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Micro – CNC Machines for Displacements along Z-Axis and on XY-Plane

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ABSTRACT: This paper improves the performance of the existing micro Computer Numerical Control (CNC) machines. In this paper, (1) a single axis (vertical axis) CNC machine and (2) a two-axis CNC machine (X-direction and Y-direction) are re-fabricated to improve their robustness and reproducibility. The single-axis machine is aimed at producing a fast drilling machine controlled by a micro controller. The work carried out is presented in two parts. First part contains the work carried out in the design of single axis CNC machine (Z- Axis), and the second part contains the design of a two-axis CNC machine (X-direction and Y-direction). Improvised Stepper motor drivers were designed to improve the robustness and factors related to power dissipation. The traversing time of the drill bit of the drilling machine is considerably reduced by appropriately re-designing to reduce its response time. Sophistication of the two-axes machine was done to facilitate working in program mode by providing to the use number of ports in the microcontroller. Using the newly designed stepper motor drivers in this CNC machine, the run time operation in program mode of the machine has been enhanced. While the single axis machine is used to drill holes, the two-axis machine moves a platform on a XY-plane (2-Degrees of Freedom) in different geometric patterns/paths.

KEYWORDS: Single axis Computer Numerical Control (CNC) machine; Two axis Computer Numerical Control (CNC) machine; Stepper motor driver; DC Motor; Dual H-bridge Driver.

I. INTRODUCTION

Computer Numerical Control (CNC) machine is a programmable machine for doing milling, drilling, cutting and shaping on the metals like stainless steel (SS), mild steel (MS) and aluminium. The simplest definition is as the name implies “a process is controlled by numbers“. Numerical Control is a system in which the direct insertions of programmed numerical value, Stored on some form of input medium are automatically read and decoded to cause a corresponding function on the machine tool which it is controlling. While the single axis machine is used to drill holes, the two-axis machine moves a platform on a XY-plane (2-Degrees of Freedom) in different geometric patterns/paths.
The work carried out is presented in two parts. First part contains the work carried out in the design of single axis CNC machine.The design specifications of the single axis CNC machine, the approach adopted in implementing the modifications is aimed at improving the system’s response time. In the modified design of this CNC machine, it is planned to replace LPC 2148 with Arduino UNO processor board for reasons mentioned elsewhere in this paper. Considering the speed while drilling multiple holes, displacement of the drilling motor along with drilling bit and the time consumed in traversing, is found to play a significant role in the design of CNC machine. This traversing time was reduced by appropriate modification in traversing distance to drill each hole.

Second part contains the modification of Hardware and Software in respect of the two-axes CNC machine to solve certain problems encountered in earlier machine. Two-axes CNC machine uses two stepper motors for displacements along X and Y directions. As such, modifications in respect of replacement of stepper motor drivers with newly designed stepper motor drivers are incorporated.

II. SINGLE AXIS (Z- AXIS) MICRO CNC MACHINE

The Single axis (Z-axis) micro CNC machine is done in two parts. They are namely (1) Electronic Hardware Part (2) Mechanical Part.

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The first part contains the design of the Electronic hardware consisting of a micro controller (Arduino UNO) with appropriate I/O components and driver to drive the Stepper motor. The second part contains the modified Mechanical system consisting of a lead screw mechanism to drive the DC motor drill.

A. *Electronic Hardware Part:*
The following figure shows the Electronic hardware diagram of a single axis (vertical axis) CNC machine.

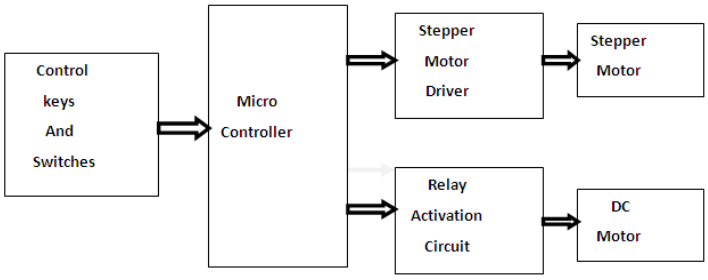

Fig 1. Electronic Hardware for Single axis (Z -axis) CNC machine

The Electronic hardware part contains control keys and switches, Arduino UNO micro controller, stepper motor drivers to run the stepper motors, DC motor to drill the hole on the PCB and finally a relay activation circuit to control the DC motor.

Control Keys and Switches
The control keys used are of push-Button type. A Push-Button is a simple switch mechanism for controlling some aspect of a machine or a process. Push-Buttons are often colour-coded to associate them with their function so that the operator will not push the wrong button in error. Commonly used colours are red for stopping the machine or process and green for starting the machine or process.
Limit switches are used to control the machine and to count objects. A Limit switch is a switch operated by the motion of a machine part or presence of an object. They are used for control of a machine, as safety interlocks, or to count objects passing a point. A Numerical Control Machine such as a lathe will have limit switches to identify maximum limits for machine parts or to provide a known reference point for incremental motions.

Micro Controller
In the design of single axis CNC machine, Arduino UNO processor is preferred. Because it is an open-source project, software/hardware is extremely accessible and very flexible to be customized and extended. It is flexible, offers a variety of digital and analogue inputs, SPI and serial interface and digital and PWM outputs. It is easy to use, connects to computer via USB and communicates using standard serial protocol, runs in standalone mode and as interface connected to PC/Macintosh computers. The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

Stepper Motor Driver
With the help of a stepper motor driver, stepper motors convert electrical energy into precise mechanical motion. The stepper motor rotates a specific incremental distance per each step. The number of steps that are executed controls the degree of rotation of the motor's shaft. This characteristic makes step motors excellent for positioning applications. The L297 integrates all the control circuitry required to control bipolar and unipolar stepper motors, Used with a dual bridge driver such as the L298N forms a complete microcontroller to bipolar stepper motor interface. The L297/A/D Stepper Motor Controller IC generates four phase drive signals for two phase bipolar and four phase unipolar step motors in micro computer-controlled applications. By combining the L297 as the motor controller and current limiter and L298 as dual H-Bridge driver, full stepper motor driver system can be performed. The step and direction data is received from the microcontroller system to the L297 and the control signals are generated for L298. These signals used to drive the stepper motor for specific steps determined with the steps number. The minimum system that is performed by above components is shown in

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below figure. Eight diodes are fast diodes and hold the supply voltage level for motor windings in +V value. The two 0.5 ohms resistors are current sensors and can enable the appropriate signals if the motor current exceeds to the threshold value.

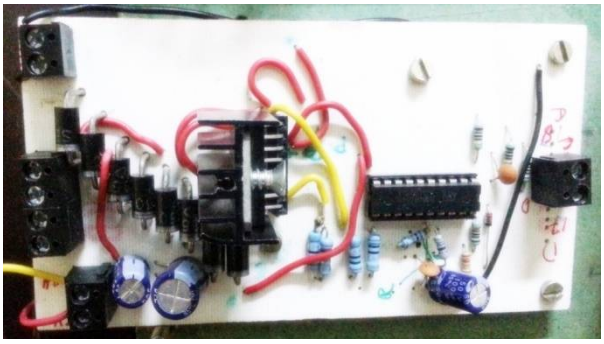

Fig 2. Dual H-bridge Driver (L297 and L298) Circuit PCB

When the voltage of sense resistors reaches to the Vref, the winding is disabled and the diodes offload the winding current. This operation continues while the internal oscillator set the stop command. The chopper rate is determined with the RC network connected to the OSC input. After getting the proper result for Dual H-bridge driver (L297 and L298), make that on PCB is shown above.

Stepper Motor

A stepper motor is a brushless, synchronous electric motor that converts digital pulses in to mechanical shaft rotation. Every revolution of the stepper motor is divided into a discrete number of steps, in many cases 200 steps, and the motor must be sent a separate pulse for each step. The stepper motor can only take one step at a time and each step is the same size. Since each pulse causes the motor to rotate a precise angle, typically 1.8°, the motor's position can be controlled without any feedback mechanism. As the digital pulses increase in frequency, the step movement changes into continuous rotation, with the speed of rotation directly proportional to the frequency of the pulses. Step motors are used every day in both industrial and commercial applications because of their low cost, high reliability, high torque at low speeds and a simple, rugged construction that operates in almost any environment.

Selection criteria of Stepper Motor

While selecting a stepper motor for a particular application various factors are to be considered.

- Starting torque (N – m)
- Maximum speed (steps/second)
- Duty cycle
- Required power
- Load inertia
- Speed control
- Reversible motor
- Time to accelerate, decelerate
- Size and weight consideration.

Stepper Motor Operation

DC brushed motors rotate continuously when voltage is applied to their terminals. The stepper motor is known by its important property to convert a train of input pulses (typically square wave pulses) into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle. Stepper motors effectively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external control circuit, such as a microcontroller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. This means that when the next electromagnet is turned on and the first is turned off, the

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gear rotates slightly to align with the next one. From there the process is repeated. Each of those rotations is called a "step", with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise angle.

Relay Activation Circuit

Relays are electromechanical switches. They have very high current rating and both AC and DC motors can be controlled through them because motor will be completely isolated from the remaining circuit.

Working of a Relay

Relays consist of an electromagnet, armature, spring and electrical contacts. The spring holds the armature at one electrical contact and as soon as a voltage is applied across the electromagnet, it coils the armature, changes its contact and moves to another electrical contact. Terms associated with relays:

- **Normally Open (NO):** contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive.
- **Normally Closed (NC):** contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive.
- **Change Over (CO)**: It's the common contact.
- **COIL:** It's the electromagnet coil inside relay.

Relay Activation and Interfacing Circuit

The below circuit is used to activate the relay. Dc motor is connected to the relay, so when relay is activated DC motor is powered on. From arduino a digital pin is used to activate the relay circuit. Whenever relay coil is activated, DC motor is powered ON.

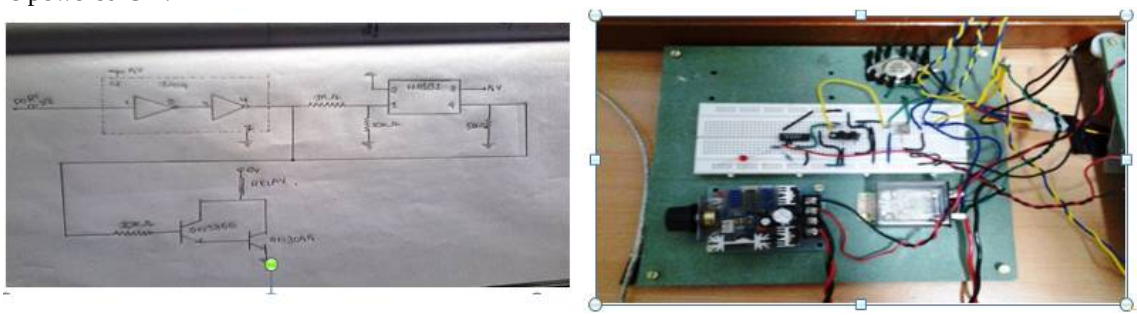

Fig 3. Relay interfacing Circuit

The above figure shows the Relay activation circuit analysis on bread board. DC motor connected to a relay activation circuit, when the relay is activated DC motor attached to linear displacement mechanical gadget goes down and drills a hole and comes back and ready to drill a another hole.

DC Motors

A DC Motor relies on the facts that like magnet poles repel and unlike magnetic poles attract each other. A coil of wire with a current running through it generates an electromagnetic field aligned with the centre of the coil. By switching the current on or off in a coil its magnetic field can be switched on or off or by switching the direction of the current in the coil the direction of the generated magnetic field can be switched 180°.

B. *Mechanical Part*

The procedure adopted to re-fabricate below mechanical system is described is as follows:

- Pulley is prepared in the work shop to hold the shaft of the stepper motor.
- L-shaped plate is prepared according to the size of stepper motor.
- Stepper motor is fixed to this L-shaped plate and L-shaped plate is fixed to a table.
- Pulley is fixed to the shaft of the motor.
- Loosen the front part of the pulley and keep a disc shaped protractor.

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Fig 4. Mechanical part of the micro CNC Machine

After re-fabrication of mechanical gadget, the lead screw is connected to the bipolar stepper motor and dual H-bridge driver (L297 and L298) connected with a arduino UNO (AT mega 328p) board. The final single axis micro CNC machine for displacements along linear axis in front view and back view is shown in above figure.

III. TWO AXIS (XY-PLANE) MICRO CNC MACHINE

A step wise design procedure of the two- axes micro CNC machine is described in two parts. They are namely as follows:

- Electronic Hardware Part
- Mechanical Part

The first part contains the design of the Electronics hardware consisting of a micro controller (Arduino Mega) with appropriate I/O components and driver to drive the Stepper motor. In Arduino Mega, the program mode operation provides way points. Each way point may need a port. The results for other operations other ports can be used. We felt that reasonable to replace with Arduino Mega. The second part contains the modified Mechanical system consisting of a lead screw mechanism to drive the two drivers.

A. *Electronic Hardware Part*

The following figure shows the Electronic hardware diagram of a Two - axes CNC machine.

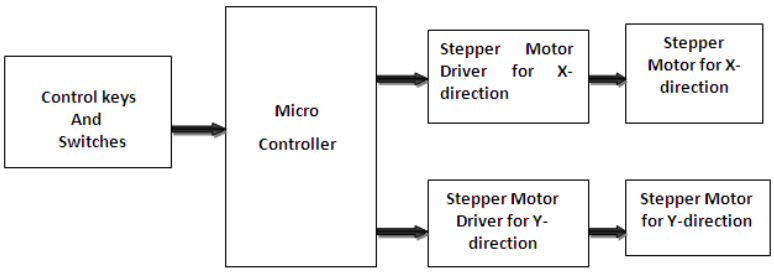

Fig 5. Electronic Hardware for Two axis CNC machine

The circuits are mainly described with the help of three blocks. The first block contains all the logical buttons that go to various ports of Arduino mega R3. Their logical states are predefined and initialized using the software/hardware. The second block represents the micro controller board (Arduino Mega R3). This is the heart of the embedded system that considers the logical states of the buttons and drives the two stepper motors in accordance with the program. The third block represents the two driver circuits. These driver circuits take the control signals from the micro controller and

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drive the two stepper motor according to the program. It is evident that the micro controller responsible for the driving the two stepper motors for the required functionality of the CNC machine. The above described electronic circuits are mounted in a 3-tire box and appropriate air cooling is provided to these circuits for proper power dissipation. Inter connection between these circuits and the stepper motors (mounted on the machine) are done using robust connection to avoid loose connections.

B. *Mechanical Part*

Movement of Test Platform

X-platform contains two aluminium plates fitted with two guider rods and a lead screw. This lead screw, with the help of stepper motor moves the test platform along X-axis. A 10mm thick glass slab of 2′ * 2′ size is mounted with the help of four 1 ½ ″ diameter rods as shown in the figure.

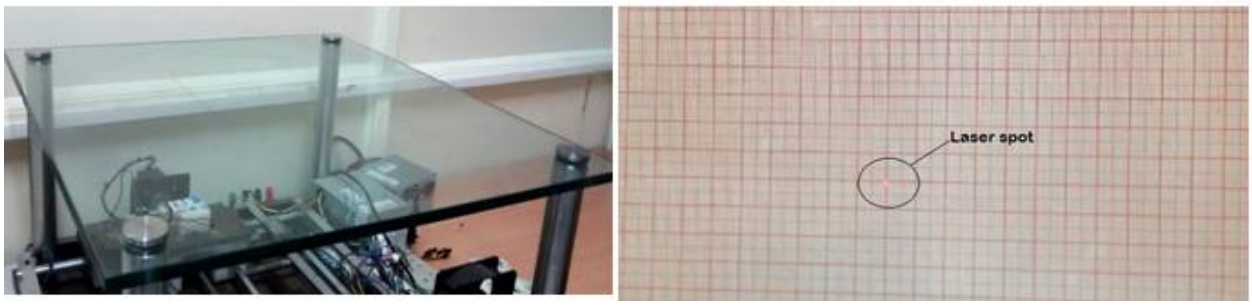

Fig 6. Glass Slab and Laser focussed spot on graph sheet

The slab is at a height of 160 mm from the laser source to enable a focussed spot on the top of glass slab. When the laser source is powered ON, the laser source produces a focussed spot on a graph sheet when placed on the glass slab. This spot moves along the XY- plane on the glass slab. The movement of the slab can be controlled with the help of software in user mode or program mode. In user mode the spot can be made to move in +X, -X; +Y, -Y directions by depressing appropriate push buttons. In program mode the software return the geometrical pattern in which the laser spot moves. In this project, three programs are written for the movement of spot in square, triangular and hexagonal paths. Two digital vernier callipers are mounted on this unit at appropriate places to enable X and Y displacements up to second decimal place of a milli meter (+/- 10 microns)

IV. **TESTING RESULTS**

Flow chart of Single axis CNC Machine

The Following figure shows the flow chart for Single axis (Vertical axis) micro CNC machine.

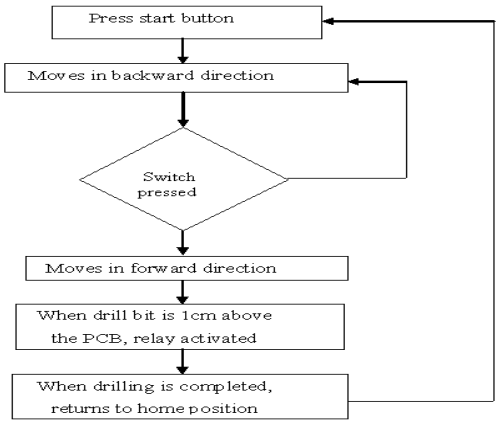

Fig 7. Flow chart for Single axis micro CNC Machine

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With the help of this flow chart the functionality of two- axes CNC machine is also tested in both user and program modes. Their displacement values are checked with the digital vernier callipers. In previously used Single axis micro CNC machine the response time to drill a hole on PCB was 3 minutes, which takes more time to drill. The modified system gives a faster response, where a hole can be drill in 28 sec. Here have the safety precautions of the home switch, this switch decides the starting point of the drill bit, when the system is reset.

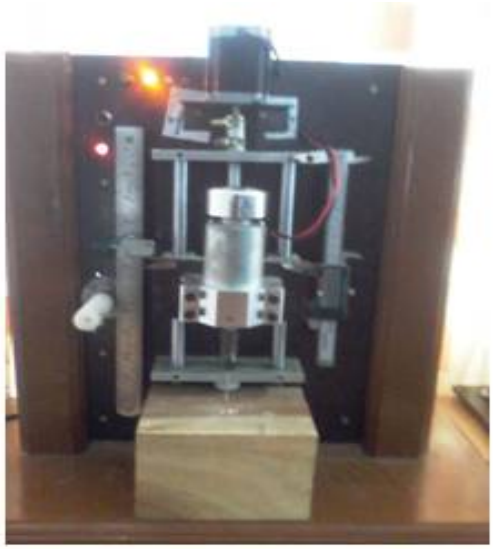

Fig 8. Motor is at home position

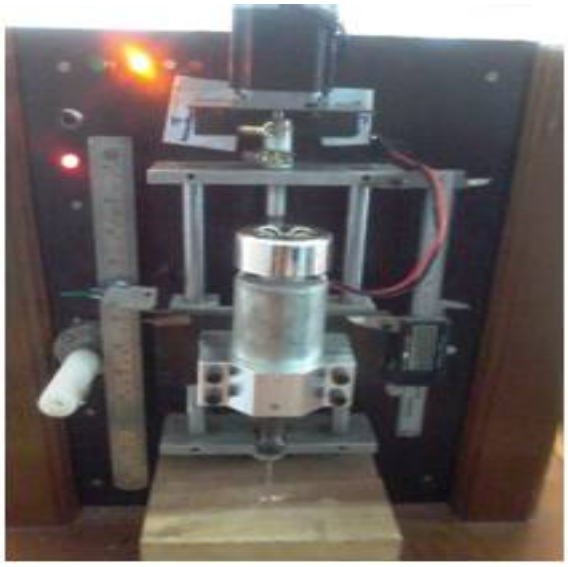

Fig 9. DC motor moving in down ward Direction

The above figures show DC motor positions. When the motor is at home position then press drill start button. The drill bit fixed to the DC motor starts moving to the downward direction to drill the hole. When the drill bit is 1cm above the PCB, relay is activated by the relay activation and interfacing circuit.

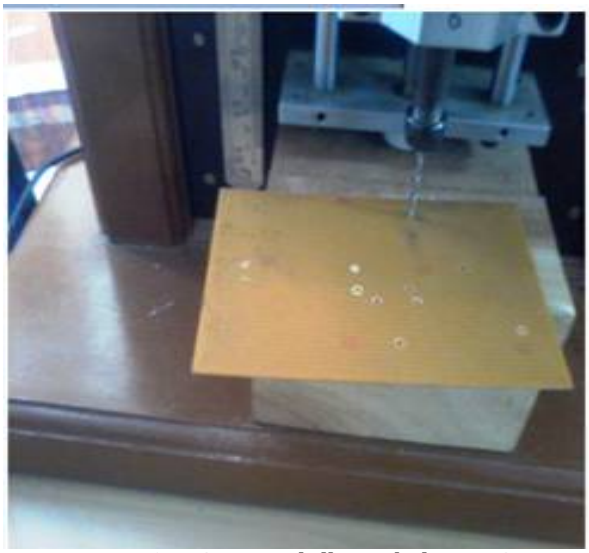

Fig 10. DC motor drilling a hole on PCB

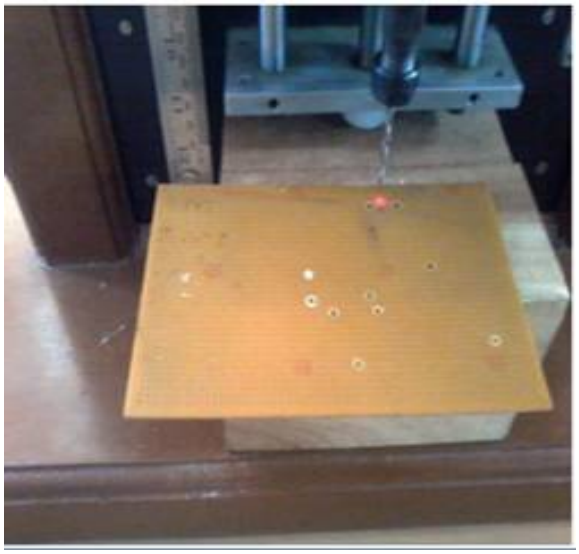

Fig 11. Holes drilled on PCB

Multiple holes are drilled on the PCB by moving the drill bit up and down ward directions with the help of relay activation circuit is shown in fig 10 and fig 11. The relay activation circuit controls the DC motor. When the drill is completed motor returns to its home position.

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V. CONCLUSION AND FUTURE WORK

Scope of Expansion for Z-axis

The most important contributions of the present work are accuracy, precision and improving the response time. The Machine can be modified to drill multiple holes simultaneously. The platform can be made to change its position in a programmable fashion, so that multiple holes can be drilled (one at a time) at with equal spacing accurately.

Scope of Expansion for XY-plane

In the X and Y movement it moves to a certain distance and comes back to home button to the initial state. It moves safely without damaging the home button or the screw and this movement is controlled by a stepper motor driver (L297 and L298) and instructed by the Arduino mega (AT mega 2560) processor. This unit in future can be operated using Remote control radio in 2.4 GHz band width presently RC radio's in the market, this unit can be operated in both user mode and also in multiple programmable modes using control switch.

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