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Design and Development of An 3-Axes Robotic System With Intelligent Sensing Mechanisms

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Abstract : The paper presents the design and fabrication of each part and construction of a stepper motor driven three-axes stationary articulated robotic arm with indigenous components and to control it with a personal computer. The work was carried out as a sponsored project taken up by the students of PDA college of engineering under the guidance of the professors. The main objective of this work was to design a prototype of an intelligent educational stationary robotic model that can do pick and place of objects in its workspace from the source to the destination by avoiding the obstacles in its path of motion.

Keywords : DOF, Stationary Robot, PNPO, Obstacle avoidance, Sensing mechanisms, Payload, Microcontroller, Stepper motors, Interfacing units, Drivers**.**

I. INTRODUCTION

Robots have in a short span of time, became man's most fascinating creations. The field of robotics has influenced almost every sphere of science. And the ever-growing interest in robot technology ensures that this influence continues to grow. Keeping this in view, we have designed & fabricated a unique 3-axes robotic system with indigenous components. The primary motive behind the work was to develop a modular educational robotic system with the help of locally available components and sub-systems as shown in Fig. 1. This paper deals with the design, fabrication and implementation of a 3-axes PC based stationary robotic system with a sensor interface for doing a manipulation task such as a pick and place task without human intervention, thus making a educational prototype model for the college laboratory.

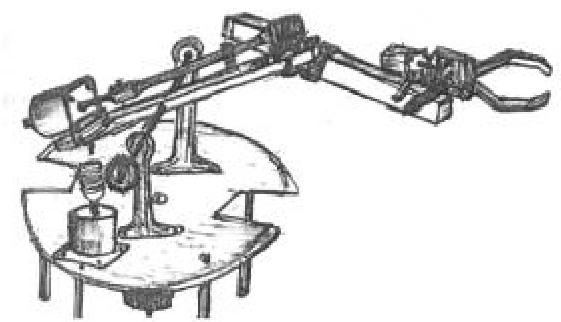

Fig. 1 A view of the designed & fabricated robot arm

The main highlight of this system is, the entire system is made from light, junk, unused and scrap materials. A provision for sensing the limits of the joints, the hard home position of the robotic system was designed & developed in the college laboratory. The designed & fabricated robot has got 3-axes / 3 DOF**.** 3 actuators (stepper motors-Base Motor BM, Shoulder Motor SM, Elbow Motor) are used to control the 3 joints, while the gripper is controlled by another stepper (Gripper Motor GM) for opening and closing of the 2 jaws, inside which 2 limit switches are used for sensing the object in between the fingers. The 3 joints are named as base, shoulder and the elbow. Sensors are used at the various joint positions to sense the position & orientation of the arm.

The developed sensor system consists of limit switch sensing circuit, a reset detection circuitry for the stationary robotic system, thus making the system a closed loop control system. Sensors are feedback devices, which are used to sense the maximum limits of various actions like gripper close / open; sense the dead ends of the joints of a robot, thus making it very intelligent. They are used to sense the changes in the environment (detect the obstacles) and get adaptable to the environment (overcome the obstacle and proceed to the destination). At each and every joint, worm and worm gear mechanisms are used in order to prevent the arm from falling down due to gravity and also to act as a locking device.

A circuit is used to generate the control signals in order to control the CW / CCW movements of the motors and also the ON / OFF control of the steppers. The generated control signals are given as input to the driver circuits through the input - output card of the 8255 IC chip. The ports A, B, C of the 8255 are used to send and take the signals in & out of the microcontroller. A driver circuit mainly consisting of a sequence generator, switching circuit, a 555 timer IC and a power supply is also used for control purposes. The speed of the stepper motor is controlled by varying the potmeter by increasing the clock frequency & consequently reducing the torque. The entire robotic structure is divided into 3 parts, viz., the mechanical assembly, electronic assembly and the software unit.

The entire mechanical assembly of the robotic system is being divided into 3 parts, viz., Base assembly, Arm assembly, End-effector (Gripper) assembly. The entire electronic assembly is divided into power supply unit, controller unit, the driver unit and the sensing unit. Controller unit, which consists of a IC circuitry to give proper control signals to the robotic system for satisfactory operation. The data to the control unit comes from computer through the port interface. A train of clockwise and anticlockwise switching pulses is generated by the controller, which in turn is given as input to the stepper motors.

The software part is entire written in the assembly language. A truth table & K-map was also designed for the pulse sequence generator. Ultrasonic sensors are mounted at 4 points on the links to prevent the collision of the robot with the obstacles. These sensors give a signal to the computer through the computer port & the computer in turn processes this signal & in turn avoids the collision by turning the arm in another direction. Limit switches are used at the inner surfaces of the grippers to sense whether the gripper has held / picked up the object properly or not. A brief direct kinematics, inverse kinematics, work space analysis and trajectory planning was also performed on the designed and fabricated system.

The paper is organized in the following sequence. In the previous section, a brief review of the system was presented. Second, the overview of the work and thirdly, the specification followed by mechanical design, electronic design, software design is presented. The control scheme & logic is explained in section 5. Finally, the conclusions are drawn followed by the references.

II OVERVIEW OF THE ROBOT SYSTEM

The design, fabrication and implementation of the work was divided into four stages, viz.,

- Design and fabrication of the mechanical hardware of the robotic system (Base-Arm-Gripper assembly) : This comprises of the entire mechanical linkages with the rotating base, the up / down motion of the arm (shoulder), the up / down motion of the arm (elbow), which serve as the major axes and a gripping mechanism for picking and placing of the objects.
- Design of the electrical / electronic hardware for the robot system : This comprises of the various electronic circuitries that are used to interface the mechanical system with the computer and to drive the motors.
- Development of the control software and various algorithms in order to control the entire designed and fabricated stationary robotic system.
- Integration of all the above three stages to perform an application such as grasping of objects from one place in one position and orientation and keeping it another place in another position and orientation.

III. SPECIFICATIONS

The specifications of the robot designed and fabricated by us are

- Degree of freedom(DOF) : **3-AXES.**
- Load caring capacity : **250 gms.**
- Overall weight of the system : 3 Kgs.
- Length of link 1 (upper arm) = 50 cms.
- Length of link 2 (fore arm) = 40 cms.
- Height of the shoulder from the base = 40 cms.
- Work space : Hemisphere.
- Joint parameters : Joint angle (θ) = {θ_1, θ_2, θ_3}.
- Stepper motor : 12 V DC, 1.5 A / phase, 200 rpm.

IV. MECHANICAL DESIGN

The entire robot arm consisting of base, shoulder, elbow and the gripper is mounted on a rotating base, which is fixed to the center of a shaft of the base motor and in turn to a bottom thick plate which is supported by 4 legs as shown in the Fig. 1. The base motor shaft can rotate about its central axis thus, providing the revolute motion for the base joint. The motion is actuated using a steppers.

On the rotating base plate, the shoulder motor, elbow motor is mounted and power is transmitted from the motors to the respective joints via the guide rails and the worms. Worm and worm wheel arrangement is used for the shoulder and elbow joints because even when the arm is in the intermediate position, it won't fall down and thus acts a locking mechanism. This type of mechanism is used because of the inherent locking facility associated with the worm and worm wheel., i.e., when the motor shaft and hence the worm stops rotating, the shoulder and the elbow links gets locked in the positions they held before the motor was stopped. Links are made of light aluminum, so that the overall weight of the arm is less and hence, the MI is less. At the end of the arm is a parallel jaw gripper operated with a stepper motor connected to a 2 jaw opening / closing arrangement as shown in the Fig. 1. Two limit switches are provided in the inner faces and outer surfaces (extreme ends) of the gripper to prevent the further motion of the fingers / jaws of the end-effector in order to see that the object does not get crushed.

V. ELECTRONIC DESIGN

The mechanical set-up forms the skeleton of the robot and what adds intelligence to it is the electronics and the software module. Electronics and software go hand in hand. Without the electronics system in place, the software has no scope and without software the electronics system is a waste. The electronic system involves many electronic and logic circuits to take care of functions like control, drive, interface, display and feedback. Electronic system consists of various cards like the power supply card, controller card, driver card, interfacing card, display card, sensing and the feedback cards, timers, sequence generators, switching devices such as the MOSFET's, etc.,.

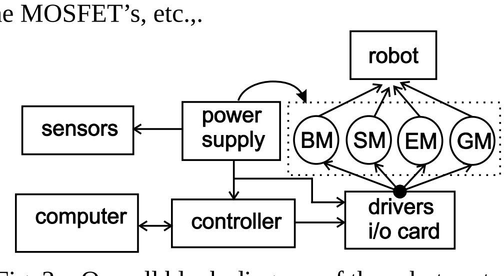

Fig. 2 Overall block-diagram of the robot system

The block-diagram shows the closed loop control system of the robotic arm control system. PC is used to generate the control signals in order to control the CW and CCW movements of the stepper motor and also the ON / OFF actions of the stepper motors. The generated control signals are given as the inputs to the driver circuits through the input-output card of the 8255.

In order to send the control signals, we are using the port addresses (Port B) as the output ports and the output ports draw 2.5 mA current. The driver circuit mainly consists of the sequence generator, switching circuit, timer (555 timer), power supply. The speed of the stepper motor can be controlled by varying the pot-meter by increasing the clock frequency, thus consequently reducing the torque. As per the requirement to lift the object and place it somewhere as desired, the program will be changed, i.e., increasing or decreasing the movement of the arm or ON / OFF signals, thus performing a specified task repeatedly.

In order to control the stepper, we require a sequence, according to the sequence, motor will rotate if the sequence is in one direction and if the sequence is reversed, motor will rotate in the anticlockwise direction. The driver unit has been designed according to the motors specifications. The timer is designed to generate the clock signals that drives D F / F, the output of the timer will be given to the sequence generator which includes DF / F Ex-OR gate and NOT gate. By using these gates, we generate the stepper motor control sequence according to the design.

MOSFET's are used because of high switching speed upto 1 MHz. These MOSFET's can be controlled by varying the voltage at the gate. The stepper motor specification is 12 V DC, but the sequence generator will produce 3.5 V, which is insufficient to turn on the stepper motors, so in order to increase the voltage at the gate, a 470 Ω resistor is connected to the V_{cc}, which will enhance the gate voltage, so that in turn, the drain current increases which is sufficient to drive the load. A diode IN 5402 (FWD) is connected across each winding to protect the back emf induced in each winding. AND gate is used to control the turn ON / OFF of the stepper motors.

The 555 timer IC is used in the astable mode, such that it will trigger itself and free run as a multivibrator. The external capacitor charges through R_A and R_B and discharges through R_B. Thus, the duty cycle may be precisely set by the ratio of these two resistors. In this mode of operation, the capacitor charges & discharges between 1/3 V_{cc} and 2/3 V_{cc}. As in the triggered mode, the charge & discharge times & therefore the frequency are independent of the supply voltage. The specifications being V_{cc} = 5 V, Time = 20 μS / Div, R_A = 3.9 KΩ, R_B = 3 KΩ, C = 0.01 μF. The charging & the discharging time is given by $t_1 = 0.693 (R_A + R_B)$ & $t_2 = 0.693 R_B C$. The duty cycle of the designed circuit is given by $D = R_B / (R_A + R_B)$. A regulated power supply is designed as shown in Fig. 3 to give a 5 V / 12V output at 5A and used to supply the power to all the electronic circuits used in the robot control.

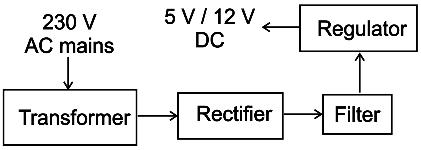

Fig. 3 RPS unit

VI. CONTROL SCHEME & LOGIC

The excitation sequence is generated by the control logic from the PC. For the designed RPS, we have used R = 600 Ω and C = 1000 µF, current ratio of $(I_{rms} / I_{DC}) = 1.11$. The sequence generator is designed as shown in Fig. 4 along with the truth table and the K-map simplification. The PCI-01 card which provides the bridge between the PCI bus and the peripheral bus is used as the interfacing medium. It enables the 8255 in the PCI-01 card to interact with the host system and provides the control, address and data interface for the 8255 to work as a PCI compliant peripheral. The I/O ports of 8255 are brought between the PCI bus and the peripheral bus. Three basic modes of operation is used for controlling the system, i.e., mode 0, mode 1 and mode 2.

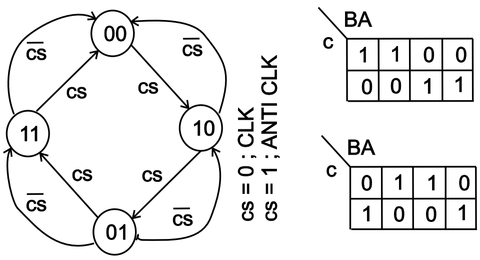

Fig. 4 Design of the sequence generator for motors

					Inputs		Motor
cs	QB	QA	QB + 1	QA + 1	DB	DA	Status
0	1	0	0	1	0	0	BM CW
0	0	1	1	1	1	1	BM CCW
0	1	1	0	0	0	0	SM UP
0	0	0	1	0	1	0	SM DOWN
1	0	1	1	0	1	0	EM UP
1	1	0	0	0	0	0	EM DOWN
1	0	0	1	1	1	1	GM OPEN
1	1	1	0	1	0	1	GM CLOSE

$$D_A = \bar{C}\,\bar{B} + CB = \overline{C \oplus B};\quad D_B = \bar{C}\,A + C\,\bar{A} = C \oplus A$$

Table 1 : Truth table

VII. Software

The robotic system designed, developed & controlled by the computer uses C++ language as the GUI. A code is written & is used to control the steppers and the control signals are generated by interfacing the I/O card to the PC. Input-output card consists of the 8255 PPI & we have used the PORT B to generate the signals, which are given to the driver unit. In the C++ code, initializing control word (CNTU_W080) is used to initialize all the ports (A, B, C). The algorithm for controlling the motors is developed as

1 Start
2 Initialize port address & control register address
3 Initialize port B as output
4 Rotate motors BM, SM, EM, GM in CW
5 Rotate motors BM, SM, EM, GM in CCW
6 If enter key is pressed, go to step no. 4, else
7 Stop.

VIII. CONCLUSION

A typical prototype of an educational robotic system was designed and implemented successfully in the college laboratory. Information about the work was gathered from various sources like libraries, web sites and project reports relating to robotics. The mechanical assembly (i.e., the base assembly, the arm assembly and the gripper assembly) was fully designed and fabricated indigenously in the workshop by us. The electronic driver interface between the computer and the robot was completed successfully and tested. Overall integration of the various systems such as the mechanical assembly, the electronic hardware and the control software for the successful implementation of the system was performed. The entire control software to control the robot doing an assembly operation was fully designed and tested and the robot was controlled using the PC in various modes. A brief kinematic analysis of the robot was also carried out. A number of pick and place operations were successfully performed by the developed robot by using teaching mode, manual mode and programming modes.

REFERENCES

[1]. Klafter, Thomas and Negin, "Robotic Engineering", *PHI*, New Delhi, 1990.

[2]. Fu, Gonzalez and Lee, "Robotics : Control, Sensing, Vision and Intelligence", *McGraw Hill*, Singapore, 1995.

[3]. T.C.Manjunath, "Fundamentals of Robotics", *Nandu Publishers*, *5th Revised Edition*, Mumbai., India, 2007.

[4]. Ramesh Gaonkar, "Microprocessor Architecture, Programming and Applications with the 8085," *Penram Int. Publ. Pvt. Ltd*., India.

[5]. Moris Mano, "Digital Logic and Computer Design," *PHI*, 2nd Ed., India.