Obstacle Detection

And

Avoidance by a Mobile Robot

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Obstacle Detection and Avoidance by a Mobile Robot

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Certificate

This is to certify that the work in the thesis entitled *Obstacle Detection and Avoidance by a Mobile Robot* by *Sejal Jaiswal*, bearing roll number *110CS0442*, is a record of an original research work carried out by her under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Computer Science and Engineering.

Banshidhar Majhi

Declaration

I hereby declare that all the work contained in this report is my own work unless otherwise acknowledged. Also, all of my work has not been previously submitted for any academic degree. All sources of quoted information have been acknowledged by means of appropriate references.

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Abstract

The project “Obstacle Detection and Avoidance by a Mobile Robot” deals with detection and avoidance of the various obstacles found in an environment. We divided the task of creating the robot into five phases namely LED and LDR component designing, comparator, microcontroller, motor driver and the motor. While designing and construction of the hardware for the robot, we followed a sequential order, starting with the circuit construction of the LEDs and the LDRs, then designed the comparator which does the task of converting the input voltage to a digital output that is fed to the microcontroller. The implementation of artificial intelligence (AI) logic in done in this phase, the AI logic is fed to the microcontroller. The robot gathers facts about the scenario through the sensors. It then compares this information to the data stored and decides what the information signifies. The robot runs through the various possible actions and then based on the collected information,, predicts which action will be most successful. The motor driver then implements the decided action and the motor helps run the robot. The robot designed was found to successfully run on an obstacle free course after being able to detect obstacles and take appropriate actions.

The accuracy of the robot was 86.62% which was determined by testing the robot against various obstacles and calculating the observations. This project describes the basic ground work which when developed further can create more advanced robots which has a wide range of application such as in unmanned vehicle driving which can be useful for space projects, situations such as bomb detection or land mine detection in war affected areas, for industrial purposes, in creating household, etc. The building of such robots will require the developers to tackle problems such as finding efficient and effective, selection and design of circuit components keeping in mind a simple and a light-weight model that allows for smooth movement of the robot. The accuracy of the robot is dependent on the accuracy of the sensors and thus the selection of the sensors should be done keeping in mind the environment in which we want the robot to function.

Keywords: Artificial Intelligence, Robotics, Obstacle detection, Obstacle avoidance, Robot.

Contents

List of Figures

List of Tables

Chapter-1

Introduction

Chapter 1

Introduction

A computer would deserve to be called intelligent if it could deceive a human into believing that it was human.

Alan M. Turing, 1950

1.1 Motion Skills and Artificial Intelligence

This thesis is about obstacle detection and avoidance for wheeled mobile robots, which have been research topics since the beginning of robotics. It has been the research topics especially for mobile robotics around the late sixties.

Mobile robot are slowly growing in number and complexity due to their applications. Technologies such as system architectures, locomotion concepts, mechatronics or control software were developed in research labs. They are making their way into real world settings. And it turns out that robustness, safety are of primary importance along with other shifts in objectives. Motion being an important characteristic of mobile robots, obstacle avoidance and path planning has a major impact on how people react and perceive an autonomous system.

But the questions to be asked are: What constitutes a convincing movement? How can a mobile robot exhibit convincing movement, behavior? Under the assumption that humans can effectively navigate in crowds because we are able to sense such intent in others, it follows that a mobile robot should also be able to indicate where it is going or is headed.

Even if the robot has to make its way through a crowd, the robot is expected to facilitate reaching the goal. Goal directedness does not stand for using the geometrically least cost path. It might be an advantage to circumvent regions with a lot of environment dynamics, or even better to go there on purpose if the flow of people goes into the right direction.

Figure 1.1 Sony Corporation's biped entertainment robot prepares to kick a ball during an interactive programme with school children in Delhi, 2004.

This thought can be summed as "human inspired motion behavior". If the robot's movements can reflect properties of human motion to an extent, then the robot can convince humans.

This is similar to the goal of yet another field called which aims at making machines behave like humans, artificial intelligence focuses on reproducing, surpassing human intellectual skills such as theorem proving or logical reasoning. This goal of artificial intelligence is reflected in the formulation of the Turing test, which is intended to be independent from non-intellectual properties of the investigated system [2].

<u>Chapter-2</u>

Literature Review

Chapter 2

Literature Review

2.1 Artificial Intelligence

Artificial intelligence is the branch of computer science that develops machines and software with human-like intelligence. It is the intelligence exhibited by software or machines. The central goals of artificial intelligence research include knowledge, reasoning, learning, planning, perception, the ability to manipulate and move objects and natural language processing [14].

The field was founded on the claim that a central property of humans is intelligence, and that it can be sufficiently well described to the extent that a machine can simulate it.

2.2 Robotics and Robots

It is a branch of technology and deals with designing, construction, operation, and application of robots. It also deals with the computer systems for their sensory, control, information processing and feedback. These technologies deal with automated machines that can replace humans in manufacturing processes or dangerous environments. These robots resemble humans in behavior, appearance, and/or cognition. Robotics requires a working knowledge of mechanics, electronics, and software [15].

Robots are machines and are of a wide range. The common feature of robots is their capability to move. They perform physical tasks. Robots have many different forms. They range from industrial robots, whose appearance is dictated by the function they are to perform. Or they can be humanoid robots, which mimic the human movement and our form.

Robots can be grouped generally as:

1. Manipulator robots (for e.g. industrial robots)
2. Mobile robots (for e.g. autonomous vehicles),
3. Self-reconfigurable robots, the robots that can conform themselves to the task at hand.

Robots may act according to their own decision making ability, provided by artificial intelligence or may be controlled directly by a human, such as remotely-controlled bomb-disposal robots and robotic arms; or. However, the majority of robots fall in between these extremes, being controlled by pre-programmed computers [2].

2.2.1 Robot Working

Human beings on a basic level are made of five major components:

- A muscle system that can move the body structure
- A body structure itself
- A power source that can activate the muscles and sensors
- A sensory system which can receive information about the body and the surrounding environment
- A brain system which can process sensory information and tell the muscles what to do.

Robots are made up of the same components as above. A typical autonomous robot has a sensor system, a movable physical structure, a power supply and a computer brain that controls all of these elements. Basically, robots are man-made versions of the animal life. They are machines that can replicate human and animal behavior [11].

2.2.2 The Actuator

All robots have a movable body (almost all). Some have motorized wheels only, while others may have a dozen of movable parts (that are typically made of plastic or metal). Like bones in a human body, the individual segments are connected together with the help of joints.

Robots use actuators to spin wheels and jointed pivot. Some robots use solenoids and electric motors as actuators; others some use a pneumatic system (a system driven by compressed gases); yet others use a hydraulic system. A robot may even use all of these actuator types together.

Robots need a power source to be able to drive the actuators. Most robots have a battery or they plug into an electricity source. Pneumatic robots need air compressors or compressed air tanks and hydraulic robots need a pump that pressurizes the hydraulic fluid. The actuators are wired to an electrical circuit. The circuit powers these electrical motors and solenoids directly. It also activates the hydraulic system by manipulating electrical valves. The valves determine the pressurized fluid's path through the machine.

2.3 Robot Learning

Robot learning is an intersecting research field between robotics and machine learning. It studies techniques that allow robots to acquire skills and adapt to its environment by learning various algorithms. Learning can take place either by self-exploration or through guidance (from a human teacher), like in robot learning that learns by imitation [5].

2.3.1 Autonomous Robot

Autonomous robots are independent of any controller and can act on their own. The robot is programmed to respond in a particular way to an outside stimulus. The bump-and-go robot is a good example. This robot uses bumper sensors to detect obstacle. When the robot is turned on, it moves in a straight direction and when it hits an obstacle, the crash triggers its bumper sensor. The robot gives a programming instruction that asks the robot to back up, turn to the right direction and move forward. This is its response to every bump. In this way, the robot can change direction every time, it encounters an obstacle.

A more elaborate version of the same idea is used by more advanced robots. Roboticists create new sensor systems and algorithms to make robots more perceptive and smarter. Today, robots are able to effectively navigate a variety of environments. Obstacle avoidance can be implemented as a reactive control law whereas path planning involves the pre-computation of an obstacle-free path which a controller will then guide a robot along [2].

Some mobile robots also use various ultrasound sensors to see obstacles or infrared. These sensors work in a similar fashion to animal echolocation. The robot sends out a beam of infrared light or a sound signal. It then detects the reflection of the signal. The robot locates this distance to the obstacles depending on how long it takes the signal to bounce back.

Some advanced robots also use stereo vision. Two cameras provide robots with depth perception. Image recognition software then gives them the ability to locate, classify various objects. Robots also use smell and sound sensors to gain knowledge about its surroundings [2].

More advanced robots are able to analyze unfamiliar environments and adapt to them. They even work on areas with rough terrain. This kind of robots can associate particular terrain patterns with particular actions.

For example, a rover robot constructs a land map with the help of its visual sensors. If the map depicts a bumpy terrain pattern, the robot decides to travel some other way. Such kinds of system are very useful for exploratory robots and can be used to operate on other planets. Figure 2.1 shows the bot developed by NASA called Urbie. It is designed for various military purposes and is able to move through stairs and other such paths [11].

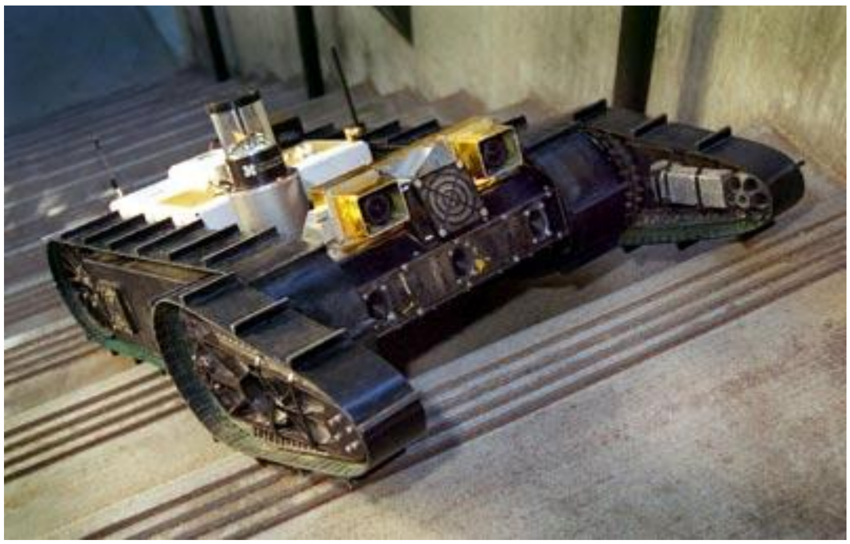


Figure 2.1 Autonomous Urbie developed by NASA, is designed for various urban operations, including military reconnaissance and rescue operations.

An ant tries to get over an obstacle, it does not decide when it needs to get over an obstacle. It simply keeps trying different things until it gets over the obtsacle. An alternative robot design takes a similar less structured approach, which can also be termed as a randomness approach. When the robot gets stuck, it moves its appendages in every way until something works out. Force sensors work very closely with the actuators, instead of the computer directing everything based on a program [11].

Chapter-3

Hardware Implementation

Chapter 3

Hardware Implementation

Flow-Chart (Hardware Implementation)

Figure 3.1 below shows the flow-chart that describes the process for the designing and development of the hardware. The hardware implementation phase is divided into five components. The components are the LEDs and LDRs [Section 3.2], comparator [Section 3.3], microcontroller [(Hardware Implementation) Section 3.4], motor driver [Section 3.5] and the motor [Section 3.6], in sequential order. Each component has been explained below along with their circuital representation as used in the building of the robot. The software implementation is included in the microcontroller phase [Chapter 4].

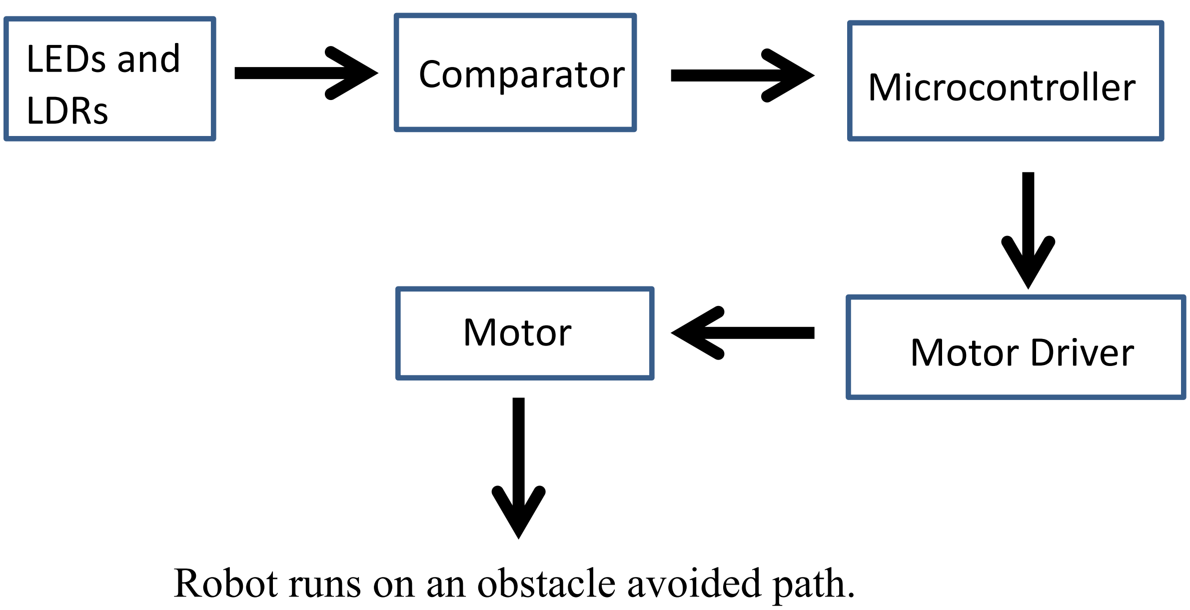


Figure 3.1 Flow chart depicting the Hardware Implementation for the project

3.1 LEDs and LDRs

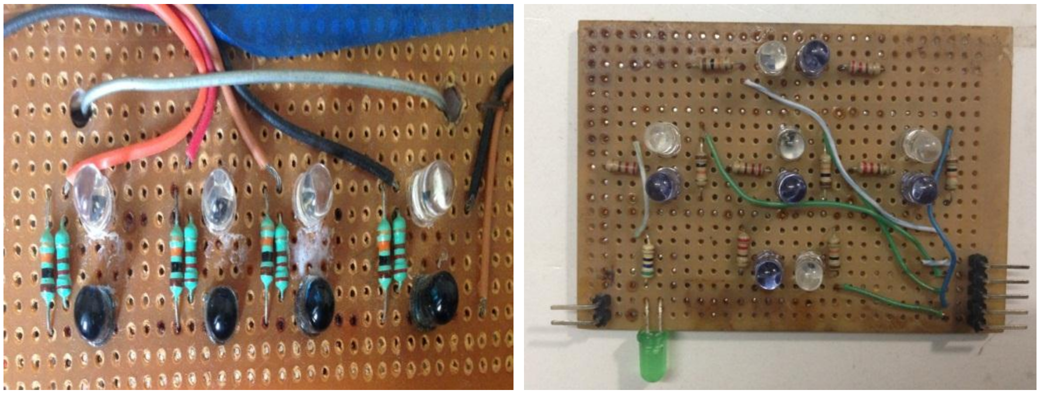
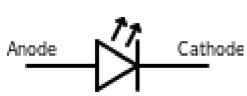


Figure 3.2 The picture shows LED and LRD circuits used in the Obstacle Detecting and Avoiding Robot. (a), Left: The LEDs and LDRs are fixed such that they are efficient for area coverage of large length. (b), Right: The LEDs and LDRs are fixed such that they are efficient for area coverage of large height.

WORKING:

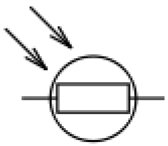
1. LED acts as the sender and LDR acts as the receiver.
2. LED and LDR are set up in an angle such that the light emitted by the LED can be detected by the LDR.
3. Change in the output voltage determines whether an obstacle is present (light condition for LDR) or not (dark condition).

3.1.1 LED



LED stands for light emitting diode. It is a light source made of two lead semiconductor. It resembles a pn-junction diode, but emits no light. When a light emitting diode's anode lead has a higher positive voltage than its cathode lead (by at least the diode's forward voltage drop), then there is a current flow. Electrons release energy in the form of photons in an electroluminescence effect. Electrons recombine with holes within the device [16].

This does not apply to white LEDs, which are blue-emitting LEDs coated with a phosphor that glows yellow and red when stimulated by blue from the LED. The merging of the blue, yellow, and red provides white light.

3.1.2 LDR 

A light-dependent resistor (LDR) is a light controlled variable resistor. It exhibits photoconductivity, as the incident light intensity increases, the resistance of a LDR decreases. A LDR can be applied in a light sensitive detector circuit [17]. We have used the LDR for a similar purpose in our robot circuit.

A LDR uses high resistance semiconductor in its making. In light condition, a light dependent resistor can have a resistance as low as a few hundred ohms. In the dark condition, a LDR can have a resistance as high as a few mega ohms (MΩ). If the light incident on a LDR exceeds a particular frequency, photons that were absorbed by the semiconductor give the bound electrons enough energy to be able to jump into the conduction band. The result is free electrons, who with its hole partners conduct electricity and thus lowering the resistance. The sensitivity range and resistance of a LDR differ within dissimilar devices. Moreover, unique LDR may react substantially differently to photons within certain wavelength bands [17].

- **LDR as a Voltage Divider**

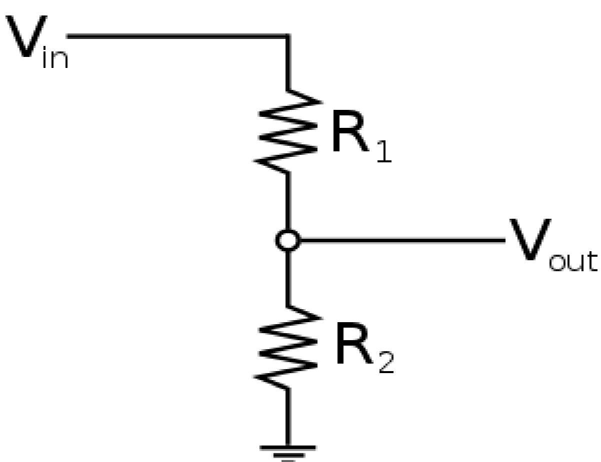


Figure 3.3 Circuit Diagram for Voltage Divider

In figure 3.3:

Voltage dividers use two resistors in the making of its circuit. The resulting voltage is the ratio of those resistors.

$$V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$$

By replacing one of the resistors with an LDR, we can make a variable voltage divider that is dependent on the light level.

If we replace R_2 with an LDR:

- In dark condition (No obstacle present), R_2 increases as well as the V_{out}.
- In light condition (Obstacle present), R_2 decreases as well as the V_{out}.

Hence, V_{out} can vary according to the R_2. Thus, the LDR acts as a voltage divider.

3.2 Comparator

It uses a quad operational amplifier, LM324 as a comparator. The two voltages that are compared are the input from the sensor module (V_{out}) and the output from the potentiometer (which is set as the reference voltage). There can be two conditions that exist:

$V_{out} > V_{reference}$ -> 1

$V_{out} < V_{reference}$ -> 0

i.e. if the output voltage is greater than the reference voltage received for the potentiometer, than the output is a digital 1 else the output is a digital 0.

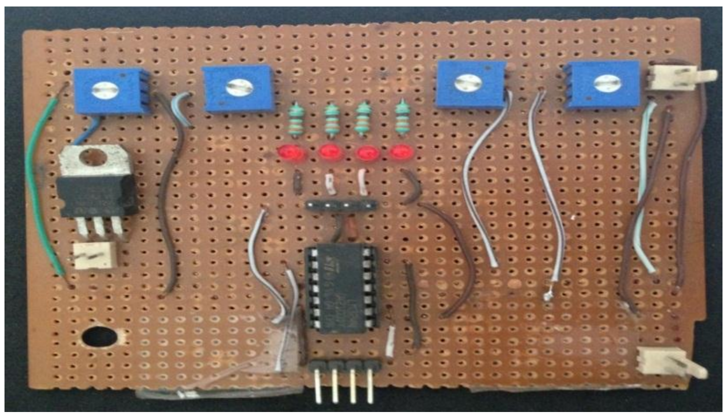


Figure 3.4 The picture shows the comparator circuit used in the Obstacle Detecting and Avoiding Robot. The circuit above shows the potentiometers and the circuit for LM324 that are explained below.

3.2.1 Potentiometer

A potentiometer, informally a pot, is a three-terminal resistor. It forms an adjustable voltage divider with the help of a sliding contact. A potentiometer measuring instrument is basically a voltage divider used for measuring electric potential (voltage) [18].

Potentiometers are used for varying resistance in a circuit. As shown in figure 3.3, a potentiometer has three terminals, the outside two that referred to as A and B and the wiper or the middle terminal referred to as W. Inside the potentiometer body, A and B are connected with the help of a length of resistive material. The wiper that is connected to potentiometer's shaft has a moveable contact point. This contact point can touch the resistive material anywhere along its length [10].

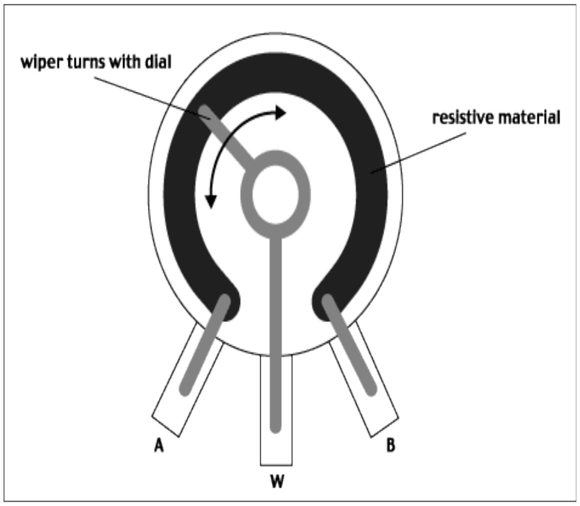


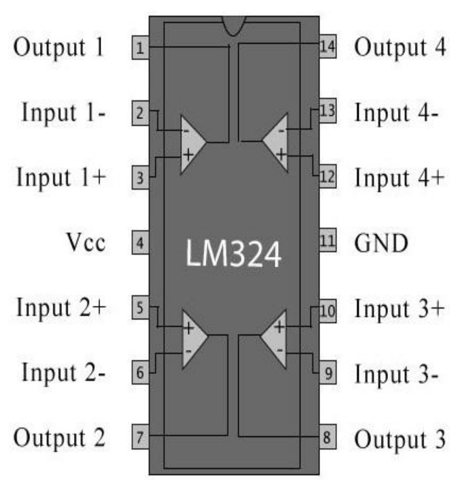
Figure 3.5 Inner built of a potentiometer

The rating of the potentiometer is determined by the total amount of resistance. If it is a 100K pot, 100,000 Ohms of resistance exists between A and B. The resistance between A and B remains the same always. However, since the wiper is moveable, there can be a variable amount of resistive material between A and W or B and W. The more resistive material that there is, the greater is the resistance and the less resistive the material, the lesser the resistance [10].

3.2.2 LM324 (Quad Operational Amplifiers)

The LM324 are quad operational amplifiers that have true differential inputs and very low cost. The device is designed to operate from a single supply and over a range of voltages. It consists of four independent high-gain frequency compensated operational amplifiers. The quad amplifier can operate at supply voltages as low as 3V or as high as 32V with quiescent currents. The common mode input range include the negative supply, thereby eliminating the necessity for external biasing components in many applications. The output voltage range also includes the negative power supply voltage [8].

Figure 3.6 Pin Diagram of LM324



Features:

- Short Circuited Protected Outputs
- True Differential Input Stage
- Single Supply Operation: 3.0 V to 32 V
- Four Amplifiers per Package
- Internally Compensated
- Common Mode Range Extends to Negative Supply
- Industry Standard Pin outs

3.3 Microcontroller

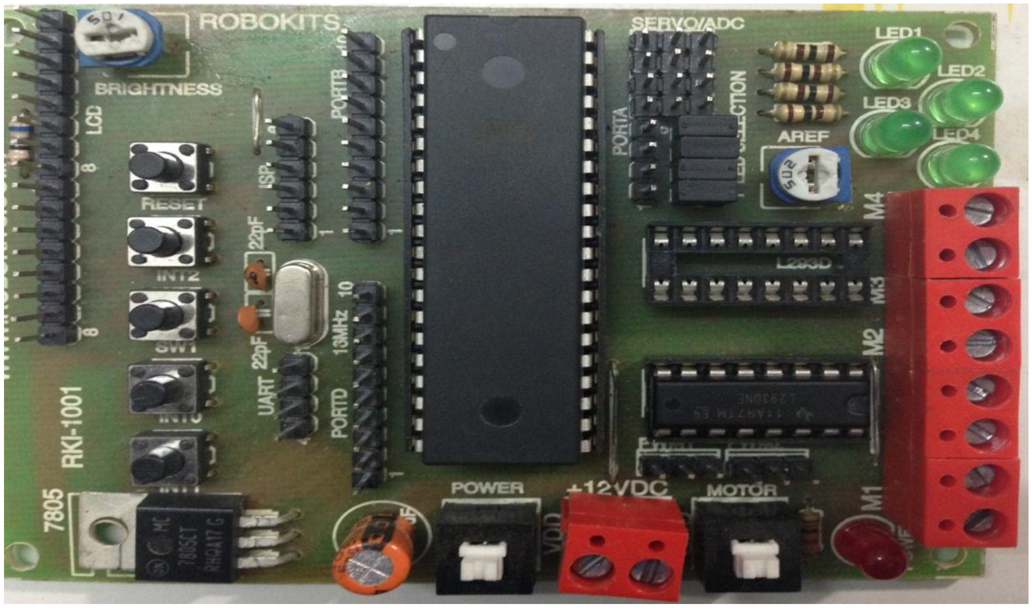


Figure 3.7 The picture shows the AVR 40 pin rapid robot controller board with ATmega32 Microcontroller.

The controller board is used to communicate with the PC using serial communicator (USB connection) and is used during the programming phase that shall give the robot its reactive control law features.

We used the port A to supply input that we got from the output of the comparator and then the output was sent out from port B to the motor driver. The ports C and D were not used for the Obstacle detection and Avoiding Robot.

3.3.1 Features of the Controller Board

Some of the important features of this board are [13]:

- Small Size : 97 x 79 mm
- Can be easily powered with a battery
- On Board Regulator with filters and Operating voltage from 6V - 20 V
- 4 LED's selectable though individual jumpers
- 3 Switches on interrupt pins
- 5 Switches including reset

- Power on/off toggle switch
- Motor on/off toggle switch
- 16MHz crystal for maximum speed
- LCD brightness control
- Frosted Blue Power Indicator
- Onboard space for two L293D motor Drivers
- 2A per channel output capacity
- 4 DC/2 Stepper motor driving capability
- PWM pins connected to motor drivers for speed control of motors

3.3.2 ATmega32 Microcontroller

ATmega32 belongs to the Atmel's Mega AVR family. It is an 8-bit high performance microcontroller. Atmega32 is based on enhanced RISC which stands for Reduced Instruction Set Computing architecture. It has 131 powerful instructions. Execution of the instructions takes place in a single machine cycle. Atmega32 can work at a maximum frequency of 16MHz [7]. ATmega32 has 32KB programmable flash memory and static random access memory (S-RAM) of 2 KB. The pin diagram for ATmega 32 is shown in figure 3.6 below.

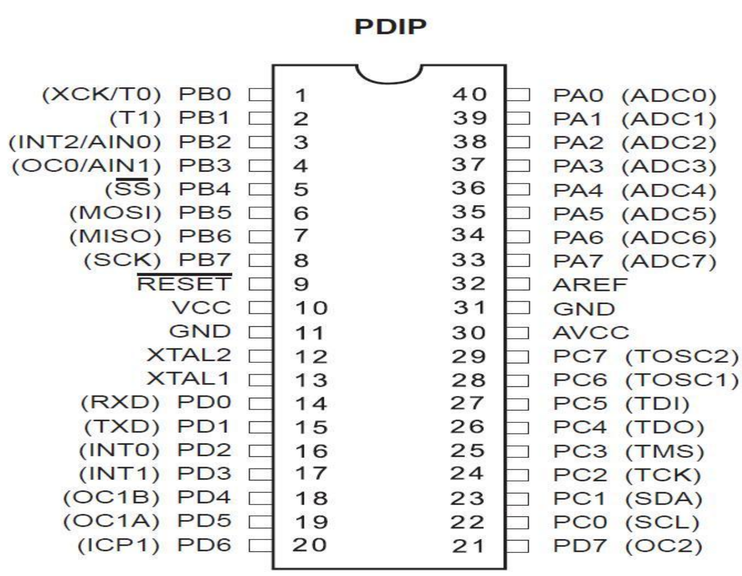


Figure 3.8 Pin Diagram of ATmega 32 microcontroller

3.4 Motor Drivers (L293D IC)

Motor drivers take a low current control signal but provide a higher current signal, thus acting as a current amplifier. The higher current signal drives the motors. L293D is a motor driver that allows direct current (DC) motor to drive on either direction. It contains two inbuilt H-bridge driver circuits [21]. To rotate the motor in clockwise or anticlockwise direction, voltage need to change its direction. H-bridge is a circuit that allows voltage to be flown in either direction. Hence H-bridge IC are ideal for driving a DC motor [20].

While operating in its common mode, it can drive two DC motors simultaneously, in forward as well as reverse direction. The motor operations can be controlled by input logic at pins [2, 7] and [10, 15]. Input logic signal 00 or 11 will stop the motor. Logic 01 will rotate it in clockwise direction and 10 in anticlockwise directions [19].

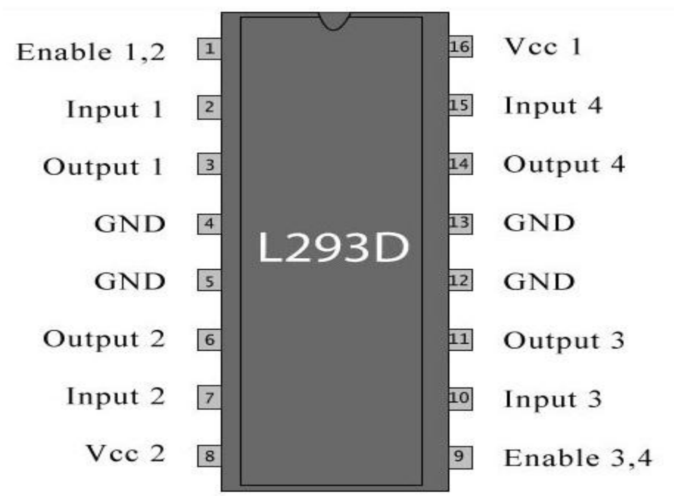


Figure 3.9 Pin Diagram of L293D

Enabling pins [1, 9] that correspond to the two motors, must be high for motors to start operating. When an enable input is high, the associated driver gets enabled. As a result, the outputs become active and work in phase with their inputs.

3.5 Motor (200rpm/ 12V DC Motor)

The obstacle detection and avoiding robot uses two 200rpm and 12V DC geared motors. The motor used has a 6mm shaft diameter with internal holes. The internal holes are for easy mounting of the wheels by using screws. It is an easy to use low-cost motor for robotics application [13].

Chapter-4

Software Implementation

(Programming the robot)

Chapter 4

Programming the Robot

The controller board is used to communicate with the PC using serial communicator (USB connection). The data is transferred between them bit by bit. An adaptor is used to supply power to the controller board and a USB programmer is used to burn the hardware program (written in WinAVR) into the AVR board. WinAVR is a software package for operating systems Windows. It includes a cross-compiler tool and development tools for microcontroller series AVR and AVR32 firm Atmel .WinAVR and all its member programs are free software, released under GNU but distributed in compiled form. [9]

The use of Artificial Intelligence in the designing of the robot is introduced in the programming phase of the robot. The programming for the Obstacle Detecting and Avoiding Robot is done in C Language and uses various pre-defined header file.

4.1 Algorithm

Following steps are taken by the robot we designed to implement the AI logic programmed and to run smoothly on an obstacle avoided path. [11]

Step 1. The artificially intelligent robot gathers facts about a situation with help of sensors.

Step 2. The robot then compares this information to stored data.

Step 3. The robot then decides the significance of the information.

Step 4. The robot runs through different actions that are possible amongst the collected information.

Step 5. The robot predicts what action will be most suitable based on the collected information.

Step 6. The robot then executed the suitable action and moves accordingly.

Chapter-5

Results, Use Cases And Challenges

Chapter 5

Results, Use Cases and Challenges

5.1 Result

A robot that can successfully detect and avoid obstacles was designed and constructed. It was found that given a number of obstacles, the robot is able to detect and avoid the obstacle with an average accuracy of 86.62%. The equation for calculating the accuracy is given below. The numerator signifies the total number of times the robot was able to avoid the obstacle it faced. The denominator signifies the total number of test cases.

$$\textbf{Accuracy} = \frac{\sum Number\ of\ successful\ avoidances}{\sum Number\ of\ test\ cases}$$

Results table

Environment	Type of obstacle	Detected	Avoided	Accuracy
Well-lit	Single solid obstacle	Yes	Yes	100%
Dimly-lit	Single solid obstacle	Yes	Yes	100%
Well-lit	Uniform Shaped surface	Yes	Yes	100%
Dimly-lit	Uniform Shaped surface	Yes	Yes	100%
Well-lit	Non-Uniform Shaped surface	Yes	No	80%
Dimly-lit	Non-Uniform Shaped surface	Yes	No	67%
Well-lit	Double solid obstacles	Yes	Yes	71%
Dimly-lit	Double solid obstacles	Yes	Yes	75%
			Average =	**86.62%**

Table 5.1 The table calculates the average accuracy of the robot when tested against various environment, number of obstacles, and the situations when the obstacle is detected and avoided.

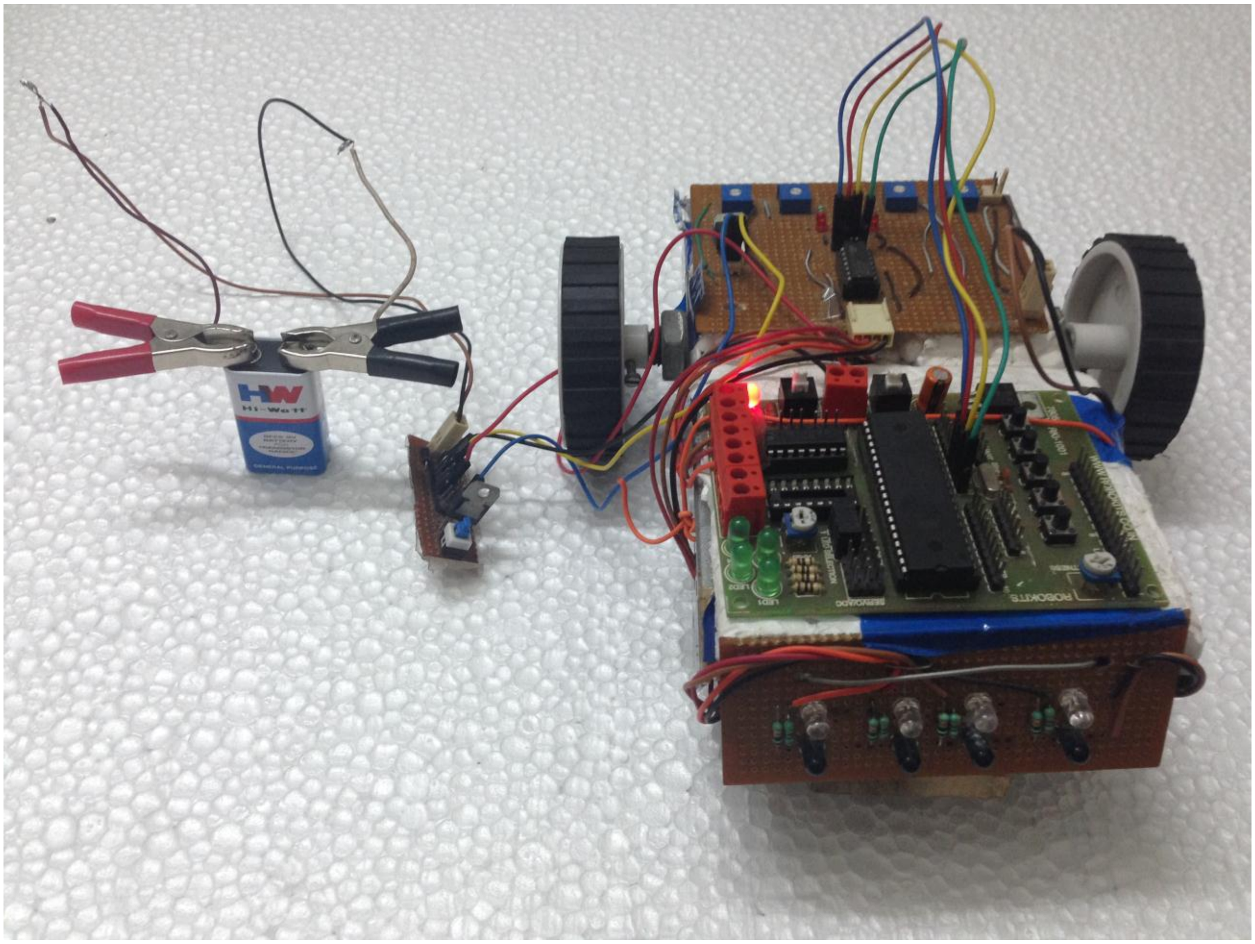


Figure 5.1 The hardware model depicting our project model, Obstacle Detecting and Avoiding Robot.

5.2 Use Cases

5.2.1 Mining Vehicle that uses Obstacle Detection

Reliable obstacle detection is an important characteristic of an auto-driving mining vehicle. Such a vehicle should be able to detect potential dangerous situations that would lead the vehicle itself, other vehicles, personnel or expensive site infrastructure towards unwanted obstacles while navigating through the mine.

Because of the harsh conditions present in mining sites, the development of an obstacle detection system for these vehicles is difficult. The operating environment for a mining site could include mud, extremes of temperature, extreme vehicle pitching, dust, rain, high humidity, diesel fumes, severe vibration, rolling and dark or no light source (underground mines) or bright light sources.

5.2.2 Unmanned vehicle driving

The human mind's ability to process sensory information is very advanced and complex. To try to replace eyes and brains of a human with equally good or better technological devices for driving purpose is extremely difficult as well as tricky.

To identify proper navigation paths and to detect obstacles present on the path, advanced control systems interpret sensory information. Autonomous vehicles sense their surroundings with techniques like radar, global positioning system and computer vision. Some autonomous vehicles update their maps depending on their sensory input, allowing vehicles to keep track of their position even when conditions change or when they enter uncharted environments [22].

5.2.3 Autonomous cleaning robot

Technology exists for complex robots that can to some extent see and feel their surroundings. But still there is a need for autonomous robotic cleaning devices. The complexity, the expenses and the power requirements of these types of robotic syatem make them unsuitable for the consumer marketplace. Therefore a requirement is there to create a robot obstacle detecting system that has a simple design, easy to calibrate or direct, easy to implement, low cost and accurate.

5.3 Challenges

We faced many challenges during the hardware implementation. Some are mentioned below:

- Unavailability of circuit components. Not all the components that we included and selected during the initial designing of the robot were available readily or within the given time frame.

- Keeping the circuit light-weight was a major issue that required careful selection and design of the circuit. It was important to keep the circuit light-weight so that the base and the motor were able to handle the weight in order to give a smooth movement to the robot.

- Cost of sensors, better sensors were available that could improve the accuracy as well as the working of the robot but due to their high cost we choose LEDs.

- Cost of better actuators, the cost of better actuators than the ones we selected makes its use infeasible in such a project. DC motors are readily available and are economically very feasible too, thus our selection.

- Unavailability of intuitive, open, flexible, interactive software that integrates well with the input/output of a robot.

- Battery, the batteries that are readily available in the market tend to be very less environmental friendly. They are never very efficient and most of the available batteries are not rechargeable.

Chapter-6

Conclusion

And

Future Works

Chapter 6

Conclusion and Future Works

6.1 Conclusion

A lot of factors determined the accuracy of the robot we designed. These factors were the environmental phenomenon in which the robot was tested such a well-lit or a dimly-lit environment, the number of obstacles present making the test space crowded or relatively less crowded the type and shape of the obstacle (the robot is designed for a uniform shaped obstacle).

These factors majorly affected the sensors. The accuracy of the robot is dependent on the sensors used. Thus the nature of the sensor and its accuracy defined the accuracy of my robot.

6.2 Future Works

To enable robots to be able to adapt to its environment is an important domain of robotics research. Whether this environment be underwater, on land, underground, in the air or in space.

A fully autonomous robot has the ability to [1]:

- Work for an extended period of time without intervention from human or a need for power supply.
- Avoid situations that are harmful.
- Gain information about the environment and learn ways to adapt to changes in the environment.
- Move either all or part of itself throughout its operating environment.

The work that can be done on our robot in the future in order to enhance its performance are to find ways to meet the challenges described in Section 5.2 of the same thesis. More research can be done to find out lighter weight materials to form the base of the robot. This will provide a smoother movement of the robot. The most effective method to increase the accuracy of our robot is the inclusion of better sensors, although the project cost might increase but the accuracy will definitely increase as well as the problem space where the robot can be used. Better actuators will result in a faster and more efficient robot. The project helped us to see the requirement of more environmental friendly batteries that not only last longer but are also rechargeable. More research could be done on developing environmental yet cost efficient batteries.

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