the motor and the rotation of the shaft also causes the rotation to the second arm. In this case, the gear transmission system was not used to transmit the power to the second arm shaft.

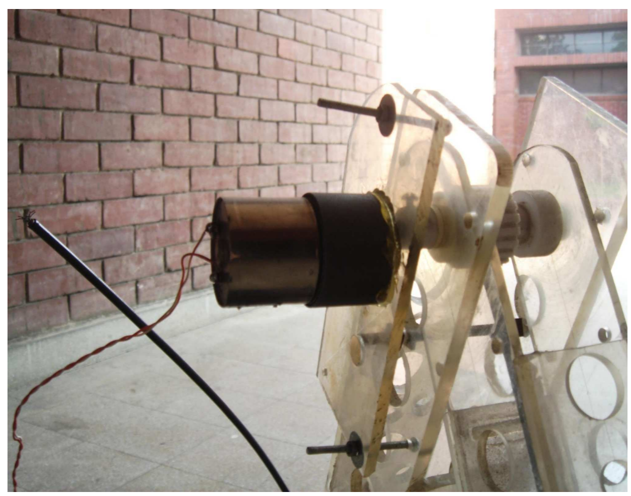


Fig.3 Third DC motor is used in the set up for moving the arm up and down.

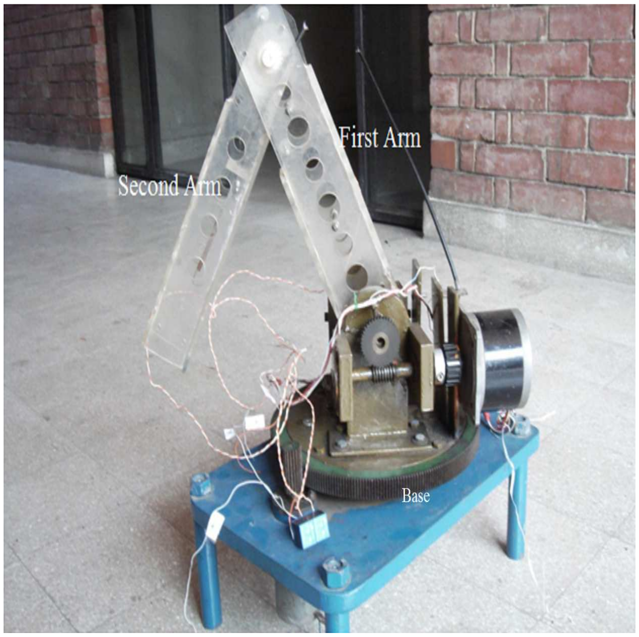


Fig.4 Mechanical structure of the robotic arm.

IV. DIMENSION OF THE ARM

The dimension of the first and second arm is shown here. The mechanical design is prepared by the Autodesk Inventor 2010 software.

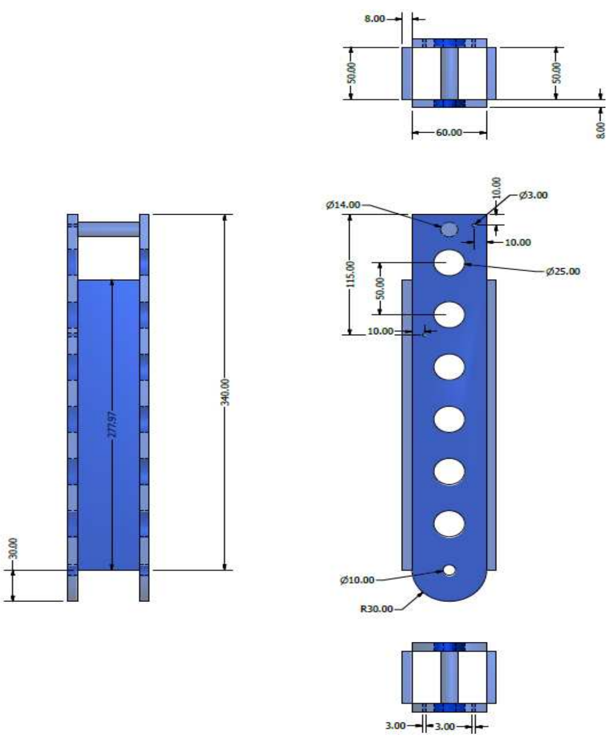


Fig.5 Showing the design of the first arm (dimensions in mm).

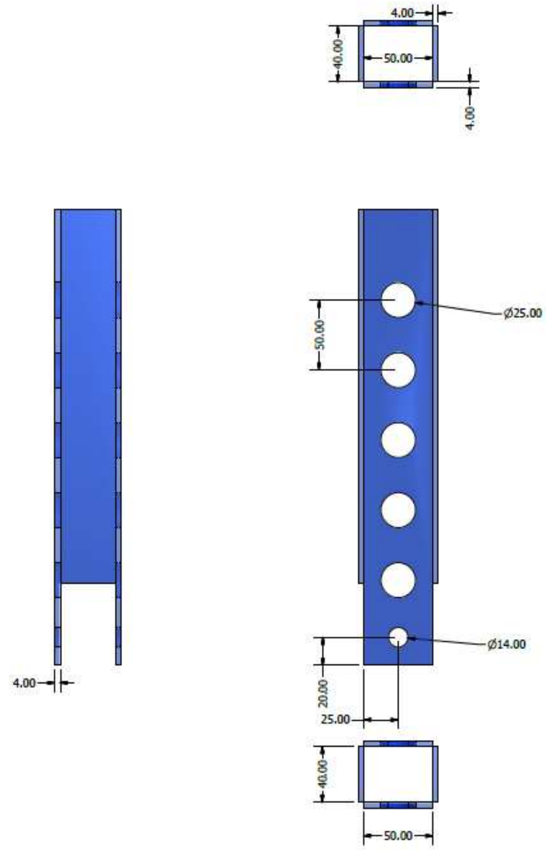


Fig.6 Showing the design of the second arm (dimensions in mm).

V. THE CONTROL STRUCTURE

The intelligence of the control structure is composed of a microcontroller ATmega32L manufactured by ATMEL, a 7447 BCD to seven segment display driver with 3 DC servomotors. The basic block diagram of the robotic arm with three different joints is given below. As it has been discussed in the earlier section the arm is capable of employing three different movements, and three DC motors are mounted on the joints which are responsible for these movements. First DC motor is used for rotating the waist. Second DC motor is used for moving up and down the first arm (lower). Third DC motor is used for moving up and down the second arm (upper). These motors will be controlled by user through microcontroller. The microcontroller is controlled by an external interface that will be operated by the user. This interface will consist of an array of ten switches which are durable and simple to use. User will be able to control the movements of each joint by pressing specific button or switch in the interface.

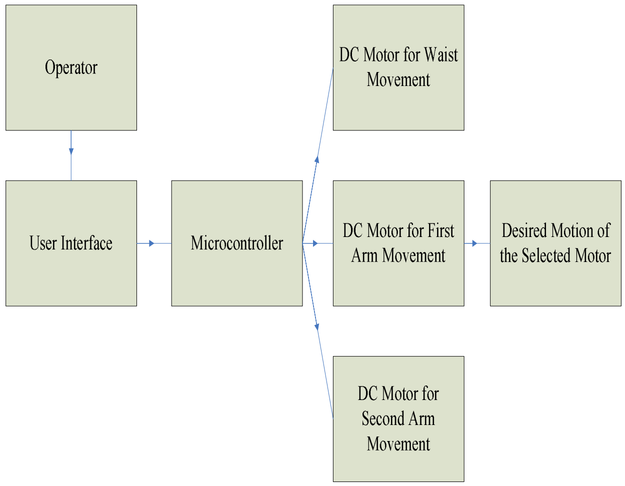


Fig. 7 Robotic arm function.

VI. User Interface

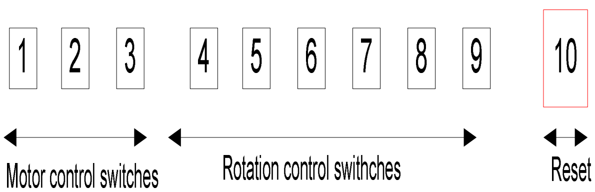


Fig.8 User interface of the system.

The figure shows the ten user interface switches for the system. Switch 1, 2, 3 are used for selecting the motor which to be activated. Switch 4, 5, 6, 7, 8, 9 are used for controlling the rotation angle of the selected motor. The degree of rotation of the DC motors can be controlled by the switches 4 to 9. If switch 4 is pressed then a lower rotation angle is selected for the DC motor. Then if switch 5 is selected a rotation angle is selected for the motor which is higher than the previous one. The process will be continued in the same way. Maximum rotation angle is obtained when switch 9 is pressed. Switch 10 is for resetting the whole system.

VII. Display Unit

A seven segment display device is used to display the number of the motor which is in operation at that time. A BCD to 7-Segment Decoder/Driver with Open-Collector Outputs is used with the seven segment display for displaying the data taken from the microcontroller.

VIII. Control Circuit

The detail design of the circuit is shown in the following figure.

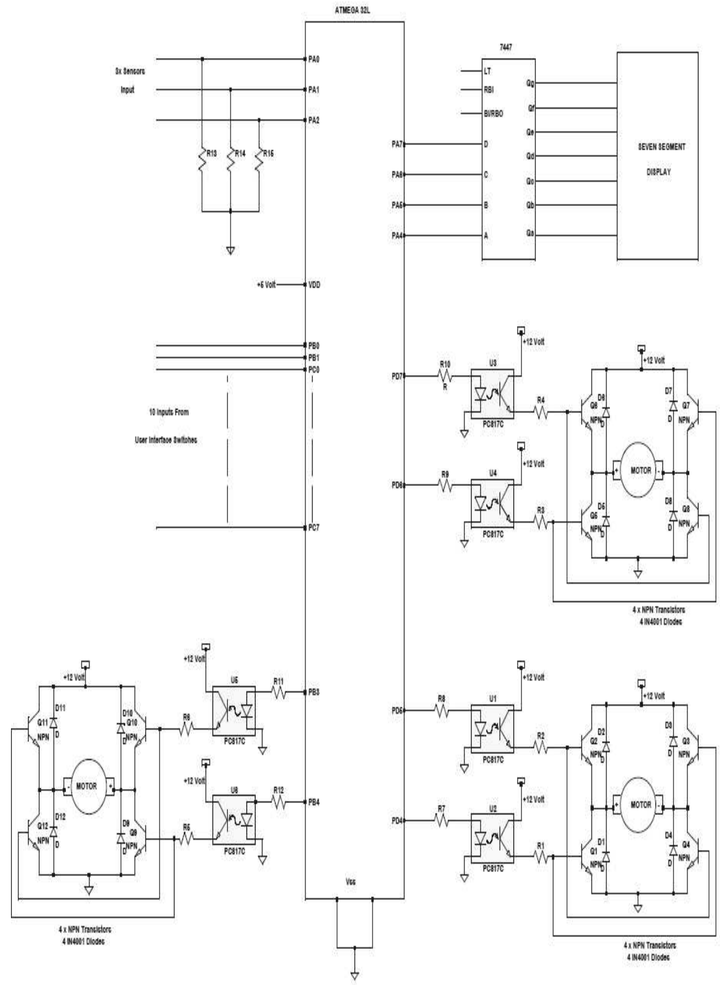


Fig.9 Circuit diagram of the articulated robotic arm.

The heart of the control circuit is the ATmega32L microcontroller. Three DC motors are driven by three H-bridge circuits. H bridge circuits are the driver for the DC motors. In each H-bridge circuit four NPN transistors are used as switch to change or choose the direction of current flows to the individual motor. Opto-coupler is used between each motor and microcontroller for isolation. For the feedback of this system three potentiometers are used which are connected to the ADC port of the microcontroller. IC 7447 is connected to the microcontroller which is the driver for the seven segment display. Inputs are given to the system through ten user interface switches which are connected to the ten pins of the microcontroller.

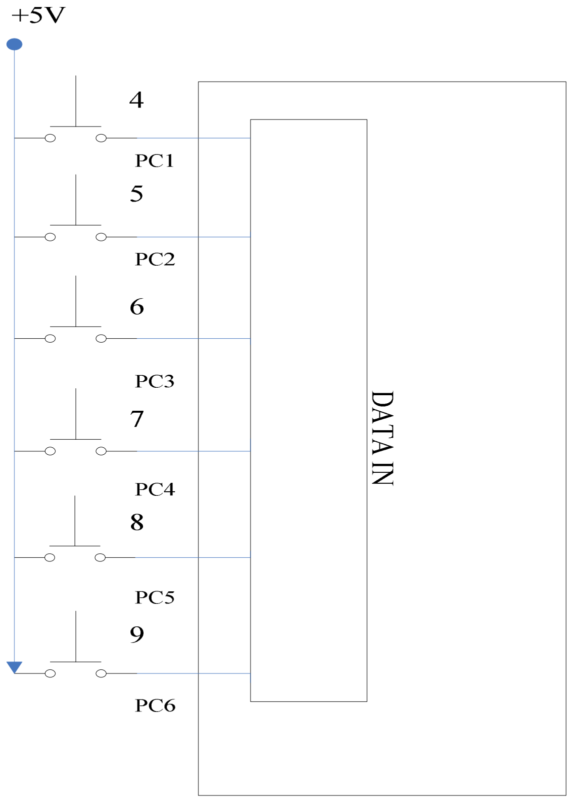


Fig.10 Schematic diagram of interfacing the pushbutton with microcontroller for providing input for the rotation of the motor.

Table 2: Input Command

Push Button	Digital data stored in the port PC1 to PC6	Angle of rotation of the base motor (degree)	Angle of rotation of the first and second arm	Remarks
4 5 6 7 8 9	000001 000010 000100 001000 010000 100000	60 120 180 240 300 360	15 30 45 60 75 90	Port PD7 or PD8 will be high for operating the base motor Port PD6 or PD4 will be high for operating the first arm motor Port PB3 or PB4 will be high for operating the second arm motor

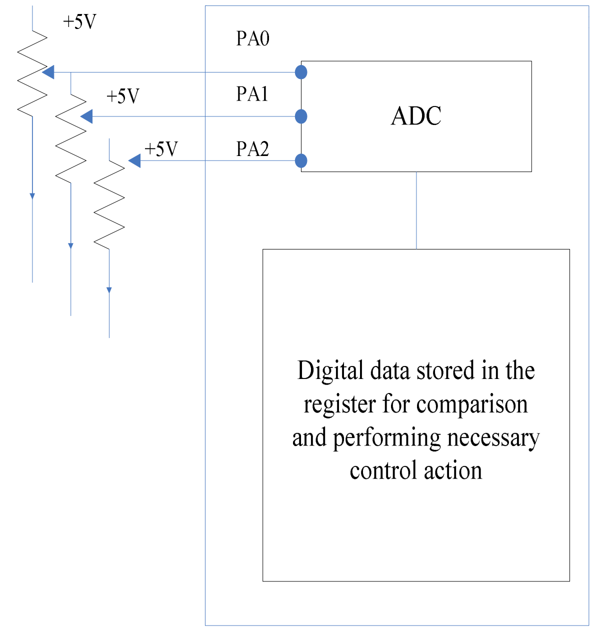


Fig.11 Schematic diagram of interfacing the feedback potentiometer with the microcontroller for detecting the angular position of the arm.

Table 3: Feedback data acquisition

Angle of rotation for first and second arm	Angle of rotation for base	Voltage across the potentiometer (V)	Output value generated by ADC	Equivalent digital value assigned to internal register	Remarks
0 15 30 45 60 75 90	0 60 120 180 240 300 360	0 0.833 1.666 2.499 3.332 4.165 4.998	0 171 342 513 684 855 1024	000 001 010 011 100 101 110	Respective output port will go to 'low' state

Input data are taken through PC1 to PC6 ports of the microcontroller where V_{ref} signal is generated. Depending upon the rotation of the motor, feedback voltage is taken through ports PA0 to PA2 from the potentiometer and equivalent binary data is generated. These are the feedback values of the voltage. Now by comparing the values of V_{ref} and V_{fb} the degree of rotation of the motor can be controlled. By developing programming algorithm, microcontroller can do the comparison as well as controlling work by taking the value of reference and feedback voltages.

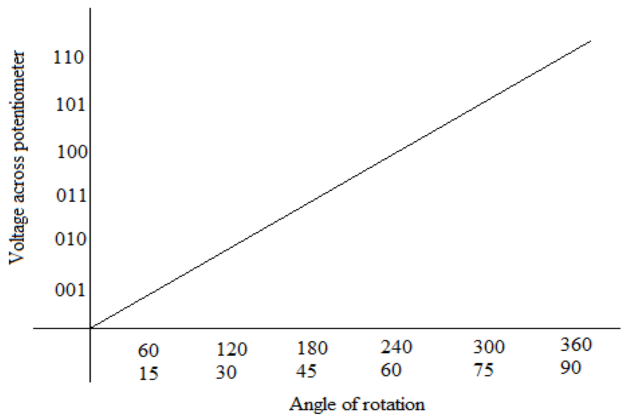


Fig.12 Comparison of analog voltage value to digital value.

Table 4: Implementation of the algorithm used for controlling the rotation of the arm

Input value of port PC1 to PC6	Logic for comparison	Value stored in register depending on the output of ADC	Motor arm response (Angle of rotation in degree)	Operation to be performed
000000 000001 000010 000100 001000 010000 100000	AND LOGIC	000 001 010 011 100 101 110	0 60 120 180 240 300 360	Respective output port operating the motor will move to low state to cut-off the power supply of the motor when desired amount of rotation is completed

Table 5: Motor operation

Motor sequence	Assigned output port	Output port activated for clockwise rotation	Output port activated for anti clockwise rotation
Base motor First arm motor Second arm motor	PD7 & PD8 PD6 & PD4 PB3 & PB4	PD7 PD6 PB3	PD8 PD4 PB4

IX. Software Flow Chart

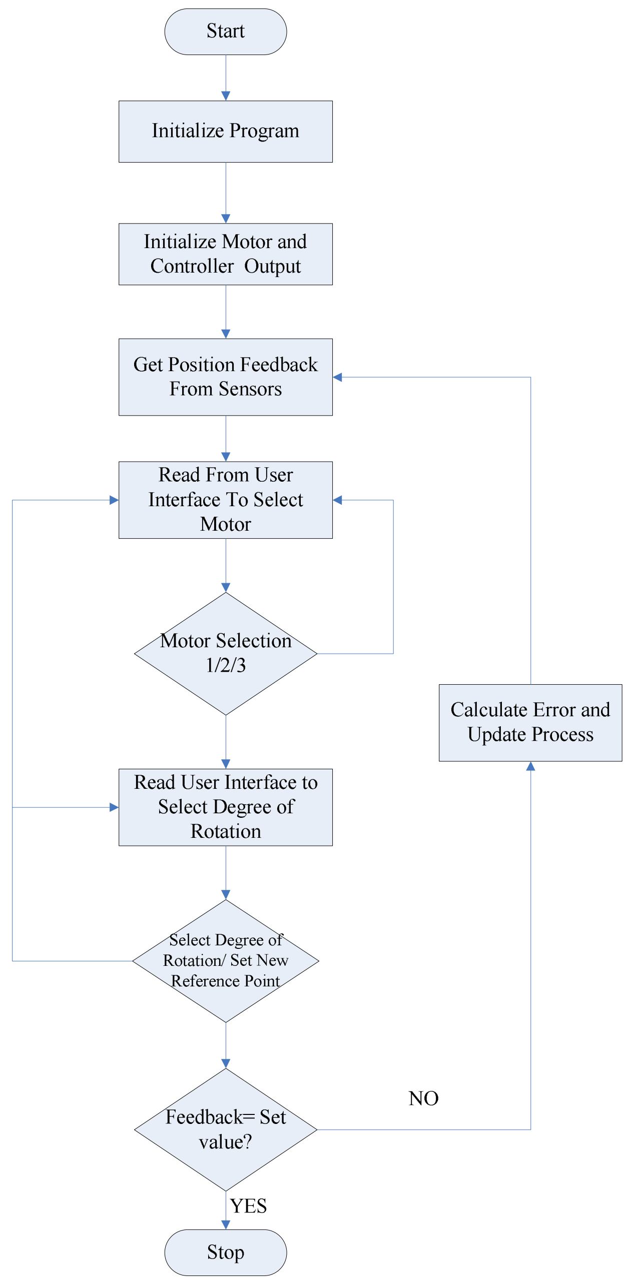


Fig.13 Software flowchart of the system.

X. Modeling and Analysis of the Robotic Arm

DC motor produces a torque T proportional to the armature current i_a,

$$T(t) = K_t i_a(t)$$

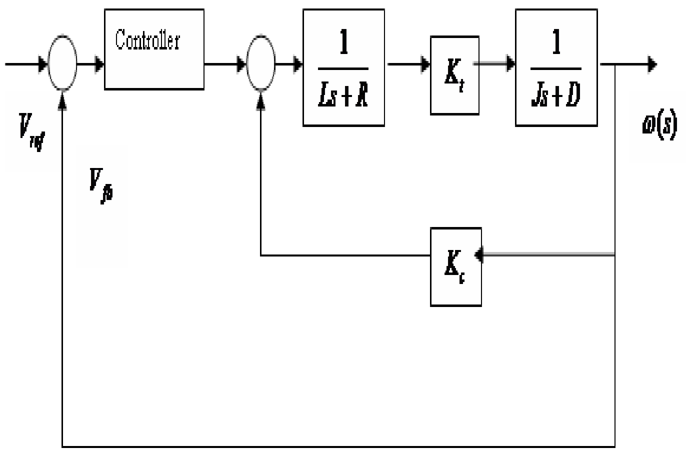


Fig.14 Block diagram of the system.

The back emf is proportional to the motor speed, ω

$$V_b(t) = K_e\omega(t)$$

Where

K_t = Torque Constant

K_e = Back emf constant

Applying Kirchhoff's voltage law,

$$V(t) = i_a R + L\frac{di_a}{dt} + K_e\omega$$

The mechanical load which is the robotic arm can be modeled as

$$J\frac{d\omega}{dt} = T - D\omega = K_t i_a - D\omega$$

Taking Laplace Transformation

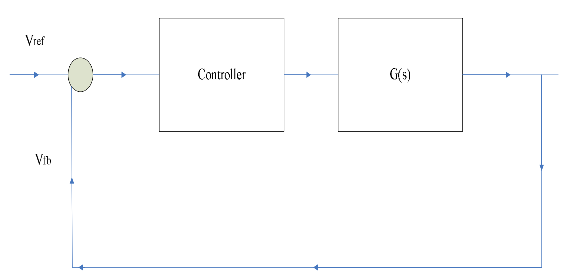
$$V(s) = (Ls+R)I_a(s) + K_e\omega(s)$$

$$J_s\omega(s) = K_t I_a(s) - D\omega(s)$$

From which the transfer function can be determined as

$$\frac{\omega(s)}{V(s)} = \frac{K_t}{(Js+D)(Ls+R)+K_e K_t} = G(s)$$

Now the whole system can be modeled as



The controller has a gain of 2.4 (as it is the driver opto-coupler changing 5V to 12V). The total transfer function can be obtained as

$$T(s) = \frac{\omega(s)}{V_{ref}(s)} = \frac{2.4K_t}{(Js+D)(Ls+R)+K_e K_t + 2.4K_t}$$

$$= \frac{2.4K_t}{JLs^2 + JRs + DLs + DR + K_e K_t + 2.4K_t}$$

$$= \frac{2.4K_t}{JLs^2 + (JR+DL)s + DR + K_t(2.4+K_e)}$$

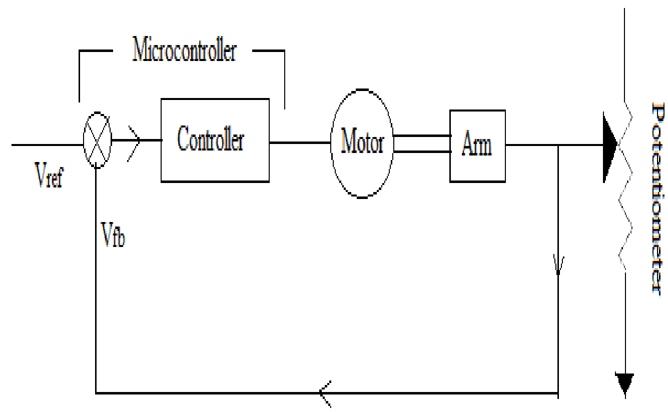


Fig. 15 System block diagram representing one dc motor coupled with the mechanical load.

The step response of the arm is simulated and obtained using MATLAB. The response curve of the base, first and second arm due to a step signal is shown in fig.16, 17, and 18 respectively. The system behaves in an under damped manner defined by the curves shown. The step time or the rise time is 0.02s which is highly dependent on the ratio of the torque to inertia (load) as well as the type of driver used. High value of torque causes a high acceleration, which causes overshoots and ringing as can be seen in the curves. The system has certain amount of overshoots and needs some time to settle down. For this system this much of overshoot and oscillation can be allowed to have a quick rise time. A critically damped response would be more desirable but it will give a lower rise time or step time. From the response curve, the accuracy of the rotation of the motor can be observed. The rotation of the motor is almost 1.3 degree for a step signal generated which is very close to one degree of rotation angle. There is steady state error which causes the amount of rotation a bit higher for each step signal. In this system no compensator was used. Using a PID controller this much amount of error can be avoided.

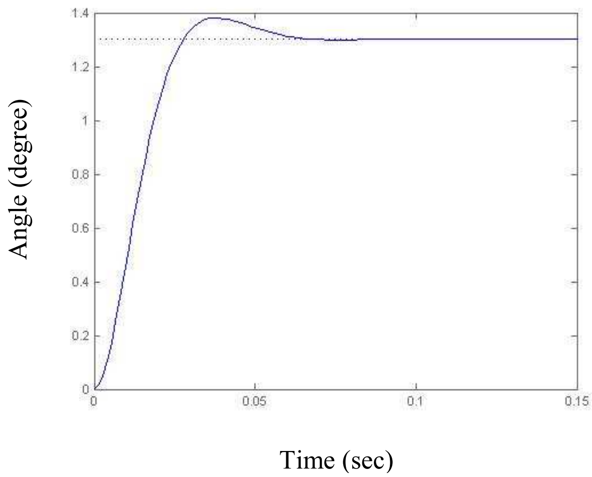


Fig.16 Step response of base.

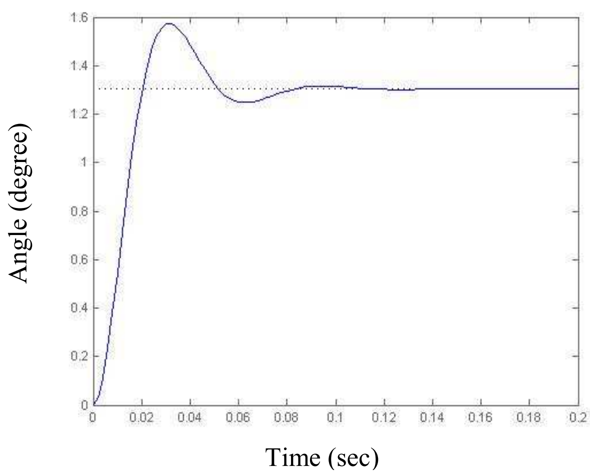


Fig.17 Step response of the first arm.

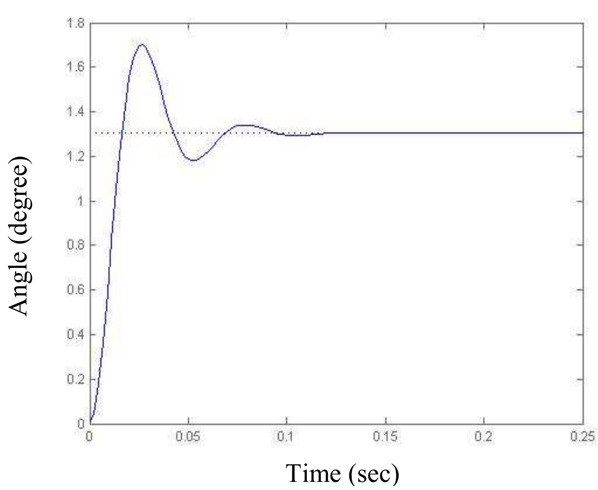


Fig.18 Step response of the second arm.

XI. CONCLUSION

In this paper, concentration has been focused to design a microcontroller based circuit for the overall control of the robotic arm. Three degrees of freedom of the arm is controlled by the circuit developed. End effectors design is not considered here as the main purpose is to implement the robot arm in spot welding which will be controlled by the microcontroller based circuit. The logics and facts are carefully introduced in the microcontroller programming. The modeling and analysis of the arm is also done by the established equations and MATLAB. In this presented work no compensator was used. Steady state error and overshoots found in the obtained response curves can be minimized by using a PID controller. Adaptive fuzzy logic and neural networking techniques will be implemented in future to minimize the system errors. With the help of the DC servomotor as well as microcontroller precise positioning is achieved which gives a positive direction towards the industrial automation.

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