Development of an Autonomous Mobile Robot for Obstacle Avoidance in Dense Forest Navigation

Submitted By

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Development of an Autonomous Mobile Robot for Obstacle Avoidance in Dense Forest Navigation

Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology in Computer Science and Engineering

Submitted By

Mudit Gupta

(13MCEC11)

Guided By

Prof. K. P. Agrawal

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Certificate

This is to certify that the major project entitled **"Development of an Autonomous Mobile Robot for Obstacle Avoidance in Dense Forest Navigation"** submitted by **Mudit Gupta (Roll No: 13MCEC11)**, towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Computer Science and Engineering of Institute of Technology, Nirma University, Ahmedabad, is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Statement of Originality

I, **Mudit Gupta**, Roll. No. **13MCEC11**, give undertaking that the Major Project entitled "**Development of an Autonomous Mobile Robot for Obstacle Avoidance in Dense Forest Navigation**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Computer Science & Engineering** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. It contains no material that is previously published or written, except where reference has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

Signature of Student
Date:
Place:

Endorsed by
Prof. K. P. Agrawal
(Signature of Guide)

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- Mudit Gupta

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Abstract

Autonomous Moblie robots have been extensively used for conducting the reconnaissance of those areas which are still out of reach of humans or the ones which are very hardly accessible.Hence, development of these types of robots is a very critical task at hand . Therefore, using them for various purposes involves a very important task and that is of making a robot know of obstacles coming in its way. Therefore we deal here with the issues of obstacle avoidance in navigation and the techniques that we are going to deploy. Also the basic control and mechanical aspects which are utilised in developing of the robot.

Abbreviations

GPS	Global Positioning System.
CCD	Charge-Coupled Device.
DC	Direct Current.
RAM	Random Access Memory
ARM	Acorn RISC Machine
USB	Universal Serial Bus
GPIO	General-Purpose Input/Output
HDMI	High-Definition Multimedia Interface

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Contents

List of Figures

Chapter 1

Introduction

Autonomous Mobile Robots are used in various applications like locomotion inside the nuclear reactors to switch the reactions or in case of a shopping mall where the autonomous trolleys follow the person doing shopping at the mall. Hence , the control, mechanical and localisation aspects become a critical issue of such development. Here, a discussion is made regarding these aspects.

1.1 Objective

To develop an Autonomous Mobile Robot for dense forest navigation where communication equipments fail.

1.2 Motivation

In a Dense forest scenario, it is very hard for the communication equipments to work , also it is very hard to create a map of the dense forest area where the aerial picture is not sufficient to show all the possible paths inside the forest. Hence, an effort is made to develop an autonomous mobile robot that will navigate on its own without the help of GPS and will create a map of that area.

1.3 Scope and Methodology

One of the basic assumption made here is that finding a dense forest region nearby is very hard, therefore we will try to make a map of a small area which is not dense vegetation. Second Assumption will be that there will be no living obstacle and the possibility of that is nullified. Third assumption is that communication equipments do not work in

that area and the robot also does not use any communication equipment.
An Autonomous mobile robot will be developed in order to create a map of an area which is similar to dense forest in terms of communication failure and that will localise itself according to the kalman filter localisation approach. This will require meticulous study of mechanical design and strong Localisation concepts.

1.3.1 Limitations

The limitation of this project is that if in case any living obstacle comes in front of it , it won't destroy it as it is basically fabricated for generating maps so in case any animal comes in front of this robot and destroys it. it will take no action. Speed limitation is there as for generating maps sophisticated level of processing is done to generate accurate maps.

Chapter 2

Literature Survey

2.1 General

In Literature Survey many papers related to the field of Autonomous Mobile Robot development were studied by me. The basics of Control Theory were studied in order to get into the depth of working control system of the robot. Mechanical Aspects were studied to get into the depth of design so as to cater to the base design and kind of wheels that are going to be utilised. Localisation strategies were studied in order to get the idea of which localisation strategy is to be used.

2.2 Literature Review

2.2.1 Control Theory Aspect

The control theory aspect basically covers the following key concepts which govern the behaviour of the robot in an environment :

- State = What the system is presently doing
- Dynamics = Description of how changes occur in states
- Reference = What we need the system to do
- Output = Measurement of (some aspects of the) system
- Input = Control signal
- Feedback = Mapping inputs from outputs[1]

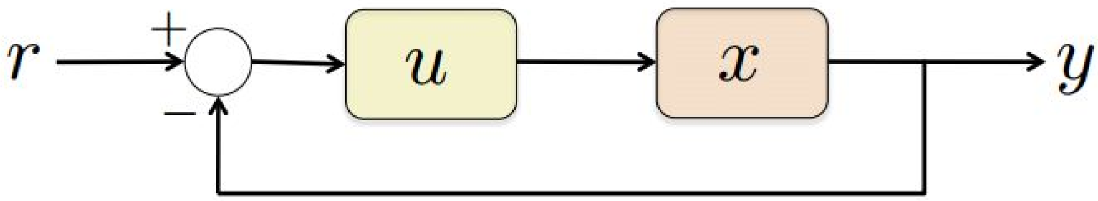


Figure 2.1: Control Diagram[1]

The basic objective regarding the control aspect is how to pick the control signal[1][2]. Main goals to be fulfilled are :

- Stability
- Tracking
- Robustness
- Disturbance Rejection
- Optimality

The control system environment is very unpredictable and hence full of errors. [1]. To overcome those errors, regulators are required:

P-Regulators

Without any regulators, for small errors, the controller over-reacts.
If we Modify control equation as :

$$u = ke \tag{2.1}$$

The result will be:

- Small error produces small control signals
- Nice & smooth

P-Regulator provides stability but does not provide tracking

PI-Regulators

In PI-Regulator, equation used is:

$$u(t) = k_P e(t) + k_I \int_0^t e(\tau) d\tau \qquad (2.2)$$

where,

k_P = Constant for proportional term.

k_I = Constant for integration term.

The above Regulators provide stability but they are error prone[1].

PID-Regulators

$$u(t) = k_P e(t) + k_I \int_0^t e(\tau) d\tau + k_D \frac{de(t)}{dt} \qquad (2.3)$$

- P: Contributes to stability, medium-rate responsiveness
- I: Disturbance rejection and Tracking, slow-rate responsiveness. It may cause oscillations
- D: Fast-rate responsiveness. Sensitive to noise
- PID: By far the most used low-level controller. But stability is not guaranteed.
- Feedback has a remarkable ability to fight uncertainty in model parameters.

Behavior-Based Robotics

- The world is fundamentally unknown and changing
- Does not make sense to over-plan
- Key idea: Develop a library of useful controllers (=behaviors)
- Switch among controllers in response to environmental changes[1]

2.2.2 Mechanical Aspect

The mechanical aspects consider what kind of design is going to be employed in this project. Also, considerations regarding wheels are made keeping in mind the terrain.

1)Three-omnidirectional wheel control on mobile robot

Traditional two wheels differential drive normally used on mobile robots have maneuverability limitations and take time to sort out. Most teams use two driving wheels (with one or two cast wheels), four driving wheels and even three driving wheels. A three wheel drive with omni-directional wheel has been tried with success, and was implemented on fast moving autonomous mobile robots.Hence, the kinematics were studied to finalise the three-omnidirectional robot[3].

2)Analytical Configuration of wheeled robot

Because of their ability to navigate and perform tasks in unstructured environment, robots

have made their way into applications like cultivating, earth moving, waste clean-up and

exploration. All mobile robots use locomotion that creates traction, negotiates territory and

conveys payload. A well-designed robotic locomotion stabilizes a robots frame, smooths the movement of sensors and accommodates the deployment and control of work devices.

Locomotion is the

means by which robot responds to gravitational, inertial and work loads, because it is the physical interface between a robot and its environment.[4][5].

In spite of its significance, locomotion design and its implications on robotic function have not

been addressed. Actually, except for a modest bunch of detailed analyses, the issue of how to

blend robotic locomotion configurations remains a point of ad hoc speculation and is

regularly sought after in a manner that needs defense.

Here, the project concentrates on the

design of wheeled robotic locomotion through the systematic evaluation and formulation of configuration equations.[4] They are mathematical functions which shows quantitative connections among configuration parameters (e.g., wheel diameter, chassis articulation location), performance parameters (e.g. drawbar pull, max gradeable incline) and natural/task parameters (e.g. geophysical properties, soil and thickness).

3)Autonomous Mobile Robot Design

The configuration of AMR equipped for adroit movement and action includes the reconciliation of numerous diverse assemblages of learning. The point of this venture is to glorify a current Autonomous Mobile Robot, on all levels. This incorporates the mechanics, kinematics, dynamics, perception, sensor fusion, localization, path planning and navigation. All these perspectives must be assessed and adjusted to a modular system, if important new modular modules must be planned and created. Thus a strong and secluded Autonomous Mobile Robot, capable of adroit motion and performing diverse assignments will emerge[4].

Mechanical configuration is fundamentally an creative activity which includes a decision making procedure. It is guided at the fulfillment of a specific need by means of a mechanical system, whose general arrangement, performance particulars and detailed definition conforms the definitive assignment of the design activity[6].There is no bounded approach or system to design a system, in such a great amount as there does not exist a unified approach to creativity. Given a specific need, every individual planner would presumably design something else.

4)Geometric kinematics of mobile robot

For wheeled mobile robots, many types of kinematics modeling and platform designs have been studied. For large and heavy outdoor mobile robots, car-like driving mechanisms or skid-steer platforms have been used. Although, nonholonomic constraints on their wheel mechanism restricts motion of these mobile robots in tight indoor environments[6].

To reduce these restrictions one way is to substitute the coupled steering wheels with one wheel. Wheel-to-ground contact in the three-wheeled mobile robot has the advantage that contact can be sustained on all wheels without any suspension system.

The single wheel is the drive as well as the steering wheel, hence put all other wheels in idle. [6].

Chapter 3

Proposed Architecture

3.1 Details of Each Components

- Sharp Infrared Sensors:

  Analog Rangers and Digial Detectors are two major types of Infrared Sensors. Analog rangers provide information about the disance between robot and object. If an object happens to be present closer than a predefined distance, digital detectors gives a digital indication. Distance of objects in the field of view can be computed by using triangulation and a linear CCD array, used by these rangers. For triangulation, emitter emits a pulse of IR light. The light is never reflected in the case of no object, and the reading shows no object. If the light reflects due to an object, it returns to the detector and creates a triangle between the point of reflection, the emitter and the detector.[7] Based on the distance to the object, the angle of incidence of the reflected IR light differs. The receiver portion transmits reflected light onto different portions of the enclosed linear CCD array depending on the incident angle of the reflected light. CCD array then determines the incident angle, and thus calculate the distance to the object.[7]

- Wide Angle Camera:

  A wide angle camera will be mounted on the robot so that obstacles can be identified through image processing.

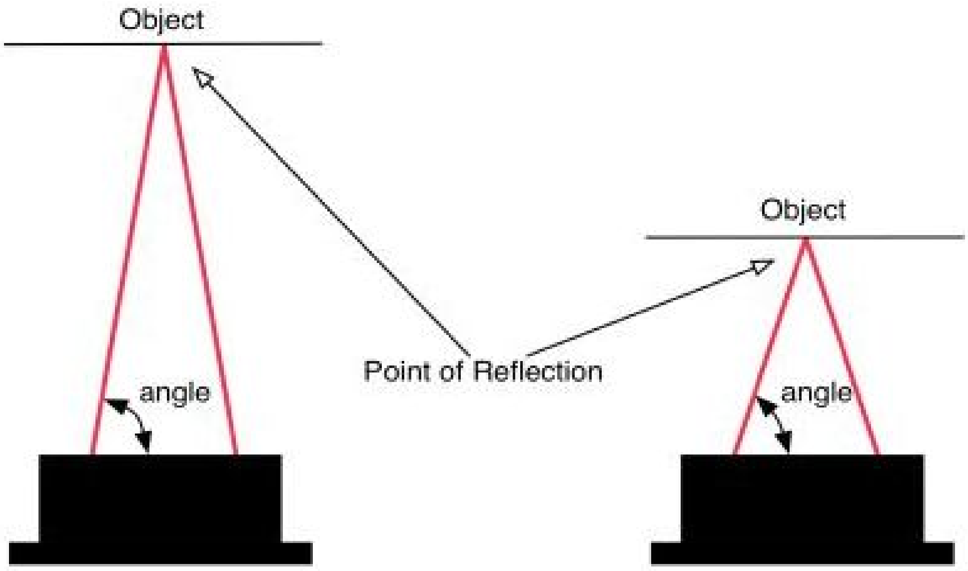


Figure 3.1: Sharp IR detector
[7]

- Servo Motor:

  A servo motor will be attached to the camera, which will rotate it, to get large field of view.

- DC Motor:

  12V DC Motor will be connected to wheel to make it move forward/ backward direction and left/right direction.

- Wheels:

  There will be two types of wheels attached to the robot:

  – Caster Wheel:
    A caster wheel is designed to be mounted at the bottom of a large object so as to make it move easily. In this project Caster wheel will be connected to dc motor and attached at front base of the robot to steer the robot in any direction.

Figure 3.2: Caster Wheel
[8]

- Support Wheels:

  These wheels will be used to maintain the balance of robot and prevent it from falling backward

- Raspberry Pi:

  The Raspberry Pi is a single-board computer developed in the UK by the Raspberry Pi Foundation with the intention to promote the teaching of basic computer science in schools.[9] It includes:

  - ARM Processor(700MHz)
  - 512 MB of RAM
  - 4 USB ports
  - Micro SD socket for boot media
  - 100mb Ethernet port
  - 40 pins of GPIO
  - HDMI Port

- Audio Outlet port

In Differential Drive:

At each time instant, the left and right wheels must follow a trajectory that moves around the ICC at the same angular rate ω i.e.

$$\omega(R + \frac{L}{2}) = V_R \tag{3.1}$$

$$\omega(R - \frac{L}{2}) = V_L \tag{3.2}$$

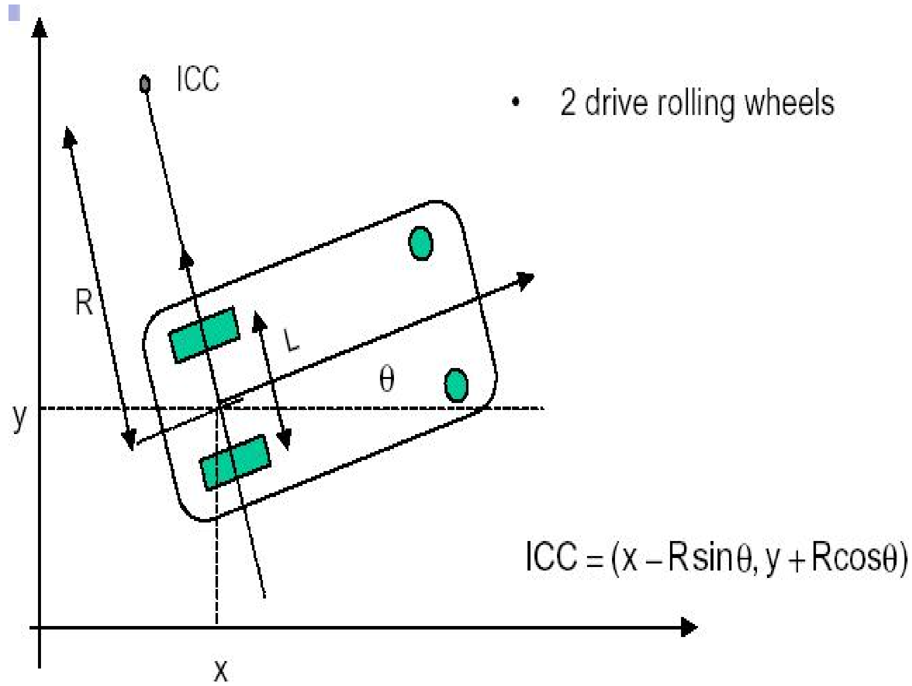


Figure 3.3: Differential Drive
[10]

where,

V_R(t) : Linear velocity of Right Wheel

V_L(t) : Linear velocity of Left Wheel

R : Instantaneous curvature radius of the robot trajectory

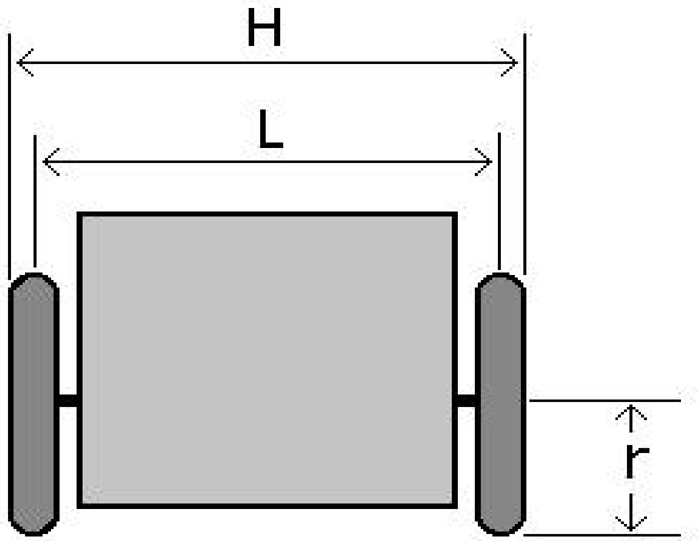


Figure 3.4: Parameters of Robot Body
[10]

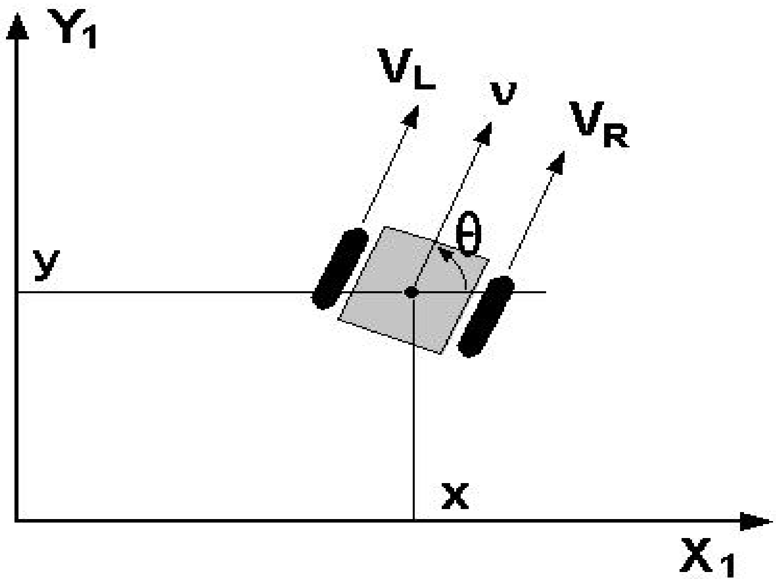


Figure 3.5: Notations for Differential Drive
[10]

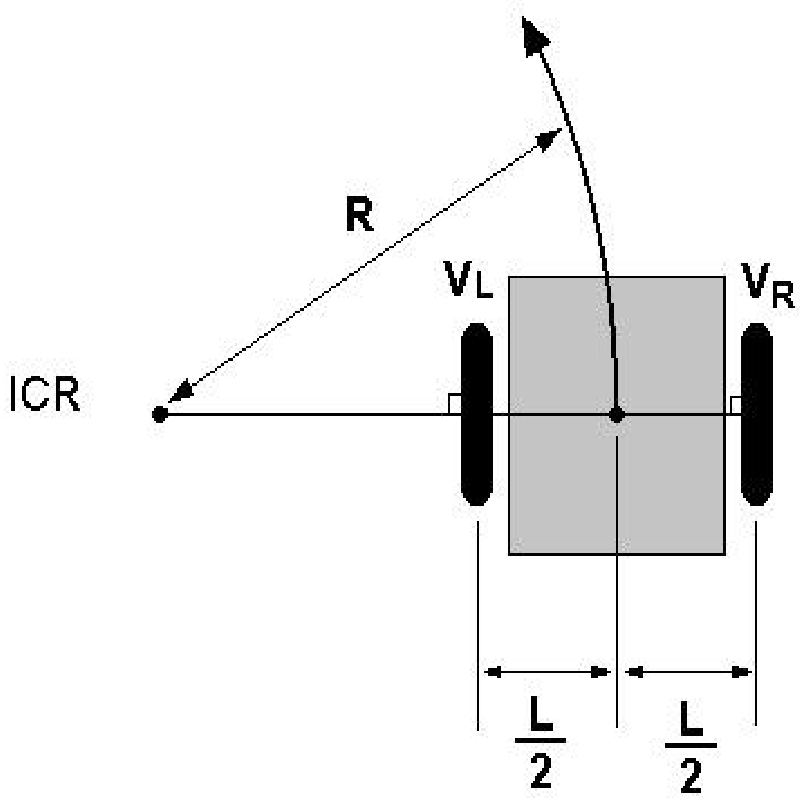


Figure 3.6: Notations for Differential Drive
[10]

- Posture of Robot:

$$P = \begin{pmatrix} x \\ y \\ \theta \end{pmatrix} \tag{3.3}$$

where,

(x,y) : Position of Robot

θ : Orientation of Robot

- Control input

$$U = \begin{pmatrix} v \\ \omega \end{pmatrix} \tag{3.4}$$

where,

v = Linear velocity of robot

ω = Angular Velocity of wheels

- Kinematic Model in World Frame:

  - Relation between control input and velocities of wheel:

$$\omega = \frac{V_R - V_L}{L} \tag{3.5}$$

$$v = \frac{V_R + V_L}{2} \tag{3.6}$$

  - Kinematic Equation:

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} cos\theta & 0 \\ sin\theta & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} v \\ \omega \end{pmatrix} \tag{3.7}$$

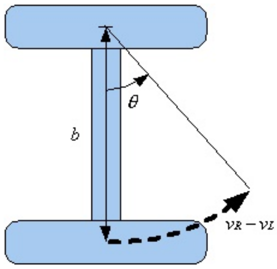
- Kinematic Model in Robot Frame:

$$\begin{bmatrix} v_x(t) \\ v_y(t) \\ \dot{\theta}(t) \end{bmatrix} = \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \\ 0 & 0 \\ -\frac{r}{L} & \frac{r}{L} \end{bmatrix} \begin{bmatrix} \omega_L(t) \\ \omega_R(t) \end{bmatrix} \tag{3.8}$$

Chapter 4

Approach and Simulation

4.1 Approach



[11]

Figure 4.1: Two wheels at different Velocities

- The definition of an angle given in radians is the length of a circular arc divided by the radius of that circle

- The relative velocity of the right wheel gives us that length of arc per unit time

- The length from the wheel to the center point gives us the radius.

- Based on these observations

$$\frac{d\theta}{dt} = \frac{(v_r - v_l)}{b} \tag{4.1}$$

- Integrating (4.1) and taking the initial orientation of the robot as $\theta(0) = \theta_0$

$$\theta(t) = \frac{(v_r - v_l)t}{b} + \theta_0 \tag{4.2}$$

- The velocity of robot is simply the average of velocities of the two wheels

$$\frac{dx}{dt} = \frac{(v_r + v_l)}{2} cos(\theta(t)) \tag{4.3}$$

$$\frac{dy}{dt} = \frac{(v_r + v_l)}{2} sin(\theta(t)) \tag{4.4}$$

- Integrating (4.3),(4.4) and taking the initial position of the robot as $x(0) = x_0$ and $y(0) = y_0$

$$x(t) = x_0 + \frac{b(v_r + v_l)}{2(v_r - v_l)}[sin(\frac{(v_r - v_l)t}{b} + \theta_0) - sin(\theta_0)] \tag{4.5}$$

$$y(t) = y_0 - \frac{b(v_r + v_l)}{2(v_r - v_l)}[cos(\frac{(v_r - v_l)t}{b} + \theta_0) - cos(\theta_0)] \tag{4.6}$$

- condition to rotate robot at particular point

$$v_l = -v_r \tag{4.7}$$

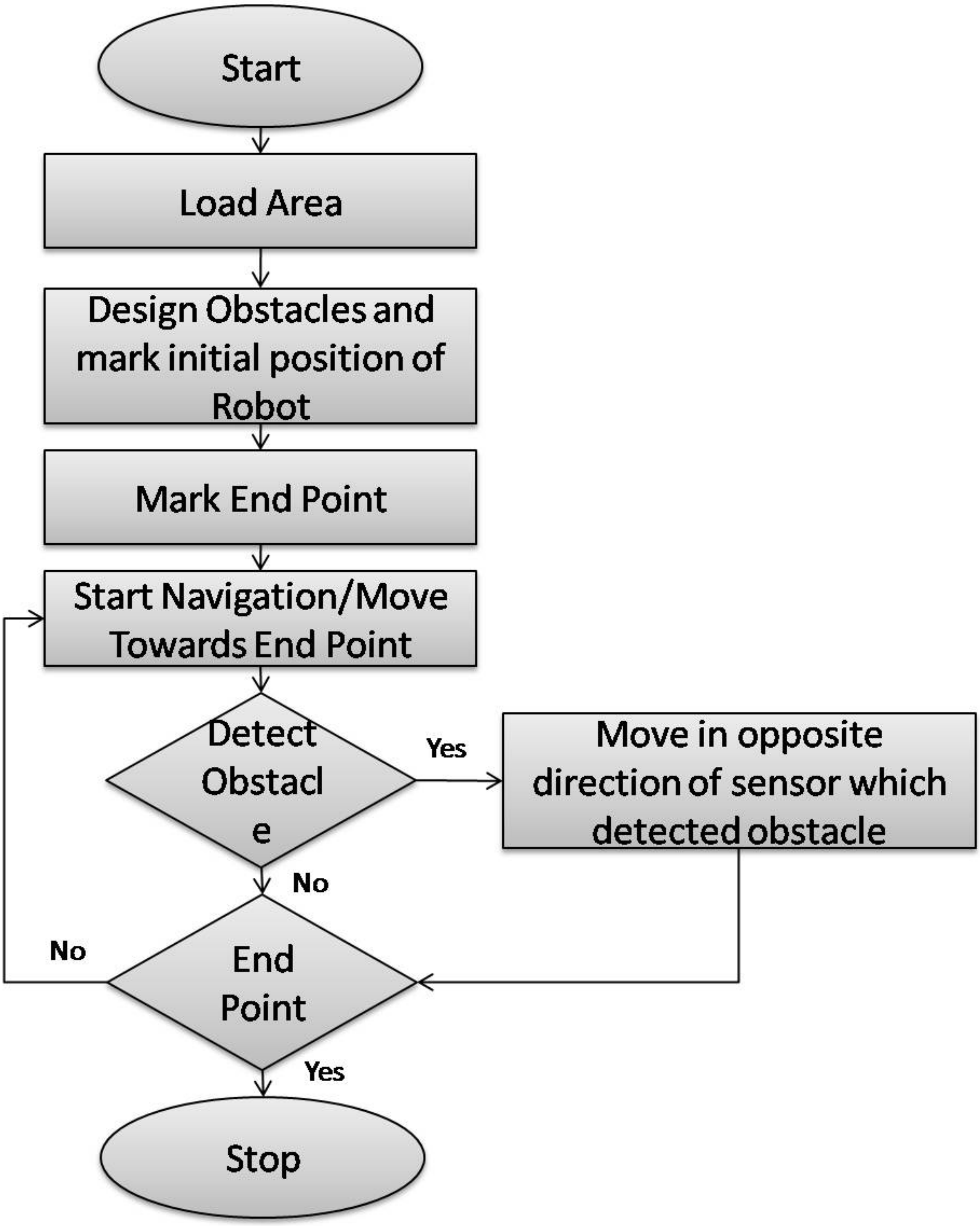


Figure 4.2: Flow graph of Obstacle Avoidance in Navigation

4.2 simulation

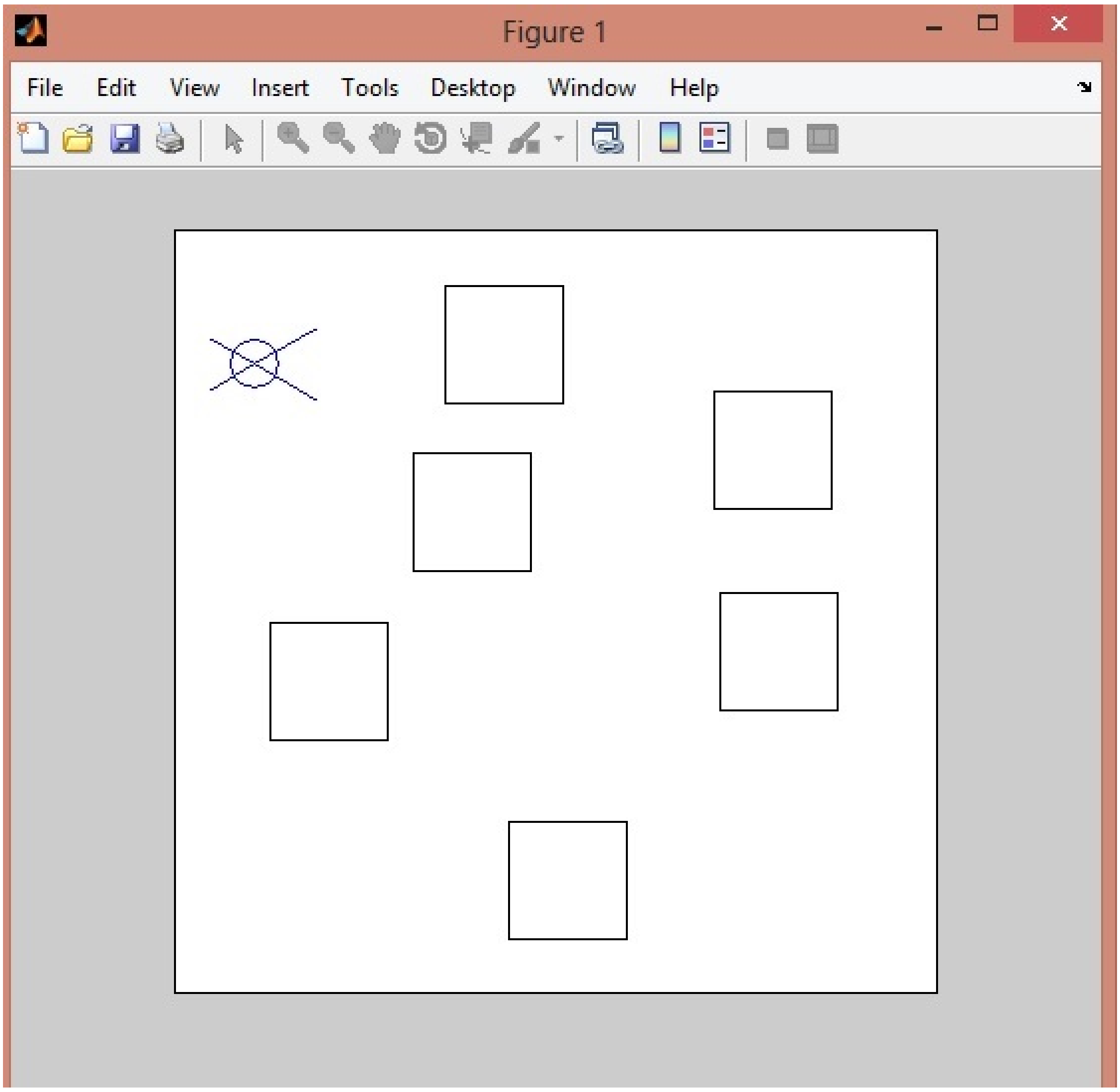


Figure 4.3: Designing Obstacle and Starting Position of Robot

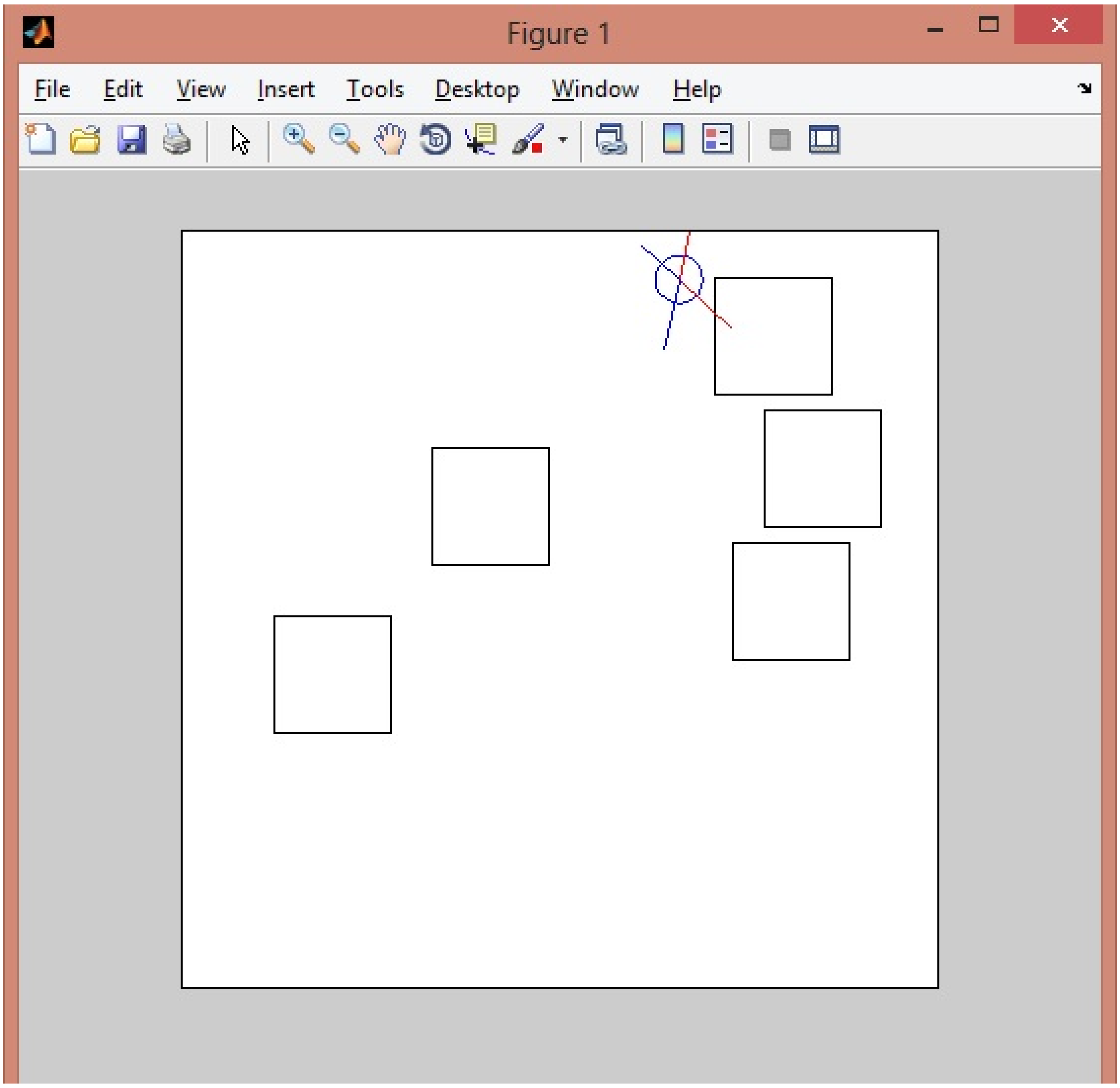


Figure 4.4: Obstacle Avoidance

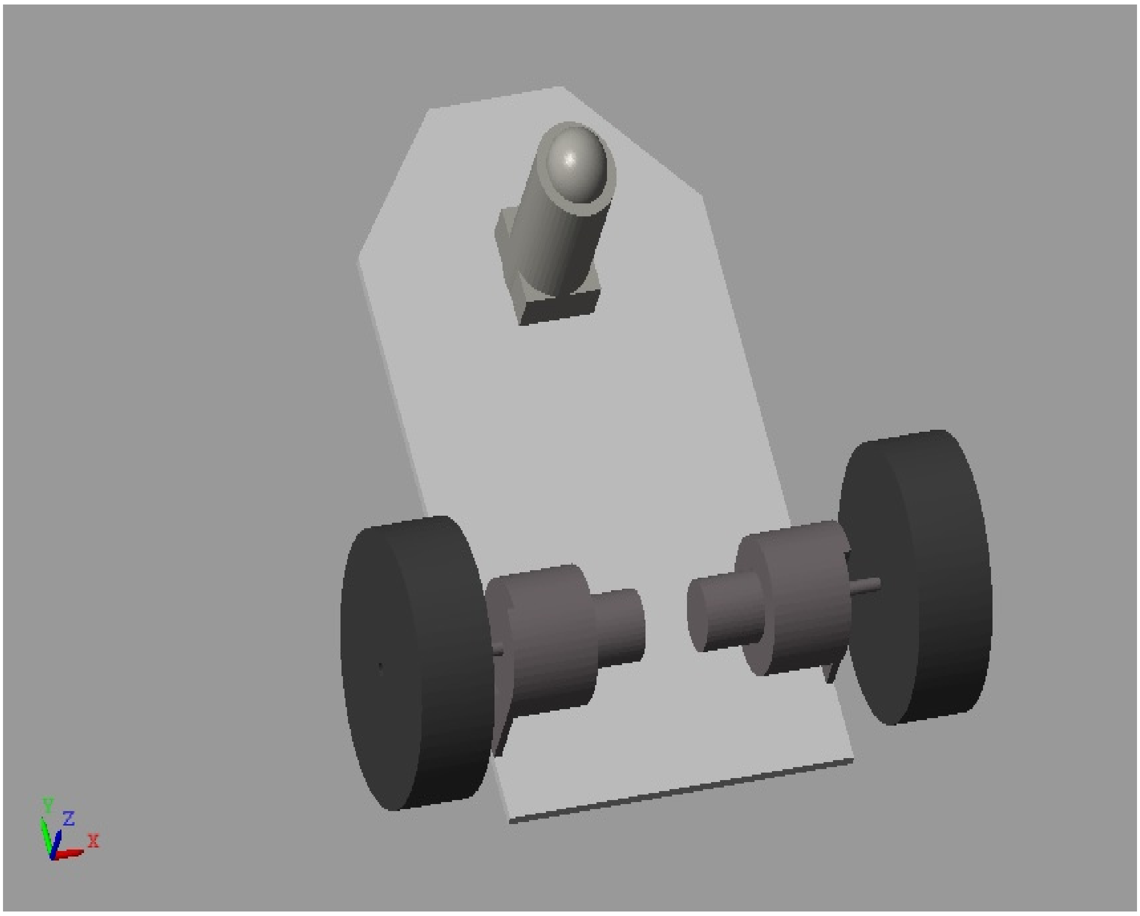


Figure 4.5: 3-D Model

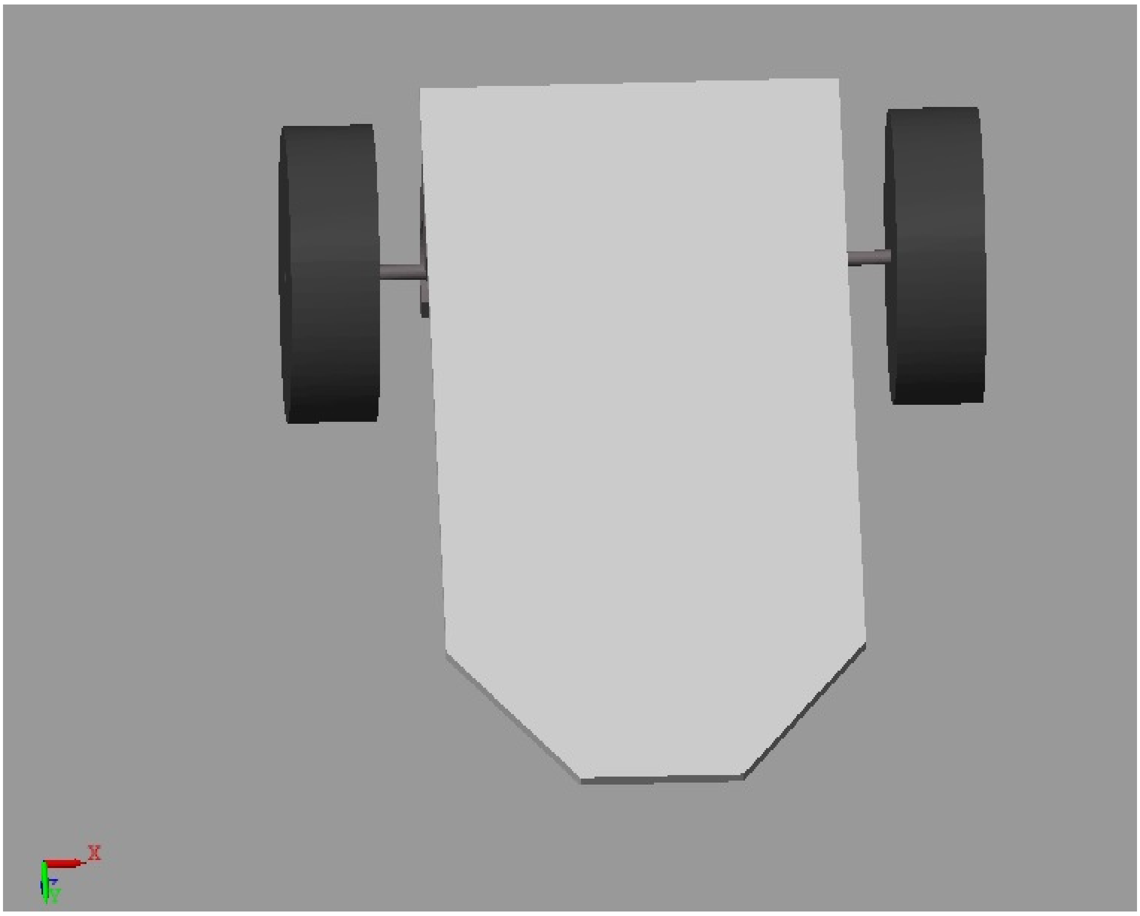


Figure 4.6: 3-D Model

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

The initial phase consisted of knowing the basic aspects of control theory. Then the design stage took place in which various designs were considered and finally one was chosen that of three wheeled robot system in which we have one castor wheel at the front and two standard wheels at the back. Some Components have been bought, i.e. 2 DC Motors,One Servo Motor, One raspberry Pi Controller Board(B+ model) and one Power Bank.

A sincere effort has been made to create obstacle avoidance algorithm for the movement strategy of robot.

5.2 Future Scope

- Algorithm can be made for 3-D Model
- A.I. Technique can be applied for Navigation Algorithm

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