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MICROPROCESSOR CONTROLLED ROBOT ARM FOR LIGHT ENGINEERING TASKS

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1. ABSTRACT :

Low cost microprocessor based robot arm has been designed and developed for light engineering tasks. The robot is small in size with three degrees of freedom (Revolute Configuration). The robot has been programmed using BASIC as high level language and 6502 based assembly language. It has been used for feeding handicapped people and can be programmed for some other simple tasks. The robot is controlled by 6502 microprocessor based BBC computer.

2. INTRODUCTION :

The design and decision making capability of the robot controller depends upon the nature of engineering tasks and the cost of the system. The task of extra mechanical complexicity would result in an increase in cost due to the requirement of more sensing devices and higher speed of the computer.

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The robot includes all the basic requirements necessary for a light engineering task. It is initialized automatically as the system is switched on and can also be initialized as required during the performance of a task. The vibration in the elbow and shoulder joints has been minimized by running the stepper motor in half step mode, refining the final signal given to the motors and by minimizing the play in the elbow joint.

The robot has been designed for maximum reach position of 500 mm measured from the center of its base plate to the end effector and load carrying capacity of 0.4 kg attached to the end effector with a position accuracy of +/- 2.2 mm for full step mode and +/- 1.1 mm in half step mode of the stepper motor. The robot can be run with three speeds i.e, slow, medium and fast. These speeds in radians/sec are :

ROBOT JOINT	SLOW	MEDIUM	FAST	GEAR RATIO
WAIST	0.105	0.206	0.306	11.27 : 1
SHOULDER	0.119	0.232	0.345	10 : 1
ELBOW	0.119	0.232	0.345	10 : 1

The waist, shoulder and elbow joints are capable of rotation at 0 - 315 degrees, 90 - 20 degrees and 20 - 150 degrees respectively. The total weight of the unit is 14.5 kg. The bulk of the programme is written in BASIC and the pulse generation routine to run the stepper motor is written in 6502 assembly language.

To keep the cost to the minimum, formica chipboard is used for the base of the robot and the waist drive motor and the waist axis bearing housing is mounted on it. The waist axis is driven by the two toothed pulleys, one mounted at the motor and the other on the bearing housing. The robot arm base plate is made of Aluminium and the robot arm is kept close to center of gravity. The arm mounting plate is made of mild steel and is designed to hold the arm weight when the arm is in the fully extended position.

The elbow and shoulder are fabricated from glass reinforced plastic (GRP). Although it has an inherent lack of stiffness but this lackness has been overcome by a competent design of the arm. The stiffness has been further improved by means of carbon fibre bounded in various directions to the inner surface of the arm.

3. DESIGN OF THE ROBOT :

Designing of a robot is a multi-disciplinary work i.e., mechanical, electrical and computer programming. In the following sections while the first two disciplines have been covered in more detail, the programming part has been given a peripheral treatment leaving to the details to be discussed else where {1} .

3.1 MECHANICAL DESIGN :

The robot is a revolute form with three degrees of freedom, [Fig 1]. Mechanically the built robot consists of, base of the robot, base plate of the arm, the arm mounting plate, the shoulder joint, the waist axis drive mechanism, the elbow joint and its transmission linkage.

The base of the robot is made of formic chipboard. It accommodates the waist axis motor and various interfacing hardware. The robot hardware is protected against overheating by the slots all around the base, [Fig 2] .

The robot arm base plate is designed to provide a rigid link between the arm mounting plate and the waist axis bearing housing so that the arm can be rotated along the "Z" axis, [Fig 1] . A slot is made at the top to guide the arm mounting plate and arm mounting plate is rigidly fixed to the base plate by means of bolts. A blind hole at the bottom side of the plate guides the waist axis pulley, [Fig 3] . The pulley is fixed at the bearing shaft by means of two Allen screws. The robot arm base plate is made of Aluminium and the weight of the arm is kept close to the center of gravity of the robot base plate to minimize the torque at the waist axis drive motor.

The arm mounting plate is designed to hold the arm in the fully extended position. Much consideration is given to keep the weight to the minimum and hence the inertia load for the waist axis motor, [Fig 4] .

The shoulder joint is the simplest joint in the said robot. The shoulder joint motor is matched to a gear box (S 30 G 05), fitted to the end of the motor. The gear box provides a reduction ratio of 10 : 1 and the upper arm is directly screwed to the gearbox with the help of an Allen screw and taper pin passing through both the shaft and sleeve [Fig 5] . This arrangement provides a rigid link and allows the shoulder to be positioned accurately.

The waist axis drive mechanism consists of two toothed pulleys, a toothed timing belt (180 XL 037) and a gear box (S 30 G05) attached to the stepper motor. The bearing unit consists of two angular contact ball bearing (CAT 7208 B TVPO) running back to back to bear thrust forces, [Fig 1] .

The elbow joint and its transmission linkage is the most complex joint in the robot, [Figs 6, 7] . The stepper motor used for the elbow joint is also used to keep the end effector in a horizontal position throughout the motion of the arm so that the fluid carried by it does not spill out of the spoon. The linkage is used to transmit drive from the elbow motor to the elbow joint and to control the motion of the end effector, [Fig 8] . The linkages are made from 3/16 inches steel rod with plastic end pieces secured by a screw, threaded to adjust its length. This allows to set the initial position of the end effector.

3.2 ELECTRICAL HARDWARE :

The electrical hardware of the robot consists of stepper motors, motor driver, and interfacing board.

The term stepping implies the action whereby these motors actually step from one position to the next. The existing motors to drive the arm are bipolars, four phases, hybrid type with the torque of 380 mNM, step angle of 1.8 degree and current per coil of one Amp. Each phase is excited by the unipolar current. If each phase is excited in turn, four steps are executed while the rotor moves one tooth pitch. Therefore, one step length corresponds to a quarter tooth pitch.

Phases of these motors can be excited in different ways depending upon the requirement of the system. For example if the requirement of the system is to improve torque them it can be done by exciting several phases at a time but it will need more power. If two phases of the motor are excited at the same time, [Fig 9] , the power supply must be double in capacity but the torque produced will be increased by a factor of 1.4 {2} . This means that by exciting two phase simultaneously there is a net gain in torque per watt of about 20% with a maximum of 40%. If the four windings of the motor are energized then the sequence is called wave drive, [Fig 10], and successive steps will have the normal spacing of 1.8 degree. If a drive is used that alternates between the wave type and the two phase drive, [Fig 11] , the stepper motor output will be half the normal step {2} . The half step mode reduces resonance problems and also the arm can be positioned to an accuracy of double of full step mode but the torque of the motor is reduced by 30% to 40% of full torque of the motor.

The motor driver or State Generator is used for changing the charging pattern of interactions between the rotor magnetic field and the stator magnetic field {2} . The function of the state generator is to create the proper sequence and pattern of states in response to the serial pulse train produced by the BBC microcomputer by using the developed programme. To drive the stepper motors a chip SAA 1027 is used to create the logic sequence for full step mode. This chip is supplied by the stepper motor vendor. It has two inputs, one for the direction (pin 3) and the other for the clock (pin 15) , [Fig 12} . The chip uses a different logic voltage than the standard TTL, i.e., 7.5V to 18V is considered as "1" and less than 7.5V as "0". This problem is solved by designing a simple interfacing circuit which switches over incoming signals from 5V to 12V {5} . The interfacing circuit uses a 74007chip which has an output open collector pulled to the required voltage value via 10K Ohms resisters. Output signals of the chip SAA 1027 are transmitted to the input terminals of a power driver by which the turning on and off of the motor winding is governed. The chip

SA1027 can provide up to 350 mA current at each output, which is good enough to operate the chosen power transistor TIP 121. The outputs of the power transistor are open collectors, pulled to the 12V via 1K Ohms resisters, [Fig 12] .

When the transistors Q_1 to Q_4 are turned off, a high voltage builds up due to L*di/dt and this voltage my damage the transistor {3}, where "L" is inductance and di/dt is rate of change of current. There are several methods to suppress this spike voltage thus protecting the transistors. A diode/resistor suppressor method is used to suppress the high voltage, [Fig 12] . A circulating current will flow after the transistor is turned off but the resistor in series with diode will quickly damp the circulating current.

There are three ports in the BBC computer. These ports are, user port, analog input port and bus port. Physically the user port is divided into two ports, one for printer and the other for general purpose use. The general purpose port has eight date lines of which six have been used for three stepper motors. For initializing purpose three data lines, one for each axis, are used. Bus port is used through an interfacing board, [Fig 13, 14]. Analog port is not used as an analog to digital convertor is needed which though a relatively expensive but an easy choice.

The bus port is converted into an input/output port by using a peripheral interface adapter (PIA) Motorola Mc 6821 chip. This chip provides two peripheral ports, A and B, and each is associated with its data direction registers (DDR) and a control register. Although both ports can be used as either input or output ports, port B has three-state drivers allowing its use directly as an output port with an current sinking capacity 10 mA at 1.5 V. Initializing of the PIA will be described elsewhere {1}.

For Initializing of robot there is a need to sense the position of all the three axes at a particular point for each axis. It can be done with the help of proximity switches, linear encoders or micro switches. Micro switches have been used for the initializing purpose due to less cost as compared to other options. These switches suffer from bounces of contracts to a greater or lesser extent i.e., soon that the switch is operated it makes a contact but will not remain in contact thereafter. They bonuce open again and may bonuce several times before finally resting in the contact position. The setting time may extend to several milli seconds which is of little consequence in this case but the stepper motor can stop at one place and in a second initialization at another place. However the difference can be lesser than a few millimeters. There are two solutions for debouncing the switches, one is to add a delay routine in the software and the second is to debounce the switches in the hardware. The first is disregarded as it slows down the pulse generation loop of the motors so reducing the speed of the motors. In the second method a 10 micro F capacitor with 270 Ohms resisters across the switch for the debouncing purpose has been used. The capacitor

is charged as the power is turned on and it takes 0.0027 seconds to discharge after the switch closes, [Fig 13]. Discharge time is calculated by the formula, Discharge time = R*C Sec, where "C" is capacitance and "R" is resistance {3}.

3.3 ROBOT CONTROL

The bulk of the programme is written in BASIC and only the pulse generation routines are written in 6502 assembly language {4 - 6}. If whole of the programme is written in BASIC then speed of the steeper motors will be severely affected. The main routine of the programme provides three main modes to the user, the teach mode, the reply mode and initialization mode. The teach mode allows the user to teach the arm in terms of Cartesian coordinates, or directly in terms of joint angles. When the desired position of the arm is entered by the user, the programme looks at whether the position required is within the reach of the arm, if not the programme allows the user to enter a new position. Once the position is entered then the programme calculates the number of steps to be moved by the stepper motor and then it offers three standard speeds; slow, medium and fast. Once the speed is entered the assembly language programme is invoked automatically. The assembly language programme generates a train of pulses which are out-putted to the user port and moves the arm and the user is given the option of keeping the move or rejecting it. The same routine is moved until the user has entered sufficient moves. These moves can be saved on the disk for replaying them at later stage.

The replay mode allows the user to load a series of stored moves from the disk and to replay it any number of times with any given speed. The main programme is illustrated by the flow chart, [Fig 15] .

4. CONCLUSION :

A microprocessor based robot arm is designed and manufactured for light engineering tasks by using the stepper motors. The robot has been used for feeding disabled persons. Other simple tasks can be carried out by using the approach e.g; moving a tool in X, Y, and Z directions simultaneously with various speeds.

Based on the same analogy, explained in the above text, robots for carrying out heavy work can be devised by using extra sensing devices, electrical and mechanical components and higher speed computers.

ACKNOWLEDGEMENT

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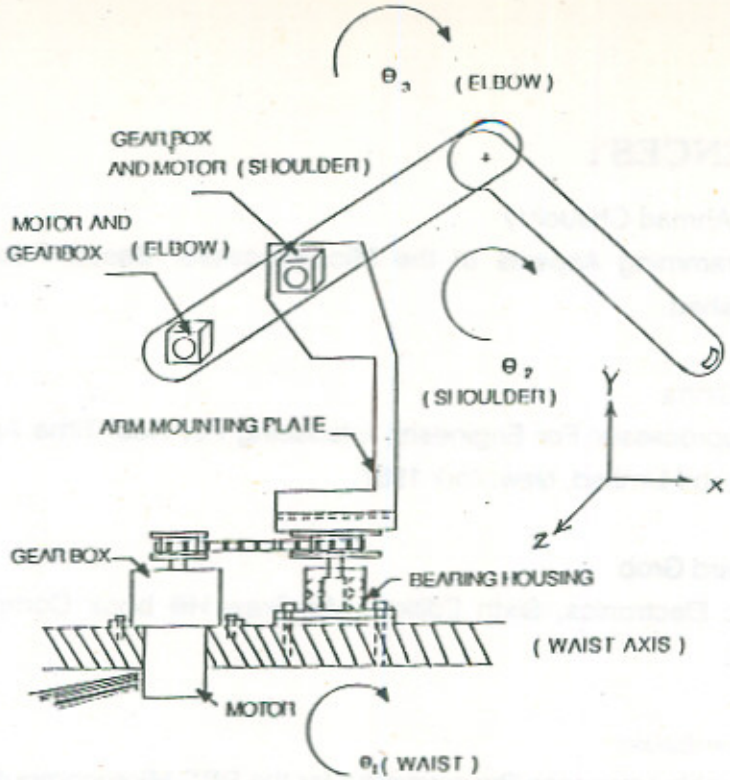
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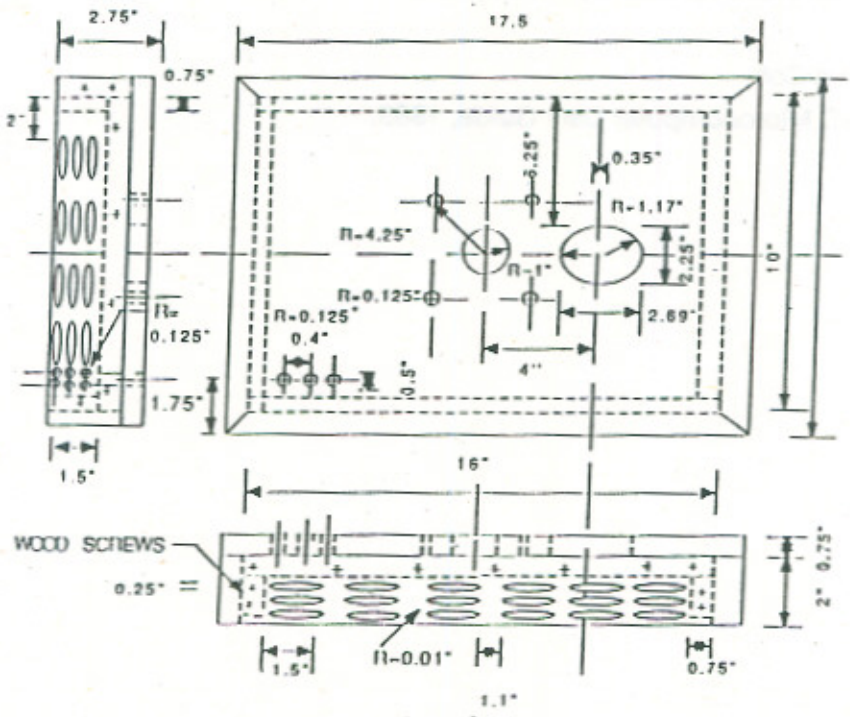
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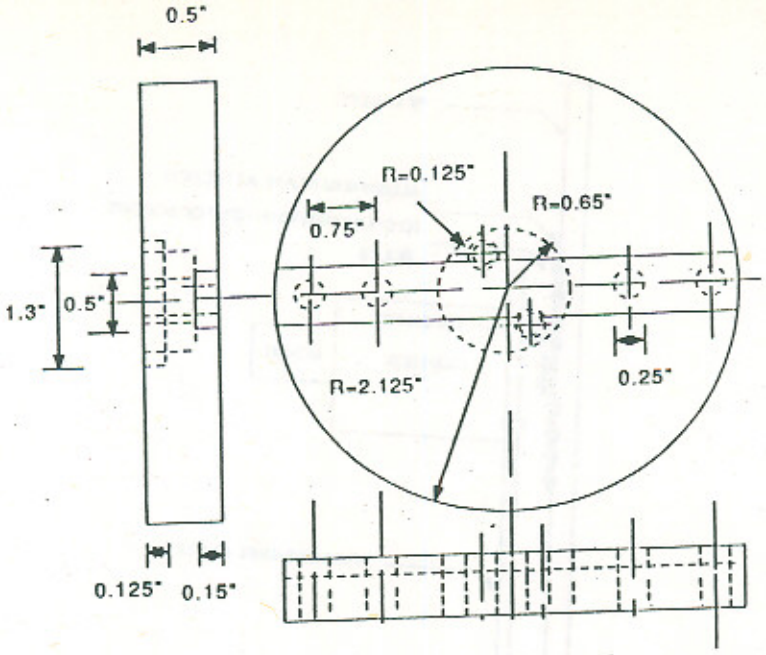
MICROPROCESSOR BASED ROBOT ARM

Figure 1



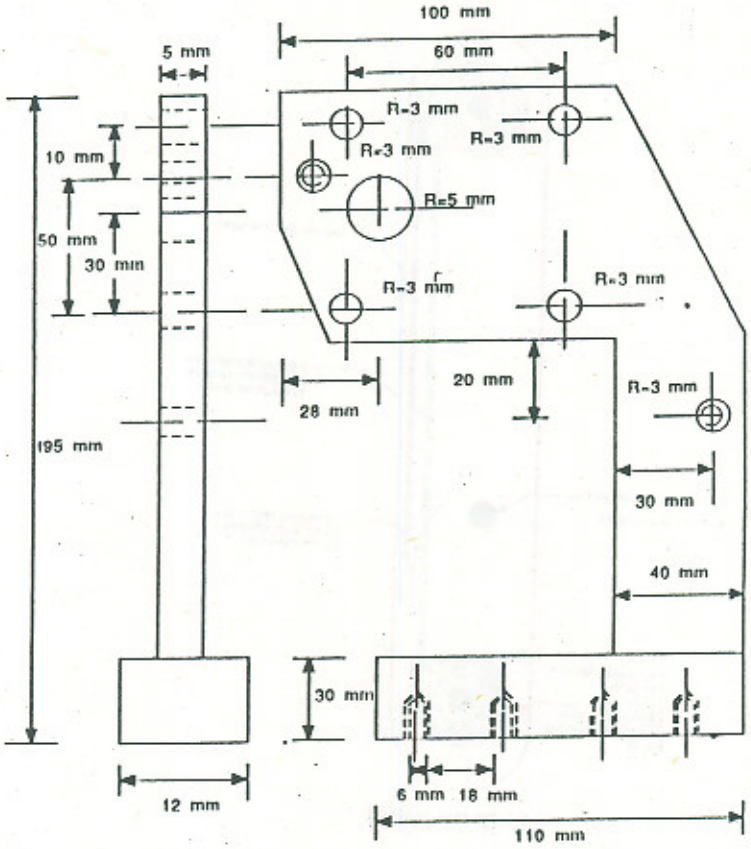
ROBOT BASE

Figure 2



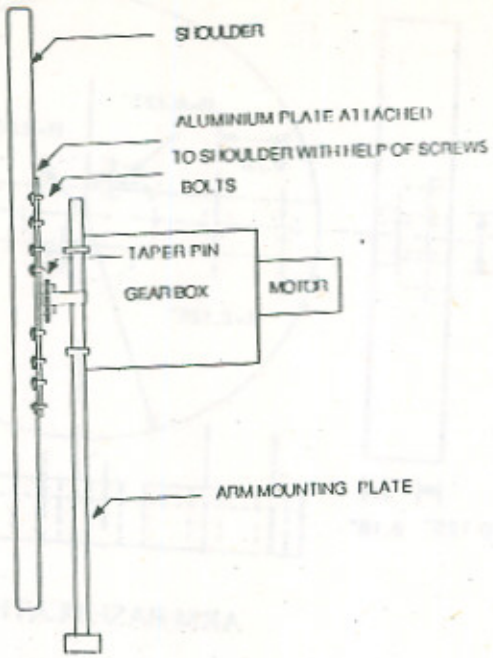
ARM BASE PLATE

Figure 3



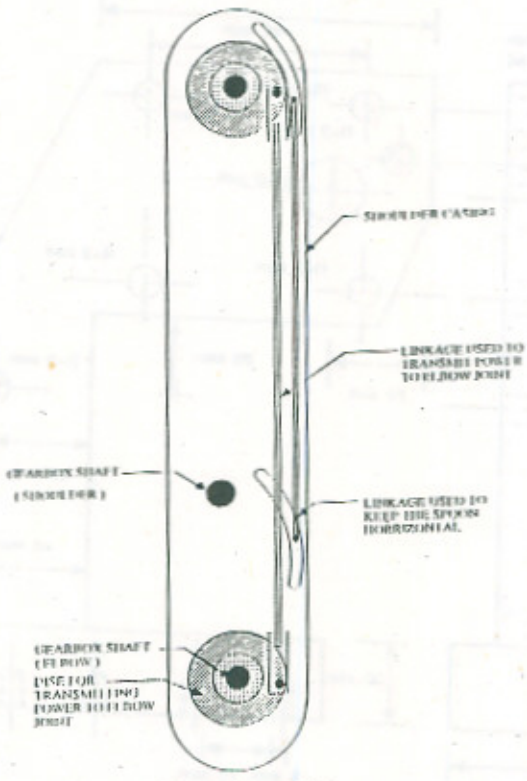
ARM MOUNTING PLATE

Figure 4



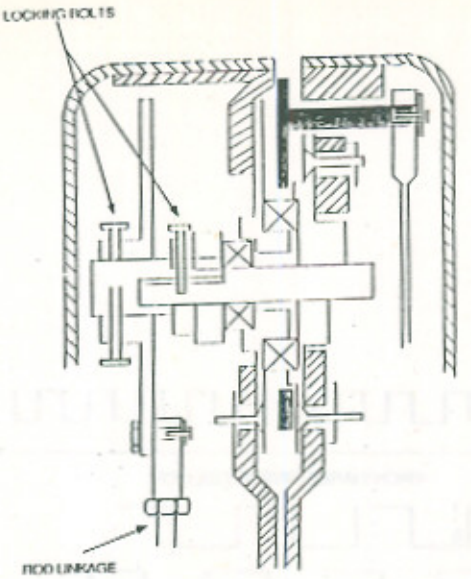
SHOULDER JOINT

Figure 5



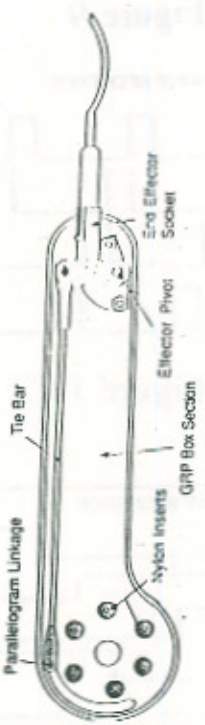
ELBOW JOINT

Figure 6



CROSS SECTION VIEW OF
THE ELBOW JOINT

Figure 7



END EFFECTOR DRIVE LINKAGE

Figure 8

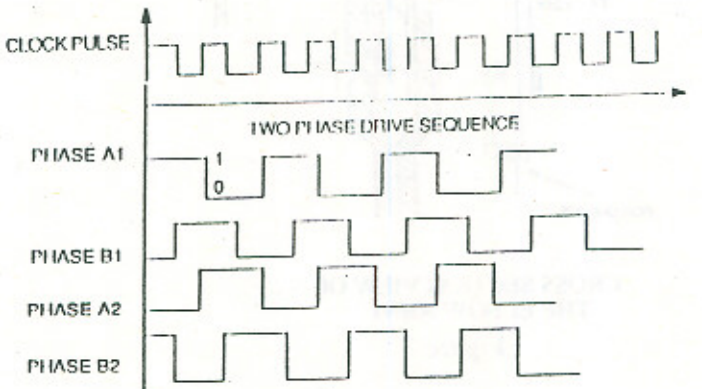


Figure 9

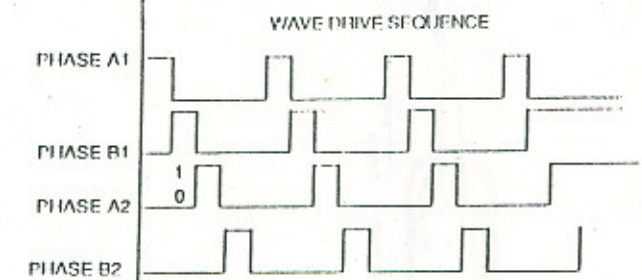


Figure 10

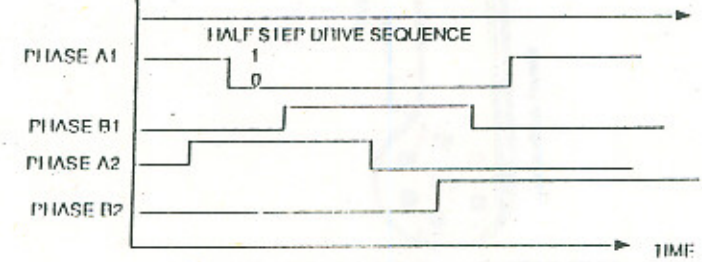


Figure 11

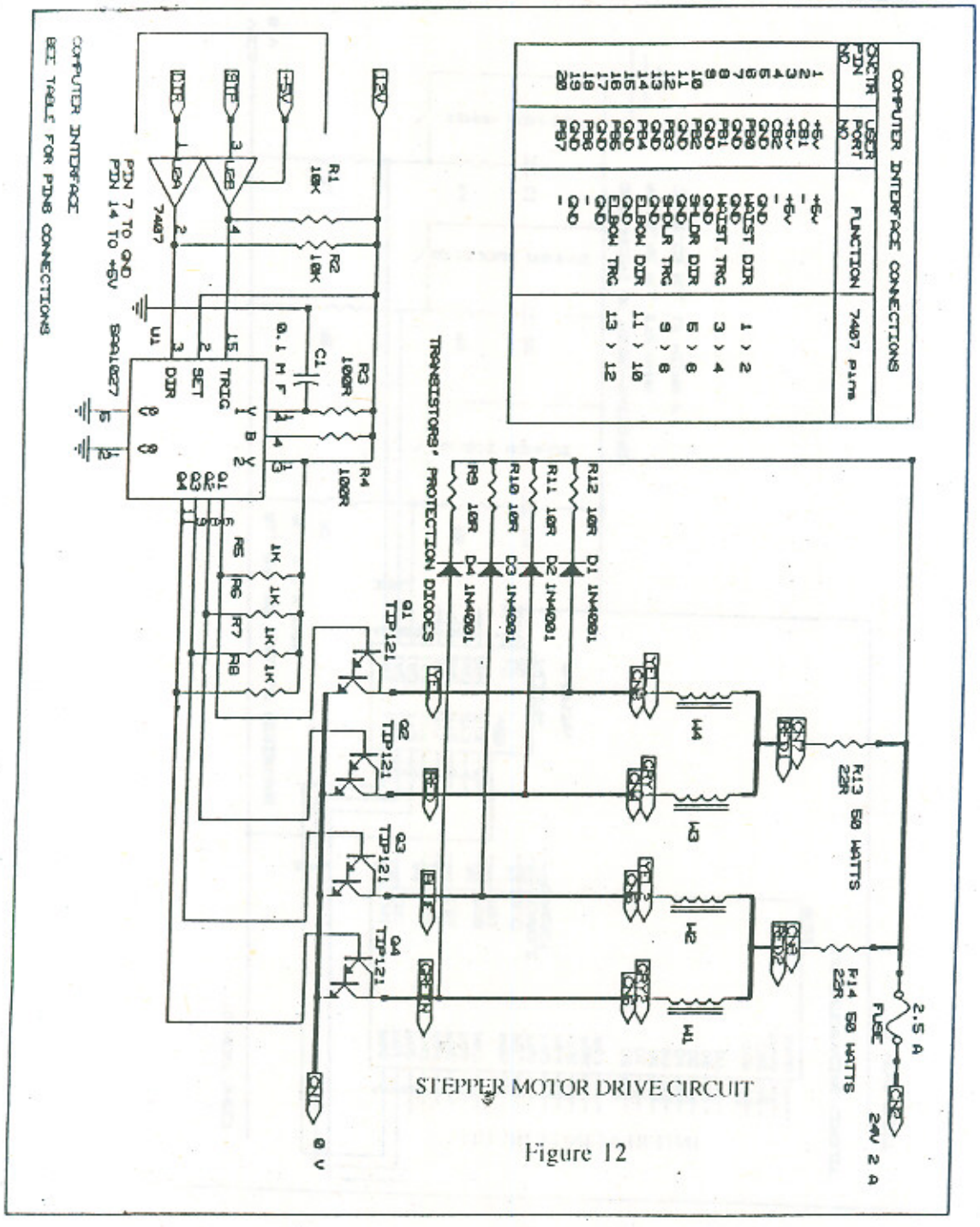

COMPUTER INTERFACE CONNECTIONS
CONCTR PIN NO
USER PORT NO
FUNCTION
7407 PINS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
+5V PB1 +5V PB2 PB0 PB3 PB4 PB5 PB6 PB7
+5V - +5V - GND - GND
GND WAIST DIR GND WAIST TRG GND SHLDR DIR GND SHLDR TRG GND ELBOW DIR GND ELBOW TRG
1 > 2 3 > 4 5 > 6 9 > 8 11 > 10 13 > 12
COMPUTER INTERFACE
SEE TABLE FOR PINS CONNECTIONS
PIN 7 TO GND
PIN 14 TO +5V
7407
U1
R1 10K
R2 10K
C1 0.1 M F
R3 100R
R4 100R
SN75627
DIR
SET
TRIG
Y B Y
Q1 Q2 Q3 Q4
TRANSISTORS' PROTECTION DIODES
R12 10R
R11 10R
R10 10R
R9 10R
D1 1N4001
D2 1N4001
D3 1N4001
D4 1N4001
R5 1K
R6 1K
R7 1K
R8 1K
Q1 TIP121
Q2 TIP121
Q3 TIP121
Q4 TIP121
H4
H3
H2
H1
R13 22R 50 WATTS
R14 22R 50 WATTS
2.5 A FUSE
CN2
24V 2 A
GND
0 V
STEPPER MOTOR DRIVE CIRCUIT

Figure 12

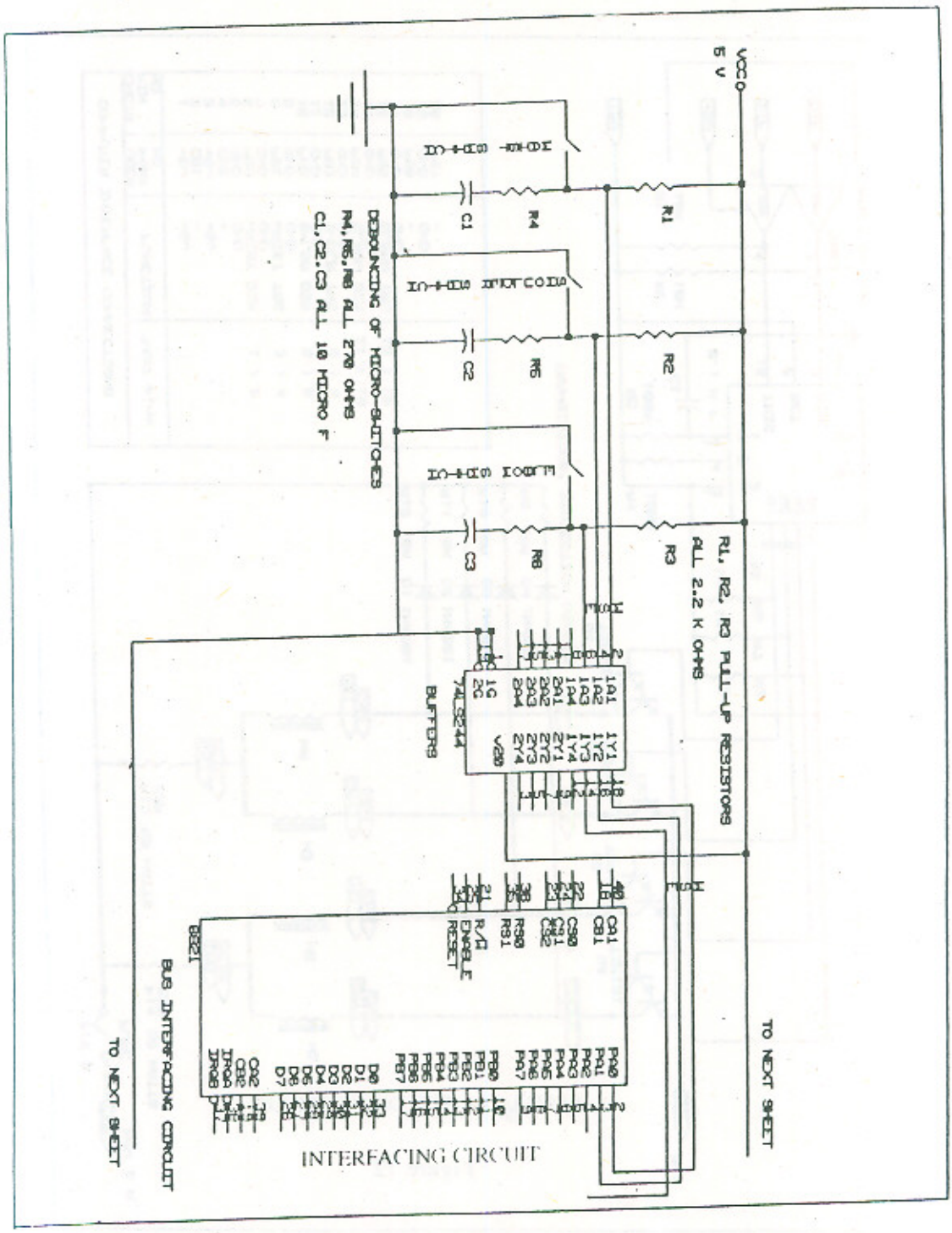

VCC
5 V
DEBOUNCING OF MICRO-SWITCHES
R4,R5,R6 ALL 270 OHMS
C1,C2,C3 ALL 10 MICRO F
C1
C2
C3
R4
R5
R6
R1
R2
R3
R1, R2, R3 PULL-UP RESISTORS
ALL 2.2 K OHMS
74LS244
BUFFERS
TO NEXT SHEET
BUS INTERFACING CIRCUIT
INTERFACING CIRCUIT
TO NEXT SHEET

Figure 13

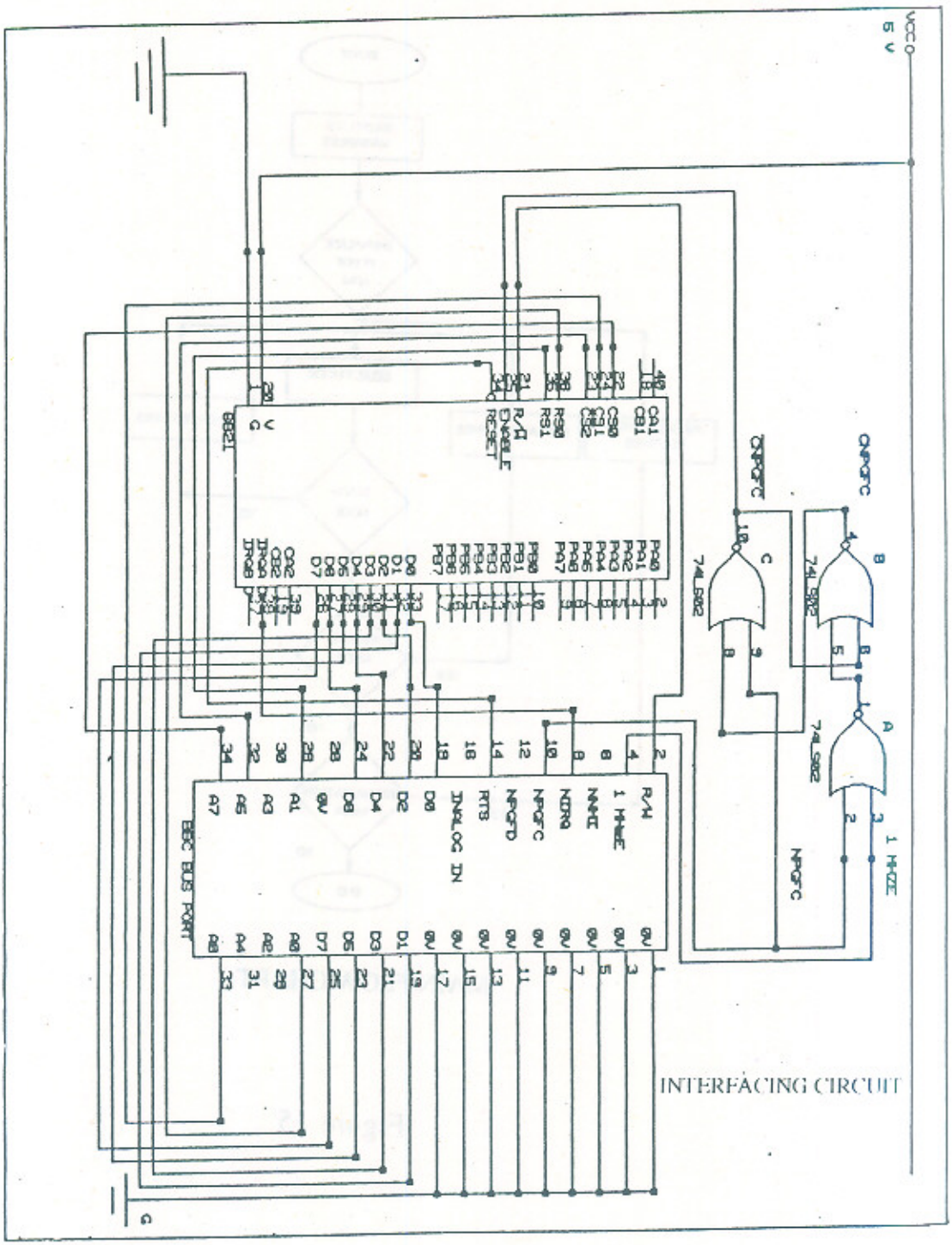
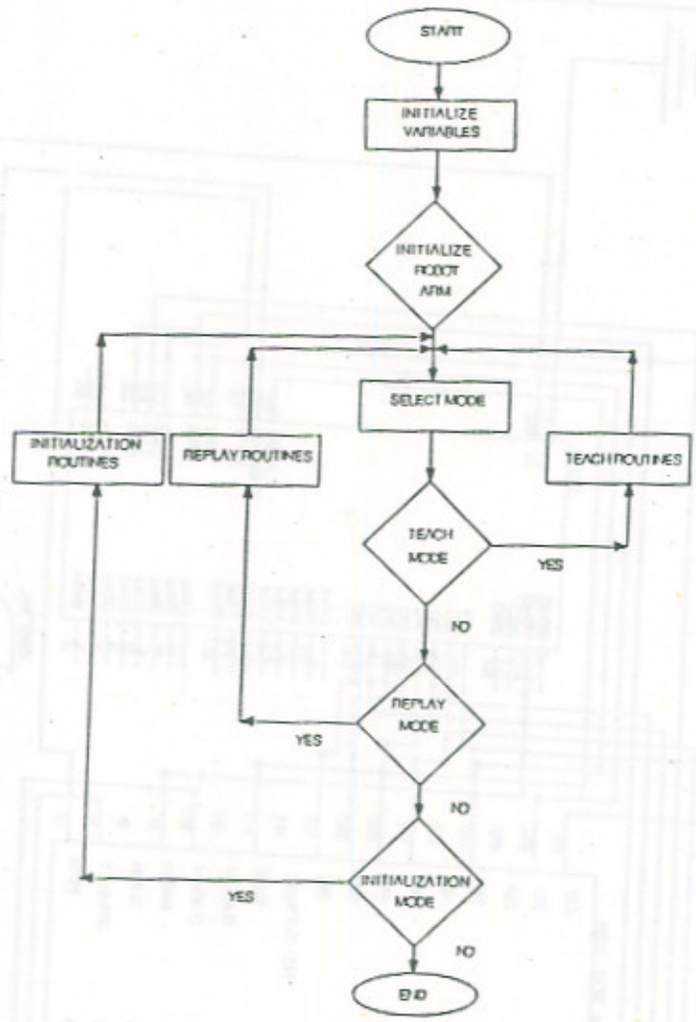


Figure 14



MAIN FLOW CHART

Figure 15