CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A robot is a mechanical or virtual artificial agent. In practice, it is usually an electro-mechanical system which, by its appearance or movements, conveys a sense that it has intent or agency of its own. The word robot can refer to both physical robots and virtual software agents, but the latter are usually referred to as robots.

Throughout the history, people have tried to make robots, but only in the 20th century that technology became advanced enough to create fully autonomous machines with the ability to make decisions of their own. Today robots are in widespread use in factories for welding, assembling and packing and are beginning to appear at homes too. There is a huge variety of robots helping us in medicine, space, the battlefield and helping scientists study intelligence and learning.

For robotic engineers, (Deb 2003) the physical appearance of a machine is less important than the way its actions are controlled. The more the control system seems to have agency of its own, the more likely the machine is to be called a robot. A typical robot will have several, though not necessarily all of the following properties:
• It is not natural, but artificially created.

• It can sense its environment, and manipulate or interact with things in it.

• It has some ability to make choices based on the environment, often using automatic control or a preprogrammed sequence.

• It is reprogrammable.

• It makes dexterous coordinated movements.

• It moves without human intervention.

The robotic field has achieved its greatest success to date in the world of industrial manufacturing. Robot arms or manipulators comprise a billion dollar industry, bolted at its shoulder to a specific position in the assembly line, the robot arm can move with great speed and accuracy to perform repetitive tasks. Yet, for all of their successes, these commercial robots suffer from a fundamental disadvantage: Lack of mobility.

A fixed manipulator has a limited range of motion that depends on where it is bolted down. In contrast, a mobile robot would be able to travel all over the manufacturing plant, flexibly applying its talents wherever it is most effective.

1.2 MOBILE ROBOT

Mobile robotics is a young field that studies the mobile robot. Its root includes many engineering and science disciplines from mechanical, electrical and electronics engineering to computer, cognitive and social sciences. Mobile robot is an automatic machine that is capable of movement in a given environment. Mobile robots have the capability to move around in
their environment and are not fixed to one physical location. In contrast, industrial robots usually consist of a jointed arm and gripper assembly or end effector that is attached to a fixed surface.

Mobile robots (George Giralt 1988, Crowley 1989, Jerome Barraquand and Latombe 1991, Jin-Oh Kim and Khosla 1992, Johann Borenstein and Yoram Koren 1991, Johann Borenstein and Liqiang Feng 1998) are the focus of a great deal of current research and almost every major university has one or more labs that focus on research of mobile robot. Mobile robots are also found in industry, military and security environments. They also appear as consumer products for entertainment or to perform certain tasks like vacuum cleaning. Mobile Robot must be:

- able to perceive the environment,
- able to make decisions,
- able to represent sensed data,
- able to acquire knowledge,
- able to infer rules concerning the environments.

1.2.1 Challenges in Mobile Robot

In order to achieve the mobility, the mobile robot should meet out the challenges mentioned below; (Rolland Seigward and Nourbaksh 2004)

i. Low level locomotive ability and Perception
ii. Higher level localization and Cognition

Locomotion begins with a survey of the most popular mechanisms, wheels and legs. Numerous robotic examples demonstrate the particular talents of each form of locomotion. But designing a mobile robot’s
locomotive system properly requires the ability to evaluate its overall motion capabilities quantitatively. One should understand the principles of kinematics to the whole mobile robot beginning with the kinematics contribution of each wheel and graduating to an analysis of robot maneuverability for getting mobility.

The greatest single short coming in conventional mobile robots is perception. Mobile robots can travel across much earth’s man-made surfaces, but they cannot perceive the world nearly as well as humans and other animals. Perception starts a discussion of this challenge by presenting a clear language for describing the performance envelope of mobile robot sensors. The most promising sensor for the future of mobile robots is visions sensors, particularly, charged coupled device (CCD) and complementary metal oxide semiconductor (CMOS) sensors. But perception is more than sensing. Perception is also the interpretation of sensed data in meaningful ways. i.e. feature extraction. The strategies for feature extraction that have been most useful in mobile robotics applications including extraction of geometric shapes from range based sensing data as well as landmark and whole image analysis using vision based sensing.

Armed with locomotion mechanism and outfitted with hardware and software for perception, the mobile robot can move and perceive the world. The first point at which mobility and sensing must meet is localization. Mobile robot localization describes approaches that obviate the need for direct localization and then delves into fundamental ingredients of successful localization strategies, belief representation and map representation using various localization schemes like Markov localization and Kalman filter localization.

Mobile robotics is so young a discipline that it lacks a standardized architecture. There is as yet no established mobile robot operating system. But
the question of architecture is of paramount importance when one chooses to address the higher level competences of a mobile robot: how does a mobile robot navigate robustly from place to place, interpreting data, localizing and controlling its motion all the while? For this highest level of robot competence, which termed as navigation competence, there are numerous mobile robots that show cases of particular architectural strategies.

The general aspects of a mobile robot control and navigation are described as various modules as shown in Figure 1.1.

Figure 1.1 Module structures of mobile robot system

Planning and navigation surveys the state of art of mobile robot navigation, showing that various techniques are quite similar, differing
primarily in the manner in which they decompose the problem of mobile robot control.

1.2.2 Classification of Mobile Robot

Mobile robot may be classified by the environment in which they travel and the device they use to move:

- The environment in which they travel,
  - Land or home robot. They are most commonly wheeled, but also include legged robots with two or more which are resembling animals or insects.
  - Aerial robots usually referred to as unmanned aerial vehicles (UAV).
  - Under water robots usually called as autonomous under water vehicles (AUV).

- The device they use to move,
  - Legged robot: human-legs like (i.e. Humanoid) or animal-legs like.
  - Wheeled robot.
  - Track robot

Based on navigation, the classifications of mobile robots are:

**Manual remote or tele-operated Robot:** A manually tele-operated robot is totally under control of a driver with a joystick or other control device. The device may be plugged directly into the robot, may be a wireless joystick, or may be an accessory to a wireless computer or other controller. A tele-operated robot is typically used to keep the operator out of harm's way.
Examples of manual remote robots include Foster-Miller's Talon, iRobot's, PackBot and KumoTek's MK-705 Roosterbot.

**Guarded tele-operated Robot:** A guarded tele-operated robot has the ability to sense and avoid obstacles but will otherwise navigate as driven, like a robot under manually tele-operated. Few of any mobile robots offer only guarded tele-op.

**Autonomously guided robot:** Some of the earliest AGVs were line following mobile robots. They might follow a visual line painted or embedded in the floor or ceiling or an electrical wire in the floor. Most of these robots operated a simple "keep the line in the center sensor" algorithm. They could not circumnavigate obstacles; they just stopped and waited when something blocked their path.

**Autonomously randomized robot:** Autonomous robots with random motion basically bounce off walls, whether those walls are sensed with physical bumpers like the Roomba cleaners or with electronic sensors like the Friendly Robotics lawn mower. The simple algorithm of bump and turn 30 degrees leads eventually to coverage of most or all of a floor or yard surface.

**Autonomous under water vehicle:** An Autonomous Under water Vehicle (AUV) is a robot which travels under water. In military applications, AUVs are also known as unmanned under sea vehicles. AUVs constitute partly of a larger group of under sea system of unmanned vehicles, a classification that includes non autonomous remotely operated underwater vehicles. It is controlled and powered from the surface by an operator or pilot.

**Unmanned aerial vehicle:** An Unmanned Aerial Vehicle (UAV) is a remotely piloted aircraft. UAVs come in two varieties, some are controlled
from a remote location, other fly autonomously based on preprogrammed flight plans using more complex dynamic automation algorithm. Currently, UAVs perform reconnaissance as well as attack missions. They are also used in a small but growing number of civil applications such as fire fighting. UAVs are often preferred for missions that are too dull, dirty or dangerous for manned aircraft.

**Domestic robot:** A domestic robot is one used for household purposes. There are different types and classes of domestic robot.

- Low level basic home robot that is entertaining robot like AIBO, cleaning robot ROOMPA etc. that can be used at home.
- High level domestic robot called as domobot used for smart environment that outdoor robots like lawnmowers, automated pool cleaners etc.

**Humanoid robot:** A humanoid robot is one with its overall appearance based on that of the human body, allowing interaction with made-for-human tools or environments. The humanoid robots have a appearance with a head, two arms and two legs, although some forms of humanoid robots may model only part of the body, for example, from the waist up. Some humanoid robots may also have a face with eyes and mouth. Androids are humanoid robot built to aesthetically resemble a human.

**Truck like mobile robot:** The truck like mobile robot is an autonomous vehicle that can drive itself from one point to another without assistance from driver. It is a truck in conjunction with the increased use of virtual reality for travel and various materials handling work could reduce the world’s huge number of trucks to a fraction of that number with in few
decades. In this thesis, the whole content is focused on the truck like mobile robot. In the modern industry, automation is inevitable. The truck like mobile robot plays a vital role in the automated industry mainly in the materials handling division for loading and unloading the containers. In the automated industry, in order to eliminate the drivers from the truck by the path tracking controllers to get more accuracy while driving the truck, it should successfully meet out the following competences.

### 1.2.3 Competences in Truck like Mobile Robot

In order to drive the truck like mobile robot, the system would need to:

- Understand its immediate environment (Perception)
- Know where it is and where it wants to go (Navigation)
- Find its way in traffic (Motion Planning)
- Operate the mechanics of the vehicle (Control and Actuation)

**Perception:** Perception employed in truck like mobile robots vary from the low level monochrome stereoscopy sensing to mobile eye’s intermodal sensing i.e. video, infrared, laser, radar approach. The low level sensing system imitates the human situation most closely, while the multimodal approach is greedy in the sense that it seeks to obtain as much information as is possible by current technology, even at the occasional cost of one vehicle’s detection system interfering with another. Mobile eye is a company making detection systems for mobile robots, which are currently used only for driver assistance, but are eminently suitable for a full fledged driver less trucks. The capabilities of the system, all pedestrians, movement of other handling devices etc are clearly displayed in the video of mobile eye, with a frame around them and the distance between the truck like mobile
robot and the object observed. The system also detects the object’s motion (direction & speed) and can calculate relative speeds and predict collisions.

**Navigation and Path Planning:** The ability to plot a route from the place where the vehicle is and to the place where the user wants to be. Now the challenge turns its attention to the mobile robot’s cognitive level. Cognition generally represents the purposeful decision making and execution that a system utilizes to achieve its highest order goals. In case of a truck like mobile robot, the specific aspect of cognition directly linked to robust mobility is navigation competence. Given partial knowledge about its environment and a goal position or series of positions, navigation encompasses the ability of truck like mobile robot to act based on its knowledge and sensor values so as to reach its docking positions as efficiently and as reliably as possible. With in the mobile robot research community, a great many approaches have been proposed for solving the navigation problem.

However any one discusses two key additional competences required for mobile robot navigation. The first one is path planning that involves identifying a path that will cause mobile robot to reach the goal location when executed, if one gives a map and the goal position. Path planning is a strategic problem solving competence, as the mobile robot must decide what to do over the long term to achieve its goals. The second competence is equally important but occupies the opposite, tactical extreme. Given real time sensor readings, obstacle avoidance means modulating the path of the mobile robot in order to avoid collision. A great variety of approaches have demonstrated competent obstacle avoidance; and one can survey a number of these approaches as well.

In the artificial intelligence community, planning and reacting are often viewed as contrary approaches or even opposites. These two are
considered as the strong competences for mobile robot navigation. In fact, when applied to physical systems such as mobile robots, planning and reacting have strong complementarity, each being critical to other’s success. The navigation challenge for a mobile robot involves executing a course of action or plan to reach its goal position. During execution, the mobile robot must react to unforeseen events such as obstacles in such a way as to still reach the goal. Without reacting, the planning effort will not pay off because the mobile robot will never physically reach its goal. Without planning, the reacting effort cannot guide the overall behavior of the mobile robot to reach a distant goal again, the mobile robot will never reach its goal.

**Control and actuation of truck like mobile robot:** A mechanism that controls or regulates the operation of a machine or system is called a controller. In a mobile robot control there will be some desired point of operation and some difference from that point i.e. error. Without controller, the target will not be achieved by the mobile robot. In order to minimize that error through feedback control, a pervasive algorithm PID can be used.

Feedback control means measuring the controlled variable CV(t)- an output, comparing that measurement to the set point SP(t)-desired value and acting in response to the error E(t) difference between set point and controlled variable by adjusting the manipulated variable i.e. an input.

\[ E(t) = SP(t) - CV(t) \] \hspace{1cm} (1.1)

The control algorithm is the set of calculations and decisions that lie between the error and the directions given to the final control element. In case of a PID control algorithm, there are three control modes.

i) Proportional control

ii) Integral control
iii) Derivative control

The PID controller output is given by

\[
CO(t) = K_c \left[ E(t) + \frac{1}{T_i} \int E(t) \, dt + T_d \frac{dE}{dt} \right] \tag{1.2}
\]

where \( K_c \) is the proportional gain, or simply gain. Conventionally the gain is applied across the other two modes. \( T_i \) is the integral time. Its reciprocal is often called the reset rate. This reset rate has dimensions of "repeats/time". This is because at constant error input \( \Delta E \), the controller output will increase by \( K_c \Delta E \) in each time increment \( T_i \). Deactivate integral mode by setting \( T_i \) to infinity. Short \( T_i \), or high reset rate, represents more aggressive control response.

\( T_d \) is the derivative time. It is also called preact. Deactivate derivative mode by setting \( T_d \) to zero. Large \( T_d \) represents more aggressive control response. One suggestion is that the derivative mode be applied only to the controlled variable and not to the error term. By this, set point changes would not lead to sudden manipulated variable changes driven by the derivative mode.

**Limits on PID controller action:** We must temper the ideal mathematical representation by practical considerations. First of all, the controller output cannot increase indefinitely. Therefore we will regard the controller as the one operating between 0 and 100%.

\[
0 < CO < 100\% \tag{1.3}
\]

This means that there is an effective limit to the magnitude of the gain, reset rate, and preact. Depending on the size of the error, there is a gain that will saturate the controller output, and further increases in gain will not increase the effect. Similarly, the input error is also scaled to 100%.
\[ 0 < E < 100\% \]

This requires the user to define a reasonable domain of controlled variable variation and scale the error accordingly.

Each mode (proportional, integral and derivative) of controllers having its own merits and demerits and therefore PID is a commonsense approach to control based on the nature of error. It is defined in abstract terms and so can be applied to wide varieties of systems. It was developed long before the use of computers, so it has been executed in a variety of hardware; it is adapted to microprocessors today. It is not 'optimal control' but can be successfully applied over a range of conditions in real processes.

The control of high-performance trucks which can operate over a wide variety of paths, with the controller having to change according to the rapidly changing operating conditions for the stability reason. In self-tuning adaptive control, the plant parameters are estimated by a recursive identification algorithm, and on the basis of these estimates a "classical" controller is chosen. The latter is also called the certainty equivalence principle. Adaptive concepts are referred to as indirect or direct, depending upon whether the plant parameters are estimated first and then used to determine the controller, or the parameters are adjusted directly without intermediate calculations.

Figure 1.2 explains the behavior actuation that is circumnavigation, obstacle collision and avoidance of mobile robot hardware by means of real time intelligent controller in order to execute the overall mobility of truck like mobile robot. Truck backer-upper problem, from the work of Nguyen and Widrow (1990) has been investigated by many researchers.
1.3 **OBJECTIVE OF THESIS**

This thesis aims in the design of intelligent path tracking controllers for truck like mobile robot. The mobile robot system is a highly nonlinear process and design of an optimal control system satisfying all the constraints is a difficult task. Conventional proportional – Integral – Derivative (PID) controllers are well suitable for any linear process system. Recently, intelligent controllers has raised interest in the design of non linear controllers and well suited for non-linear processes such as truck like mobile robot system etc. Artificially Intelligent control algorithms such as fuzzy logic and neural networks have gained attraction in the design of non-linear controllers.
The integration of fuzzy logic and neural networks leads to an improved dynamic Neuro-Fuzzy algorithm for the design of path tracking controller for truck like mobile robots eliminating the shortcomings of fuzzy logic in rule creation and parameter tuning and also the block box characteristics of neural networks.

Evolutionary computational techniques like genetic algorithm and particle swarm optimization has global abilities and are gaining importance in optimally tuning intelligent controllers. The neuro-fuzzy controllers designed for path tracking of truck like mobile robot is optimally designed by tuning the control parameters using genetic algorithm and particle swarm optimization algorithms.

1.4 METHODOLOGY

Engineers are responsible to conceive new and improved analytical tools to solve a problem. When a new tool is available the problem should be reexamined to find better and more economical solutions. This thesis puts great emphasis on the development of algorithms which can be applied to truck back-upper controller problem. The research methodology employed in this thesis related to the aims and objectives of the work is described in the forthcoming paragraphs.

FLC introduces a good tool to deal with complicated, non-linear and ill-defined systems. ANN has the powerful capability to learning-adaptation, robustness and rapidity. The advantages of both the FLC and the ANN have been employed together to design a new architecture, ANFIS to improve the dynamic performance of the system of the truck backer-upper problem.

Due to its powerful optimization property, GA is currently being investigated for the development of adaptive or self-tuning fuzzy logic control systems. This thesis presents a NFLC where all of its parameters can be tuned simultaneously by GA. The GA implementation incorporates dynamic
crossover and mutation probabilistic rates for faster convergence. A flexible position coding strategy of the NFLC parameters is also implemented to obtain near optimal solutions. The performance of the proposed controller is compared with a conventional fuzzy controller and a neuro-fuzzy controller tuned by GA.

A new evolutionary computation technique, called PSO, has been proposed and introduced recently by Kennedy (1997), Shi and Eberhart (1998). This technique combines social psychology principles in socio-cognition human agents and evolutionary computations. PSO has been motivated by the behavior of organisms, such as fish schooling and bird flocking. Generally, PSO is characterized as a simple concept, easy to implement and computationally efficient. Unlike the other heuristic techniques, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities. The fusion of ideas from fuzzy control and neural networks had acknowledged a significant role in improving controller performances. Fuzzy logic has proven effective for complex, non-linear and imprecisely defined systems. The common bottleneck in fuzzy logic is the derivation of fuzzy rules and the parameter tuning for the controller.

The neural networks have powerful learning abilities, optimization abilities and adaptation. The fuzzy logic and neural networks can be integrated to form a connectionist Adaptive network based Fuzzy logic controller. Besides, the particle swarm intelligent algorithm, which has global optimizing capacity basing upon a fitness function, is used to optimize the coefficients of the TS-fuzzy scheme. While investigating control systems for real truck like mobile robot is very costly in terms of both time and money, the work is to be done in simulation of various complexities. The techniques and strategies developed here in the Appendix 1. Simulation experiments have been carried on an IBM-compatible PC using the software package MATLAB, Version 7.0. MATLAB is a powerful signal processing tool which
enables researchers quickly to convert their ideas into executable programs and to visualize the results employing the advanced graphic routines. Moreover, data can be imported and computation results can be exported. Both these features have been often utilized in this research work. Systems developed using simpler simulators can gradually be transferred to more complex simulators, and at the end of real vehicles.

1.5 OVERVIEW OF THESIS

This thesis proposes and investigates novel motion planning strategies for truck back-upper problem which fall within the areas of global path planning, and local navigation. This document is structured into eight chapters.

Chapter 1 is an introductory chapter which describes the motivation, background and methodology of the thesis and, through an overview of research work conducted in the field of robot motion planning, places the thesis in context.

Chapter 2 describes in detail with a summary of contributions made in the areas of mobile robots and various artificial intelligent techniques applied to various applications.

Chapter 3 details about the intelligence and navigation in mobile robots and the proposed methodology for the truck back upper problem dealt with in this thesis.

Chapter 4 explains about the various artificial intelligent techniques. The main processes underlying fuzzy logic control and the configuration of the Fuzzy Logic Control scheme are also dealt with in detail in this chapter. The equivalence of Fuzzy Inference System’s with RBFN under certain conditions is also discussed. Also the basic concepts of Artificial Neural Network have been discussed briefly in this chapter. The neuron model and various network connections are presented in detail. The back propagation algorithm for training the neural network has been
presented. The fusion of the fuzzy logic and neural network with its advantages are dealt with in the chapter.

**Chapter 5** proposes a neuro-fuzzy-based controller for mobile robots. This reactive system combines goal directed behavior without obstacles to maneuver a mobile robot in static as well as dynamic environments. The rule base of the robot has been constructed using learning rules. The mobile robot implementation and functioning is described and demonstrated by means of simulations, and performance measures are calculated.

**Chapter 6** proposes a global path planning strategy for mobile robot which is based on a Genetic Algorithm Optimized Fuzzy Controller. Due to their powerful optimization property, GA is currently being investigated for the development of adaptive or self-tuning fuzzy logic control systems. The basics of Genetic Algorithm and their applications in structure optimization of neuro-fuzzy are dealt with in detail in this chapter. The mobile robot implementation and functioning are described and demonstrated by means of simulations, and performance measures are compared.

**Chapter 7** proposes a new evolutionary computation technique for tuning the controller parameters, called PSO, introduced recently by Kennedy and Eberhart. This technique combines social psychology principles in socio-cognition human agents and evolutionary computations. PSO has been motivated by the behavior of organisms, such as fish schooling and bird flocking. The particle swarm intelligent algorithm, which has global optimizing capacity basing upon a fitness function, is used to optimize the coefficients of the Takagi-Sugeno fuzzy scheme. The mobile robot implementation and functioning is described and demonstrated by means of simulations, and performance measures are compared with other schemes.

**Chapter 8** summarizes and evaluates the outcomes of this research work and, moreover, suggests directions for further research.