Study and Implementation of 'Follow the Leader'

A thesis submitted to the Division of

Graduate Studies and Advanced Research

Of the University of Cincinnati

in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

In the Department of Mechanical, Industrial and Nuclear Engineering

of the College of Engineering

2002

by

Pravin Chandak

B.E (Industrial Engineering),

R.K.N.E.C, Nagpur University, India, 2000.

Thesis Advisor and Committee Chair: Dr. Ernest L. Hall

ABSTRACT

Autonomous robots with mobile capability are finding lot of applications in manufacturing, medicine, space and defense. Technology for autonomous vehicles is a very active field right now. The University of Cincinnati's Bearcat robot is a test bed for research in various technologies related to autonomous vehicle navigation. One of the challenges is to steer the robot autonomously to follow a moving vehicle over an unmapped area at a specified distance.

A single rotating sonar sensor is used with a restricted angle of sweep to obtain readings to develop a range map to plan an unobstructed path for an autonomous guided vehicle. The new rotating sonar system is certainly an improvement over the old stationary system in terms of better obstacle avoidance as well as reduced use of resources. Tuning of the motor and the installation of a new gearbox has helped in achieving better results. The laser further improves the object detection by providing us with more accurate data, larger range and the exact profile of the object. The new algorithm for follow the leader uses a laser scanner, extending and improving the rotating sonar logic.

The data from the laser scanner/sensor and the vehicle position are used as input variables. The outputs are the new curvature and velocity of the robot in order to follow the leader.

Autonomous transportation is one of the ways in which vehicle technology is developing. Intelligent Transportation Systems which involve communication between vehicle and the road are the next step in automobile future. The development of automatic collision avoidance systems is improving the safety levels on highway by reducing number of accidents and at the same time making driving easier. These systems draw ideas from the follow the leader concept in their development.

ACKNOWLEDGMENTS

First and foremost I would like to acknowledge the help provided by my advisor Dr. Ernest Hall. Without his guidance and support this thesis would not have been possible. His suggestions, feedback and constant encouragement have been the greatest help in completion of this thesis**.**

I would like to thank Dr. Richard L. Shell and Dr. Ronald L. Huston for agreeing to chair the thesis committee. I would also like to thank them for their suggestions and positive feedbacks.

Last but surely not the least I would like to thank each member of the Robotics Team, both present and past for their help and support they have given me during my graduate period of study at the University Of Cincinnati. Your contribution, support and suggestions have been the single largest factor towards the improvement of my work.

TABLE OF CONTENTS{ TOC \o "1-3" \h \z \u }

List of Tables and Figures

1. INTRODUCTION

1.1 Background

A common misconception regarding autonomous vehicle research going on in this field is either many years away from reality or that it is mostly suited to military applications and does not affect the common man. While it is not entirely true that this field is a day-to-day used one today, but it is also not as far from reality as it is perceived. The field of robotics though very popular is not correctly understood by a major percentage of the general population. Media, predominantly movies have formed an image in most people’s minds that a robot will be a moving and talking machine similar to humans. While the tasks performed are similar but this presentation has kept the people from getting a real picture. Robots in the automobile industry and other manufacturing operations have been the only ones to successfully break this image of a ‘humanoid’ and bring people closer to real robots and their vast benefits. They are primarily used to do repetitive material handling and mechanical tasks in industrial environment. Unmanned vehicles are another segment of robot research which is not very clear to most. Now the robot lawnmower and industrial cleaning machines are increasing awareness about autonomous vehicles.

Autonomous robots with mobile capability are finding lot of applications in various fields such as manufacturing, medicine and defense. Development of autonomous unmanned vehicles has been slow and less visible because it is a very complex and difficult concept to implement. One of the requirements for an autonomous robot is the ability to navigate through an unknown environment towards a target while planning its path dynamically. A lot of research has been done in the area of path planning and obstacle avoidance algorithms for navigating a robot intelligently through an unknown, unexplored environment. Among these, one of the areas is designing a mobile robot to follow a moving leader.

Automated highway systems require technology that allows vehicles to form and maintain "platoons", in which vehicles autonomously follow each other with very short headways, as short as two meters.

The following vehicles must range to the leading vehicles and maintain the headway very accurately under varying speeds, acceleration, braking, and even emergency stops, while tracking lane markers and steering to maintain their lanes. The military requirement is for convoys in which only the lead vehicle is manned, while following vehicles not only maintain headway but also steer so as to follow the leader wherever it might go in a trackless course.

The Center for Robotics Research at University of Cincinnati has been a regular participant in the annual International Ground Vehicles Competition (IGVC) organized by the Association for Unmanned Ground Systems (AUVS) [1]. The University of Cincinnati's robot called Bearcat (current version, Bearcat III) has participated and won prizes in many events in this competition.

The mobile robot provides an excellent test bed for investigations into generic vision guided robot control since it is similar to an automobile and is a multi-input, multi-output system [2,3]. In 1999 a new event called 'Follow the Leader' was introduced in a simulation of the above discussed real world example [4]. The aim is to follow a lawn mower or cart driven by one of the judges i.e. the lead vehicle while maintaining a standard safe distance.

1.2 Objective

The primary purpose of this research work was to find a suitable and reliable solution for the follow the leader concept, in form of an algorithm which can be implemented on the Bearcat. The algorithm should be feasible and practical so that it can work on the Bearcat under current configuration and also be flexible enough to adapt to future needs. The development of the algorithm is based on the IGVC 'follow the leader' event. The goal of this research was to provide a new solution for the 'follow the leader' as well as implement a previously proposed concept. The other purpose was to conduct a study of the current work going on in this field, specifically in relation to consumer automobiles.

1.3 Organization of the thesis

We begin by reviewing the main components of the Bearcat robot and the follow the leader concept in Chapter 2. In Chapter 3 the algorithm for follow the leader using rotating sonar sensor is provided. In Chapter 4, a new algorithm for follow the leader is proposed using a laser scanner, extending and improving the rotating sonar logic. Chapter 5 discusses the advantages and disadvantages of both the systems and proposes future avenues for further building the program. Finally, in Chapter 6 an in-depth study of the Intelligent Transportation Systems with special focus on Automatic Collision Avoidance Systems is done. We look at the existing research going on in this field and discuss the practicality of the smart vehicle/highway concept and how the 'follow the leader' idea will play a role in these future developments.

The appendix looks at the practical aspects of the implementation of the rotating sonar concept on the Bearcat III. We compare three tuning methods for the motor and see how the installation of a new gearbox helped in achieving better results.

2. BEARCAT AND FOLLOW THE LEADER CONCEPT

As mentioned in the introduction the Center for Robotics Research at the University of Cincinnati has built an unmanned, autonomous guided vehicle [2], named Bearcat III for the International Ground Robotics Competition [4]. In this competition the three primary events are - autonomous challenge competition, navigation contest and follow the leader contest. In the autonomous challenge the autonomous unmanned ground robotic vehicle must negotiate an outdoor course under a prescribed time while staying within the 5 mph speed limit, and avoiding the obstacles on the track. The challenge in the navigation contest is for a vehicle to autonomously travel from a starting point to a number of target destinations (waypoints or landmarks) and return to home base, given only a map showing the coordinates of those targets using GPS (Global Positioning System) technology. The follow the leader contest involves the bearcat following a lead vehicle over an unmarked course within a specified distance.

The Bearcat has been designed and improved over the years to primarily compete in these contests while at the same time providing students with a significant research and testing base.

2.1 Overall system of Bearcat-III

The Bearcat mobile robot is a sophisticated, intelligent, controllable, programmable system. The adaptability of the robot primarily depends on the conceptual, analytical and architectural design of the sensing and controlling system used. The main components of the Bearcat III robot [2,5] are (1) electrical system, (2) vision system, (3) mechanical system, (4) GPS system, (5) object tracking system, and (6) steering/motion control system. Apart from these there are also safety and health monitoring systems. All these systems are connected to and controlled by a Pentium based computer running Microsoft Disk Operating System (DOS).

2.1.1 Structure

The robot base is constructed from an 80/20 Aluminum Industrial Erector Set. Bearcat II is steered using two independent 36 Volt, 12 Amp motors. Each of these motors drives one of the wheels independently using a gearbox. The gearbox in the transmission system helps to amplify the motor torque by about 20 times. The power for the individual motor is supplied by a BDC 12 amplifier, which actually amplifies the signal from the Galil DMC motion controller. A position encoder mounted on each of the drive motors completes the control loop. A castor wheel supports the rear of the robot, which is free to swing when the robot has to negotiate a curve. The control of the motion is done by the usage of differential speed drive wheel.

2.1.2 Electrical System

The electrical system of Bearcat III consists of a DC power system and an AC power system. Both these systems derive power from three 12-volt DC 130 amp-hrs deep cycle batteries connected in series. A 36-volt DC 600-watt power inverter provides 60 Hz pure sine wave output at 115 volts. The inverter supplies AC electrical power for all AC systems including the main computer, cameras, and auxiliary regulated DC power supplies. The heart of the power system being the solenoid acts as a switch, which can be controlled to cut off the power during emergency.

2.1.3 Vision System

The vision system defines the components that assist in the line following function of Bearcat III along with pothole detection. It consists of two JVC digital cameras mounted on either side of the robot, one pothole detection camera mounted at the top, a video switching unit to switch between the camera visions. Image processing is done by the ISCAN tracking device. Image co-ordinates obtained by the ISCAN are two-dimensional while actual world co-ordinates are three-dimensional. The mapping of the two dimensional points and reorganization of the three dimensional image is done by the vision calibration.

2.1.4 Mechanical System

The mechanical system as a whole serves as steering control for the robot. Bearcat III is an outdoor vehicle designed to carry a payload of 100 pounds. The components include 40:1 reduction gearbox, two pairs of flexible couplings, two 36 volts servomotors and two sets of wheels with shafts, couplings and keys. The computer through Galil motion controller controls the servomotors, which supply power to the gear train for the mechanical motion transmission. Two separate gearboxes are used to individually power the wheels. The self-locking mechanism of the worm gears does not require the vehicle to have a separate mechanical breaking system. Power is transmitted to the front wheels. The rear castor wheel gives the Bearcat a zero turning radius.

2.1.5 GPS System

Global navigation is the ability to determine one's position in absolute or referenced map co-ordinates and to move to a desired destination point. The Bearcat uses a Motorola GPS to navigate from one point to the other. The GPS tracks the NAVSTAR constellation of satellites. The satellite signals received by an active antenna are tracked with 12 parallel channels of L1. C/A code is then down converted to an IF frequency and digitally processed to obtain a full navigation solution of position, velocity, time and heading. The solution is then sent over the serial link via the 10-pin connector.

2.1.6 Object Tracking System

The Bearcat has two different systems for object detection. One is the rotating sonar sensor and the other is the laser scanner system.

- Sonar System

Apart from the vision system for line tracking the sonar system is used for object detection. It is powered by a 12 Volts DC, 0.5 Amps power unit. The two main components of the ultrasonic ranging system are the transducers and the drive electronics. The sonar sensor is mounted on a brushless DC servo motor for rotation in different directions.

- Laser Scanner System

The Laser scanner LMS-200 is the new enhancement in the object tracking system on the. LMS 200 is a non-contact measurement system that scans its surroundings two dimensionally. LMS works by measuring the time of flight of laser light pulses. The shape of the object is determined by the sequence of impulses received.

Both these systems are described in detail in further chapters.

2.1.7 Motion Control System

Two Electro-craft brush-type DC servomotors drive the two wheels independently. The encoders provide the feedback from the system. The two drive motors are operated in parallel using the Galil MSA 12-80 amplifiers. The Galil DMC 1030 motion control board is the main controller card of the system and it is controlled through a computer.

The motion control of the Bearcat robot has the ability of turning about its drive axis, which is called Zero Turning Radius (ZTR). This feature offers extensive maneuverability and can negotiate very sharp turns with much ease. The ZTR functional capability is achieved by turning wheels in opposite directions. When one is rotated forward and the other is rotated backward the robot could turn around its own drive axis. By rotating the wheels at differential speeds BEARCAT III is able to negotiate curves smoothly.

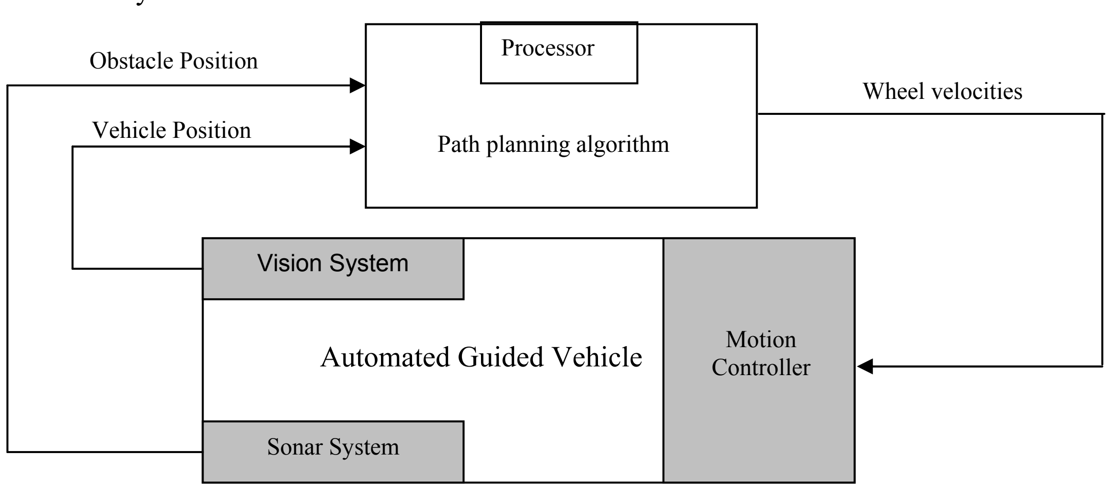


Figure-2.1 Block diagram of overall system of Bearcat

2.2 Follow the Leader Contest

The objective is to make the Bearcat III follow a lawn mower driven by one of the judges while maintaining a safe distance of about 3 meters.

The official description and rules of the Follow the Leader Contest from the 9th IGVC contest are as follows. It consists of two stages namely Phase I - Headway and Phase II - Headway Maintenance and Free Following.

Phase I - Headway

The first half of the course will consist of a 15.4 meter length that makes an S-curve with a mean radius of 3 meters. The Challenge will start with the front of the following vehicle 3 meters behind the sign on the rear of the lead vehicle, and both vehicles stationary. The lead vehicle will accelerate slowly to 3 km per hour and hold that speed to the end of the run. When the rear of the lead vehicle reaches 15.4 meters, it will stop, and a measurement will be made of the distance between the two vehicles (from the center of the sign on the lead vehicle to the front center of the following vehicle). Judges will necessarily walk and stand between the two vehicles to make this measurement. No manual adjustments to the vehicle will be permitted during this stop. The lead vehicle will then be started again and proceeds into the second phase of the Challenge.

Phase II - Headway Maintenance and Free Following

At the end of Phase I the course will continue on a track visible only to the lead vehicle, but which will consist of S-curves. Radii of curvature will be from 5 meters down to 3 meters. The lead vehicle will run at a constant 3 km/hr for a distance of 96 meters at the end of which it will stop with its rear end at the finish line, and a second measurement of distance between the two vehicles will be made.

On occasion the lead vehicle on the unmarked course will pass within 1.5 meters of a construction barrel.

Now for the robot to follow the lead vehicle it needs to be steered in that direction by the computer program. For this purpose we create a program in which the data from the laser scanner/sonar sensor and the vehicle position are used as input variables. The outputs are the new curvature and velocity of the robot in order to follow the mobile object.

3. ROTATING SONAR SOLUTION

3.1 Overview

Previously omni-directional vision based approach had been used for the follow the leader contest. As this approach actually depends on the presence of the dark and light spots on the trailing face of the leader, this implementation restricts itself to an application where such detection is feasible. There have been practical difficulties in continuously detecting the leader using omni-directional vision. Even though it gives reliable results when experimented in lab, the disturbances caused in a trackless field path due to presence of other possible reflecting interfering surfaces make the operation less reliable.

Thus it was decided to use a sonar sensor based system for the purpose. The sonar response does not depend on the surface brightness of the object. Even though sonar might end up giving wrong signals because of unintended reflections, the possibility of integrating the design with other systems in eliminating such noise makes it a better choice.

But the sonar sensor can only sense the area straight in front of its sensing face. So the requirement was to scan a larger area, one idea was to mount multiple sonars in a row in front of the robot. Now since the leader or obstacles will not be always straight ahead of the vehicle, it was decided to implement a rotating sonar where the sonar would be mounted on a motor and rotated in multiple directions to get readings in a wider area in front of the robot. But as the figure 3.1 shows a rotating sonar will cover a larger area and also without missing any objects. Also the cost is reduced and it is easier to program using one sonar rather than four.

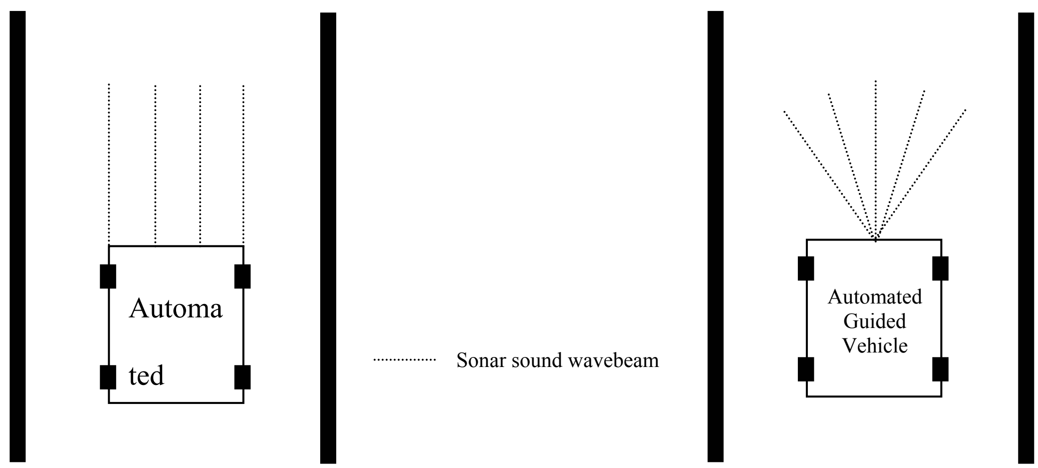


Figure-3.1 Figures showing range of stationary sonar and rotating sonar models

3.2 Sonar System Theory and Design

A single rotating sonar element is used with a restricted angle of sweep to obtain readings to develop a range map for the unobstructed path of an autonomous guided vehicle (AGV) [6]. A Polaroid ultrasound transducer element is mounted on a micromotor with an encoder feedback. The motion of this motor is controlled using a Galil DMC 1000 motion control board [7]. The encoder is interfaced with the DMC 1000 board using an intermediate IMC 1100 break-out board. By adjusting the parameters of the Polaroid element, it is possible to obtain range readings at known angles with respect to the center of the robot. The readings are mapped to obtain a range map of the unobstructed path in front of the robot. The idea can be extended to a 360 degree mapping by changing the assembly level programming on the Galil Motion control board. Such a system would be compact and reliable over a range of environments and AGV applications.

The two major components of the ultrasonic ranging system are the transducer and the drive electronics [8]. In operation, a pulse of ultrasonic sound is transmitted towards a target and the resulting echo is detected. The elapsed time between the start of the transmit pulse and the reception of the echo pulse is measured. Since the speed of the sound in air is known, the system can convert the elapsed time into a distance measurement. The transducer acts as a loudspeaker as well as a microphone. The diameter of the speaker determines the acoustical lobe pattern and acceptance angle during transmission and reception of the sound waves. In case of electrostatic transducers the foil forms the moving element which transforms the electrical energy in to sound waves and returning echo back in to the electrical energy.

The ultrasonic transducer was mounted on a motor using a bakelite base in front of the robot. The motor was powered through a DC48A amplifier connected to a Galil Breakout Board ICM 1100. The detailed system design of the motor and encoder along with motor tuning is explained in the appendix.

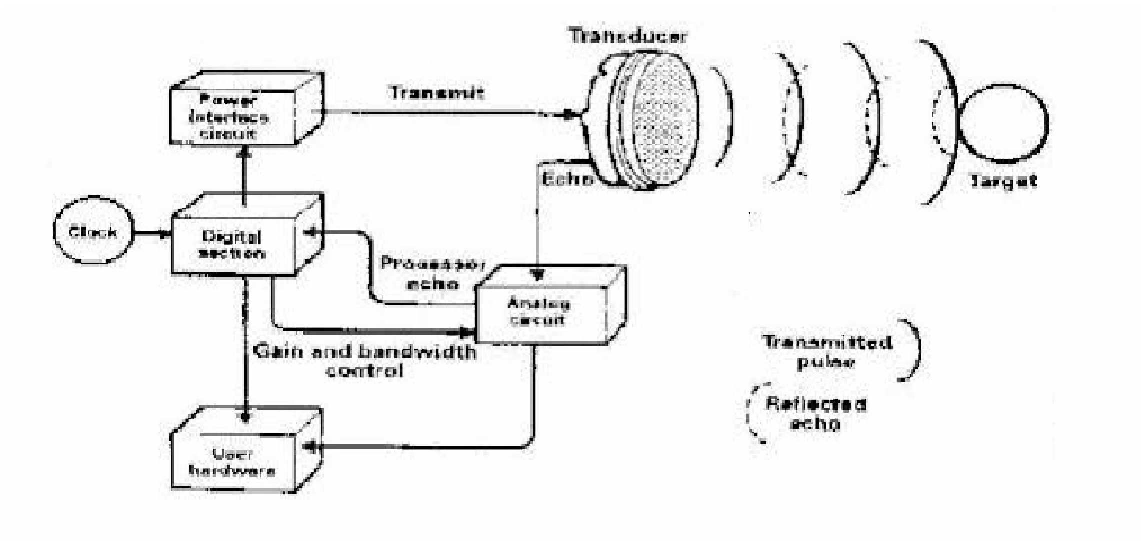


Figure-3.2 Sonar System Design [3]

3.3 Algorithm and Logic

We know that the time of flight information provides the distance measurement for the robot and the motion to the robot is actually provided by rotating the two drive wheels using corresponding motors. The orientation of the object with respect to the axis, drive axis of the robot is given by the sonar's orientation. Actually since for a given range of detection's, since only the average of the value would be considered, this should provide the orientation of the object with respect to the robot [3]. The distance between the object and the robot could be set and maintained within a desired distance level so that any change in that distance measurement would either accelerate or decelerate the robot accordingly.

The sonar is rotated to stop at 5 equiangular points as shown by BCDEF in the figure, where A is the vertex where sonar is present.

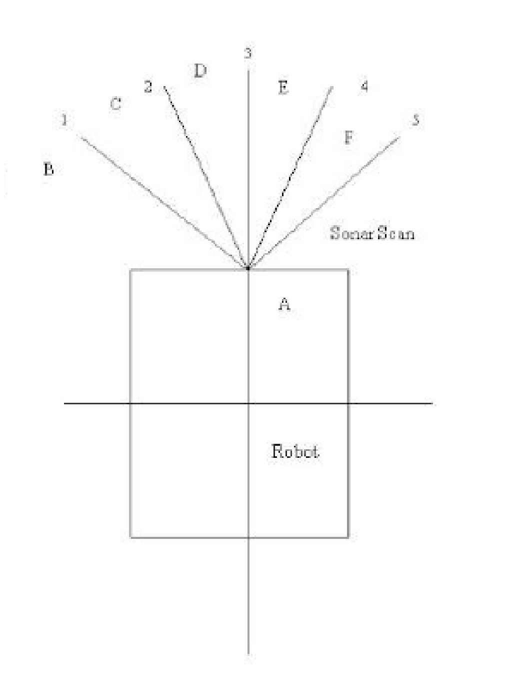


Figure- 3.3 Schematic Representation of Sonar Positions [3]

In this approach the following assumptions have been made,

(a) Counter Clockwise direction is Positive

(b) Clockwise direction is negative

Now the sonar can be made to stop and scan at any number of points. The present program considers 5 positions for it. (The current algorithm requires the sonar to be positioned at five equiangular points with the center being exactly in front of the robot. So starting initially at the center we rotate the motor by 15°, beginning twice in one direction, then four times in the opposite direction and again reverse four, thus forming a cycle of 0,15,30,15,0,-15,-30,-15,0)

The sonar is made to stop briefly and scan reading is taken only at these fixed positions. We can change these angles as per the requirements of the robot.

The general algorithm with 5 stops is as follows

Let the sonar detection positions be at angles α, β, 0, $-\alpha$, $-\beta$, at the positions 1, 2, 3, 4 and 5 respectively, assuming a symmetric scan as discussed above. The angle 0 signifies that it is along the axis of the robot.

For a detection at the position 1 a value is –2 is assigned, for the position 2 a value of –1 is assigned, for the position 0 a value of 0 is assigned and for positions 4 and 5 a value of +1 and +2 are assigned respectively. When the leader is detected at 2 positions, the average is taken as the orientation.

The logic behind deciding the orientation of the driving direction of the object with respect to the robot is as follows:

Scan using the sonar for all the five positions.

Find the sum of all the values.

If sum = -3 then Sonar detection angle $\varphi = (\alpha + \beta)/2$

If sum = -2 then

    If detection at position 4 is true

    Sonar detection angle $\varphi = \alpha /2$

    Else

    Sonar detection angle $\varphi = \alpha$

If sum = -1 then Sonar detection angle $\varphi = \beta /2$

If sum = 0 then detection angle φ =0

If sum = 1 then Sonar detection angle $\varphi = -\beta/2$

If sum = 2 then

If detection at position 2 is true

Sonar detection angle $\varphi = -\alpha/2$

Else

Sonar detection angle $\varphi = -\alpha$

If sum = 3 then Sonar detection angle $\varphi = -(\alpha + \beta)/2$

[For current settings of 5 points at 15° each, we have a set of 9 values for φ {-30, -22.5, -15,-7.5, 0, 7.5, 15, 22.5, 30}]

The distance of the object (Z) is the value of sonar reading at angle at which leader is detected. Similar to the orientation logic, if the leader is detected at 2 positions, the average is taken as the distance.

Let,

VL = the speed of the left drive wheel.

VR = the speed of the right drive wheel.

VM = the Base speed of the motion of the robot.

Vmx = the last recorded base speed of the robot

T = the time interval between the two consecutive sonar reading.

Z1 be the initial distance between robot and the leader.

Z2 be the measured distance between the robot and leader now.

D be the diameter of the wheel.

W be the width of the robot.

. φ be the angle between the axis of the robot and the direction of the motion of the leader.

$VL + VR = 2\ VM$ …………(1)

$VL – VR = W\ d\varphi/dt$ ………(2)

Substituting the value of VR from the equation (1) into equation (2)

We get

$VL – (2\ VM – VL) = W\ d\varphi/dt$

$2\ VL - 2\ VM = W\ d\varphi/dt$

$VL – VM = W/2\ d\varphi/dt$

$VL = VM + W/2\ d\varphi/dt$ …….(3)

Similarly substituting the value of VM from equation (1) into equation (2), we get

$VR – (2\ VM – VR) = W\ d\varphi/dt$

$2\ VR - 2\ VM = W\ d\varphi/dt$

$VR = VM + W/2\ d\varphi/dt$ (4)

This leads to VL and VR equations as

$VL = VM + W/2\ d\varphi/dt$

$VR = VM - W/2\ d\varphi/dt$

The Increase or decrease in the distance between the robot and the leader

$Z_{change} = Z2 - Z1$

The relative change in velocity is

$V_{relative} = Z2 - Z1 / T$

The modified Value for VM is

$VMo = Vmx + (Z2 - Z1 / T)\ (1/\Pi D)\ (86400)$

Now for the bearcat, 2048 counts of encoder makes one revolution and a 36000 counts sets a speed of 25 rpm at the wheel.

The left and right wheel velocities are therefore

VL = VMo - W/2[(φ /T)]

VR = VMo + W/2[(φ /T)]

Initially the robot could be made to move at a specified speed, base speed Vmx of 36000counts/sec and the value of the VMo could be dynamically computed to adjust the position and speed of the robot.

3.4 Results

The results of the code and algorithm were tested under laboratory conditions.

Initially the program was executed in asynchronous mode without having a feedback from the Galil Drive to position the sonar motion and take readings. However after 24-25cycles there seemed to be an overflow in the Galil buffer and the sonar motor stopped rotating. This was corrected by making the executable wait till the sonar motor got positioned in the required position, and then the reading was taken from the sonar position. This feedback from the Galil DMC was achieved by making the Galil to wait till the motion request was completed and then a value was echoed from the control, which was captured from the read buffer.

Then the sonar was checked for reliability in data by making the sonar position fixed and an object was placed at different lengths and the readings were taken both manually and via sonar. After checking for the reliability of the sonar measurement, the sonar was made to scan at 5 positions about the axis of the robot and the obstacle was placed at different lengths and different positions and the detected distance, angles (positions of the sonar) at which the object was detected, speed*x* (speed of the left wheel) and speed*y* (speed of the right wheel) were outputted to the screen and the values were verified by checking the rotation counts of the wheel and the roughly estimating the distance of the obstacle from the robot.

4. LASER SCANNER SOLUTION

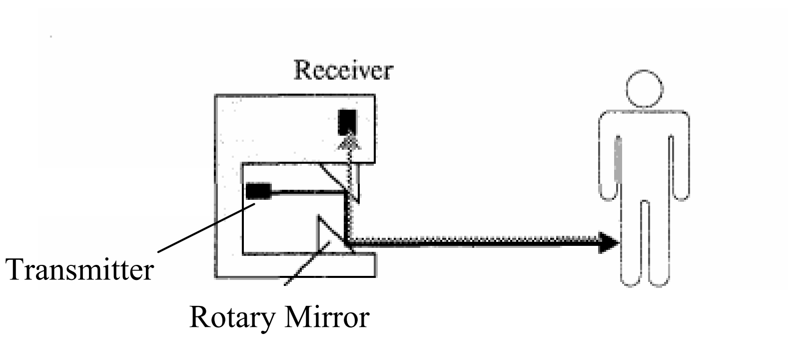
The laser scanner gives us a field of view showing the complete 180 sweep made by the laser beam. So at every angle, depending on the resolution set, we can get the distance and position of the objects along the robot's path. With these values we know exactly at what angle is the leader present. This is an advantage over the sonar algorithm where we could not get the exact position and size of the object. In this chapter we discuss the setup of the laser scanner and provide an algorithm which can be used in place of the rotating sonar program.

4.1 Laser Scanner LMS-200

A laser scanner works by measuring the time of flight of laser light pulses [9]. It is a non-contact measurement device that scans its surroundings two dimensionally. The pulsed laser beam is deflected by an internal rotating mirror so that a fan shaped scan is made of the surrounding area and the shape of the object is determined by the sequence of impulses received. The scanner provides a distance value every 0.25°, 0.5° or 1° per individual impulse, depending on angular resolution of the scanner. We can get a maximum scan angle of 180°. with a resolution of 0.25°, 0.5° or 1°. Now with this resolution and scan angle we get a clear profile of the path in front of our robot. We get data in form of the distance of the point of reflection at every angle scanned of laser beam from any object in the field of view. We can determine its coordinates from this information. Giving these values in the algorithm we can identify the objects. The main strength of the laser scanner is the data accuracy and resolution that is returned from the scanned field.

The range of the scanner depends on reflectivity of target object and the transmission strength of the scanner. So it has a minimum range for cardboard materials having a reflectivity of 10% and a maximum range for aluminum materials having a reflectivity of 130%.

Figure 4.1 A shows the schematic design of the laser in operation mode and Figure 4.1 B show the actual picture of the LMS – 200.



A. Schematic Design

B. Actual Image

Figure-4.1 Sick Laser Scanner [9]

The laser scanner operates on a similar principle to conventional radar. Electromagnetic energy is beamed into the space to be observed and reflections are detected as return signals from the scene. The scene is scanned with a tightly focused beam of amplitude-modulated, infrared laser light (835 nm). As the laser beam passes over the surface of objects in the scene, some light is scattered back to a detector that measures both the brightness and the phase of the return signal. The brightness measurements are assembled into a conventional 2-D intensity image.

4.2 Laser Scanner System Design

The implementation of laser scanner on the robot has been explained in detail by Mayank Saxena in his thesis “Obstacle Avoidance using Laser Scanner for Bearcat III” [5].

Laser scanner measurement data is used for object measurement and determining position. The measurement data corresponds to the surrounding contour scanned by the device and is given out in binary format via RS-232 / RS-422 interface.

The scanner can operate in pixel oriented or scan oriented mode. Pixel-oriented evaluation is used for suppressing raindrops and snowflakes or other particles, and thus makes the system less sensitive to environment factors. Object blanking can be used for suppressing an object that is not to be detected, e.g. a steel cable, that is located within the monitored field.

4.2.1 Interface

The Laser scanner on the robot communicates with the host computer using a serial interface. Any of the common interfaces either RS 422 or 232 [10] could be used. The transfer rate varies from 9.6 K baud to 500 K baud, which can be set as desired. The data is transferred in binary format where a byte of data consists of 1 start bit, 8 data bits, a parity bit with even parity or without parity and 1 stop bit. We are using a RS-422 serial interface card with our scanner on the Bearcat, which supports higher baud rates for faster communication. This data when seen in a GUI environment gives us the coordinates of every point in the field of view. We can see all the objects in the field of view, which reflect the laser beam so we can get the position and size of every object. In the binary format as the individual values are given in sequence, particular angular positions can be allocated on the basis of the values' positions in the data string.

The technical data regarding laser scanner is shown in Table 4.1

Laser Scanner - Technical Data	
Scanning Angle	Max. 180°
Number of beams	361 beams (For 180° at 0.5° resolution)
Resolution	0.25°/0.5°/1° (adjustable)
Light Source	Infrared diode laser
Supply Voltage	24 V +20% / -30%
Data Interface	RS 232/RS 422
Weight	4.5 Kg
Operating Temperature	0 to +50 °C
Transfer rate	9.6/19.2/38.4/500 baud
Range(measurement area)	Max. 35 m radius

Table-4.1 Technical Specifications – Sick Laser Scanner LMS -200 [9]

4.2.2 Setup

Under the laser scanner, sensing becomes an active process; the robot decides at each step of its path what sensory information is required for generating its next step. The optimal angle of sweep per reading should be obtained in such a way that it does not slow down the overall system performance. The scanner is mounted such that the sweep is 10-12 inches above the ground level. The laser scanner gives us a field of view showing the complete 180° sweep made by the laser beam. The laser beam starts from the right and goes to left. So at every angle, depending on the resolution set, we can get the distance and position of the objects along the robot's path. The data returned for every degree scanned allows us to generate a profile of the size, shape, distance and orientation of the object in the scanned area. Thus for a scanner resolution of 0.5°, we get 361 values for the field of scan. The fuzzy logic can then decide the path the robot must follow, the angle it must turn to avoid the obstacle or to follow the leader. In addition the scanners contour measurement data can be evaluated to determine the relative positions and sizes of objects.

4.3 Algorithm and Logic

In the follow the leader competition the robot must, within a specified range, follow a leading vehicle and very accurately maintain the headway under varying speeds, acceleration, braking and even emergency stops.

Similar to any other robot navigating method, the measurement data from the laser scanner/sensor and the vehicle position provide the input to the program regarding relative or absolute position of leader and current position of robot. These include all distance and angle variables. The outputs are the new curvature and velocity of the robot in order to complete its intended motion, which in this case is following the leader vehicle.

As stated above the laser scanner can provide us with a 180° sweep in front of the robot. Now the profile when viewed graphically is an arc of radius equal to the distance being scanned with indents for objects inside the area. In programming terms it will be an array of 180 numbers (with scanner set at 1° resolution) each of which is the distance of the shortest in the line of that degree. So if there is no object in the field of view of the scanner, we should get an array of 180 numbers with all reading say 8ft. So for instance the value of element 90 in the array will provide us with data exactly in front of center of robot.

The distance between the object and the robot can be set and maintained within a desired distance level so that any change in that distance measurement would either accelerate or decelerate the robot accordingly.

4.3.1 Logic for calculating orientation and angle of leader

Let α be the angle between the axis of the robot and the direction of the motion of the leader.

So considering the semi-circular laser scan area, we receive the data after every specific time period into an array. Now the values in this array are compared against the maximum value or the scan distance, say X for which the laser scanner is set.

When the value decreases, it shows that there is some object present at that angle.

Now since we are not considering any obstacles, that object is assumed to be the leader.

So from the array we will get a set of values less than X before again becoming equal to X.

Say this set extends from degree α_{min} to degree α_{max}

To get orientation of the leader, we take the average i.e. $(\alpha_{min} + \ldots\ldots + \alpha_{max})/n$ as the position of leader, where n = max - min i.e. number of laser rays < X.

To estimate distance of leader from the robot, we take an average of all the array values between α_{min} and α_{max} from i.e. $[\text{val}(\alpha_{min}) \ldots\ldots + \text{val}(\alpha_{max})]/n$

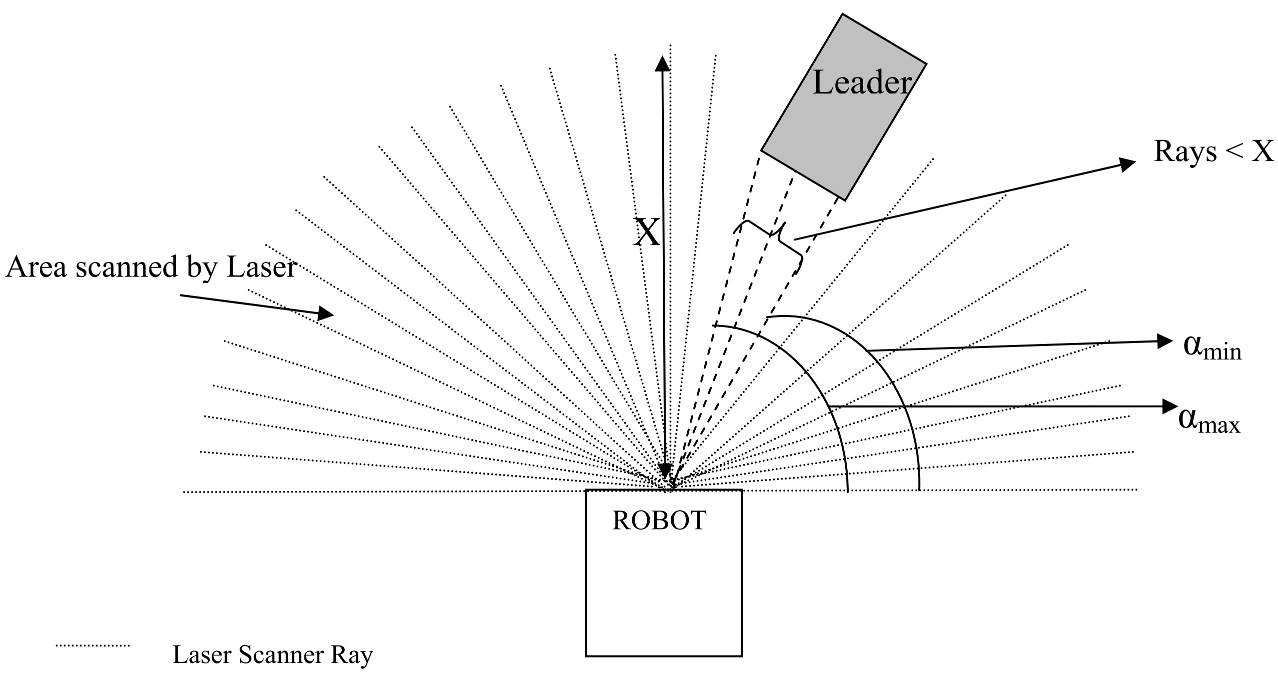


Figure-4.2 Analysis of Laser Scan

The algorithm for angle and distance of leader from robot is -

Let detect be the array containing the 180 values from the scan.

So detect[i] is the length of the scan beam at degree i.

Let sum and anglec be variables used to hold values of the sum of distances and angles of the rays < X.

```
for (int i= 0; i<181; i++)
{
        if ( detect[i] < X)
        {
        counter++ ;
        sum+= detect[i];
        anglec+= i;
        }
}
```

distance = sum/counter ;

angle = anglec/counter;

Now this is angle from the zero line. To convert this angle with respect to axis of robot, we calculate

angle = 90 – angle

(Hence –ve value represents leader to left of robot while +ve value shows leader to right of robot, while value of 0 shows leader is straight ahead of robot)

4.3.2 Algorithm for steering robot towards leader (with Galil values)

Now the next step is steering the robot towards this position. The following code gives the speeds of the left and the right wheels in Galil counts depending on the input, i.e. position of leader with relation to the robot. The Galil values in this code have been based on the runs made using the Sonar system. They can be further fine tuned by repeated testing. The clear difference is the angles here are a continuous term instead of the nine fixed values as in case of rotating sonar.

Let,

Input values -

'angle' represent the angle of the leader

'distance' represent the distance of the back of the leader from front of the robot

Output values-

spdx & spdy represent the wheel velocities of the left and right wheel in Galil counts

The code is divided into 3 different cases –

1. The leader is to the left or right i.e. when the average angle is more than 12° in either direction of the centre axis. In this case our main aim is to turn the robot first in that direction.
2. The leader is in the front area i.e. when the average angle is within 12° in either direction of the centre. In this case our main aim is to steer the robot in that direction while changing speed as per distance.
3. Leader is in a straight line ahead of the robot. We only try to accelerate or decelerate the robot to maintain the standard distance.

This categorization is advantageous because when making large turns, the straightening of the castor wheel introduces some error, thus making it unsuitable to accelerate as it will only decrease the accuracy.

Algorithm for steering:

```
-----------------------------------------------------------------------------------------
     if (angle <= -12)
     {
         if (distance < 120)
          {
                 spdx = 10000;
                 spdy = 4000;
          }
         else if (distance < 140)
          {
                spdx = 24000 - ((134.5*angle)/1);
                spdy = 24000 + ((134.5*angle)/1);
          }
         else
          {
                spdx = 34000 - ((134.5*angle)/1);
                spdy = 34000 + ((134.5*angle)/1);
          }
     }
-----------------------------------------------------------------------------------------
```

```
if (angle >= 12)
{
     if (distance < 120)
      {
            spdx = 4000;
            spdy = 10000;
      }
     else if (distance < 140)
      {
            spdx = 24000 - ((134.5*angle)/1);
            spdy = 24000 + ((134.5*angle)/1);
      }
     else
      {
            spdx = 34000 - ((134.5*angle)/1);
            spdy = 34000 + ((134.5*angle)/1);
      }
}
```

```
if ((angle <= 12 && angle >= -12) && angle!= 0)
{
    if (distance < 135 && distance >= 120)
       {
            spdx = 18000 - ((134.5*angle)/1);
            spdy = 18000 + ((134.5*angle)/1);
       }
    else if (distance < 145 && distance >= 120)
      {
             spdx = 22000 - ((134.5*angle)/1);
             spdy = 22000 + ((134.5*angle)/1);
      }
    else if (distance < 160 && distance >= 120)

      }
 }
```

```
else if (angle = = 0) // Leader straight ahead
{
      if (distance < 120)
       {
            if (distance > 100)
            {
                  spdx=12000;
                  spdy=12000;
            }
            else if (distance > 90)
            {
                  spdx = 6000;
                  spdy = 6000;
            }
            else
```

```
            {
             stopCAR();   // Stop the robot, distance too close
            return -1;
            }
     }
    else if (distance < 135 )
    {
            spdx = 18000;
            spdy = 18000;
     }
    else if ( distance < 150)
     {
            spdx = 22000;
            spdy = 22000;
     }
    else if ( distance < 165)
     {
            spdx = 26000;
             spdy = 26000;
     }
    else
     {
            spdx = 36000;
            spdy = 36000;
     }
  }
```

To prevent errors

```
    if (spdx > 36000) spdx =36000;
    if (spdx < -36000) spdx =-36000;
    if (spdy > 36000) spdy =36000;
    if (spdy < -36000) spdy =-36000;
```

4.4 Conclusion

4.4.1 Advantages of using laser

There are many advantages of using laser scanners for object detection [5]. Some of them are-

a. High measurement resolution (10mm).

b. Contact-free measurement.

c. Target objects require no reflectors or markings.

d. Target objects require no special reflective properties.

e. High scanning frequency (up to 75Hz).

f. Transfer of measurement data in real time.

In addition the scanners contour measurement data can be evaluated to determine the relative positions and sizes of objects.

Thus, the laser scanner gives very high resolution and accuracy in terms of the distance measured. Also the environmental conditions such as the temperature do not affect the accuracy of the scanner. It has multiple configuration options, which can be effectively used for elimination of stray and excess data. The object is detected irrespective of its size and its orientation.

4.4.2 Comparison of laser scanner with sonar system

We know that the laser is a much more accurate and reliable system compared with the sonar. But it also has disadvantages such as a high cost. Here we discuss the important differences, advantages and disadvantages of the two systems with respect to follow the leader.

- The laser scanner has a range of 8 meters against a maximum of 3 meters for the sonar systems, certainly a huge advantage.
- The laser scanner provides us with a larger area of scan not only in radius, but in terms of angle scanned. The laser scans 180° of area while the sonar scan is limited by the program to 60°. Though this can be changed it will lead to an increase in the program execution time.
- The sonar program turns robot in discrete angles while laser will turn it by a continuously variable angle. This provides smoother handling as less abrupt turns are there compared to rotating sonar.
- The drawback of laser scanner is that interfacing the system with the controller is complex. The algorithm for data filtering is complex and the large amount of data can cause the processing to be slower and requires higher processing power and memory. Sonar is better than vision in the sense the wealth of information available with a vision system is enormous and the problem actually becomes extracting useful, required information from the huge data available.
- The main attractions of the sonar system are its low cost, ease of implementation and inherent safety. Also sonar has been proven in numerous applications over the years.

5. POSSIBLE EXPANSION OF CODE

The current programs are directed towards the framework provided by the IGVC contests. This same code can be expanded to include many more ideas to make it more complete. It can be advanced in different directions. We discuss some of them below.

5.1 Memorizing the path

We can introduce memorizing the path i.e. if we store the path traveled by the robot while following the leader, it can repeat the same path by itself. This can be seen as a way of training the robot to navigate a path. This can be done by storing the values at which the leader was detected using the sensors or storing the path followed by the robot itself using information from the wheel encoders.

5.2 Integrating obstacle avoidance

The current contest does not have obstacle avoidance as part of the follow the leader course. But we can implement that into the code as the Bearcat already has the capability as seen in the Navigation and GPS contests. But the difference here is, when including obstacle avoidance we will need to identify & differentiate between target vehicle & obstacle, an altogether new area. Once we detect an obstacle we can decide how to avoid it.

Fernandez et al [11] provide a solution in their paper, termed as bordering strategy for obstacle avoidance.

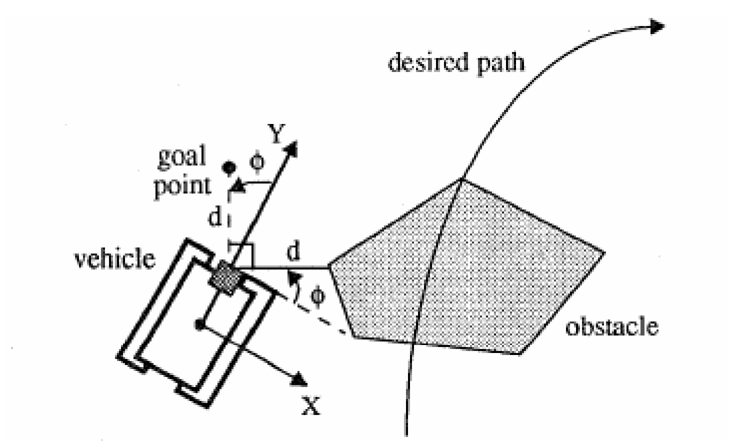
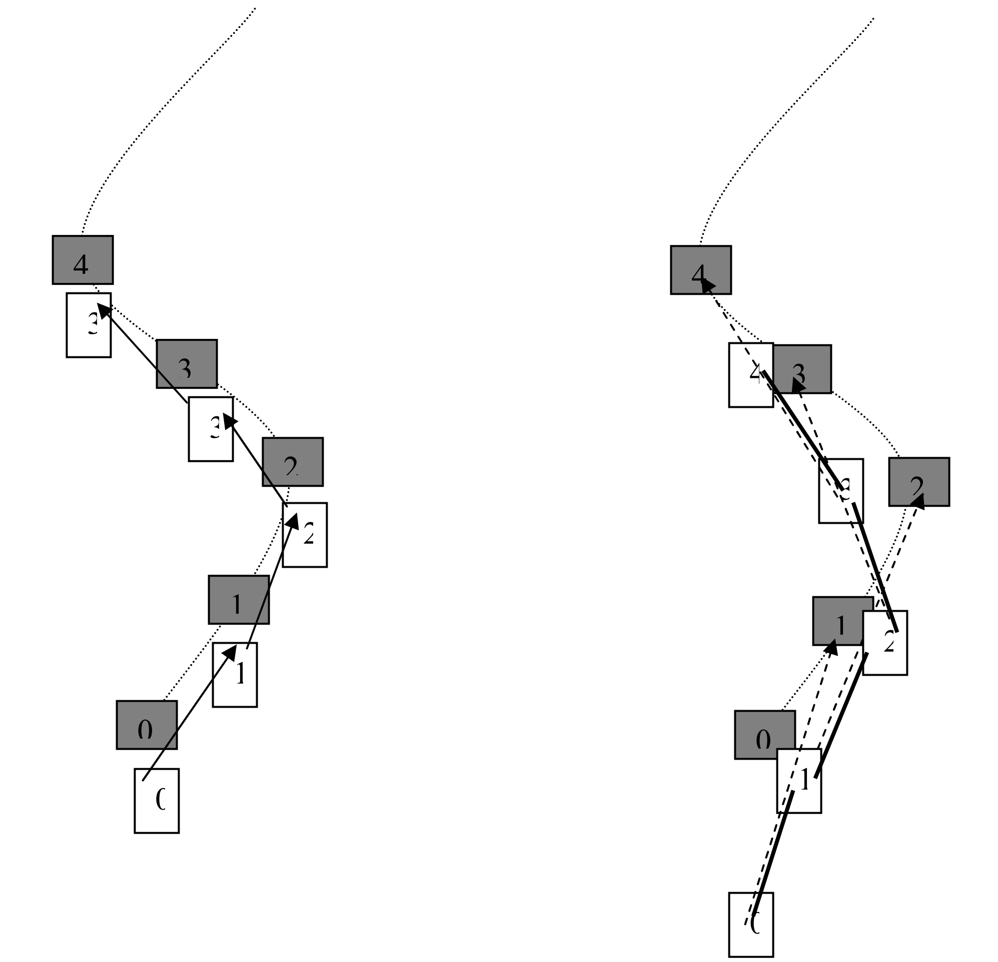


Figure-5.1 Bordering Strategy [11]

When an object is detected in the reference path at the distance *d* corresponding to the vehicles speed in the speed profile it attempts to skirt around the object as shown in the Figure 5.1. In this case, *d,* is considered the closest measured distance to the obstacle, and the angle φ is measured from the X (or – X) axis. Thus, the obstacle has the effect of repelling the vehicle in a reactive manner. We rotate the robot by an angle φ equal to the angle projected by visible edge of obstacle. Thus the robot becomes parallel to the obstacle and avoids it. When the laser scanner does not detect the obstacle to be in the path, it goes on following the path; and so on. Because the vehicle moves parallel to the obstacle and the laser unit is pointing front, one behavior continuously switches over to the other while bordering the static obstacle.

5.3 Tracing the exact path

The aim of follow the leader is to trace the path on which the leader moves. The issue here is one of strategy. Since we are following the leader at a close distance, we can afford to follow what is termed as 'pure pursuit' strategy. That is we just look at the current position of the leader and try to reach there. Due to short distance between the robot and leader the path of the robot is similar to that of the leader. But if the same logic were to be extended for use over a larger distance, say with radar sensors, we will need to change the strategy. In that case we would not look at the current position of the leader, but also store all past locations of the leader. This is better explained with the Figure 5.2



A- Robot close to leader

B - Robot far behind leader

Figure-5.2 Path of Robot following Leader

i Position of robot at time

i Position of leader at time

The leader follows along the dotted curve.

The solid arrow in A represents path being followed by robot.

In B, the dotted arrow represents the projected path to be followed by robot

And the solid line represents the actual path followed before change in the angle when new location of leader is scanned.

As we can see from the part A of Figure 5.2 when the robot is close to leader, the path followed is quite similar. But in part B of Figure 5.2, when the distance is more the path is not the same. The reason for this is under current strategy, the robot moves towards the current location of the robot. Thus after the first scan at time 1, the robot moves from its position 0 towards the position 1 of the leader. Now this mismatch between the time periods in the pure pursuit strategy leads to the robot following the shortest path and not the exact path. Specifically in case of curves this will generate lot of difference. Now this can be corrected by remembering position of leader at time 0, 1, 2, 3…, n and making the robot follow the same sequence i.e. go along the same path but delayed one time period. Though in such a case we might need to increase the scan area of the robot from 180°, as in current figure when robot is on first part of the curve and facing right, the leader is on the next curve on the left. Thus, the angle of the leader with the axis maybe more than 180° i.e. beyond the scope of current setup and we will end up losing the leader.

[Another way to view this theory is under close following, we never allow a curve to develop. Since each segment between scans is so small, we are almost always following a line]

5.4 Improving the current configuration

To improve the current configuration, we could look into the following areas

- Use of a combination of both sonar and laser scanner systems for better object detection
- Use of multiple laser scanners mounted at different heights. Multiple scanners will help us in getting a profile of the target. If each target uses a unique profile, it might be possible to track multiple targets with a single system, in a maze of different object.
- Use of a radar sensor. A radar sensor will provide a much more detailed profile compared to existing solutions. Also it can work even in unfavorable conditions like snow storms, etc.

- Use of vision systems. Vision systems provide information that is impossible to obtain in other ways. They give a clearer idea about the position of the object, the size of the object, and the kind of object.

6. CURRENT WORK IN THE FIELD OF VEHICLE DETECTION TECHNOLOGY

The IGVC website [4] lists applications of the IGVC in the real world. A major portion of the list refers to - Intelligent Transportation Systems including Collision Avoidance, Adaptive Cruise Control, Obstacle Detection, Leader-Follower, Driver Aides and Automated Highway Systems. The following is a web based study of relevant technological developments all over the world with focus on Collision Avoidance

6.1 Introduction

To understand the importance of autonomous vehicles we need to understand the need for them. The number of cars on the road in the US is increasing at a rapid rate. Some change in the United States transportation infrastructure must take place, to reduce the congestion and improve the safety, because it is not always feasible to build more roads. One of the solutions to this growing problem is the creation of **Intelligent Transportation Systems** [12]. One of the components of this system is autonomous vehicles. We have been hearing about 'Smart' Cars, 'Intelligent' Vehicles since a decade now. The transportation department of the government has invested a lot of money in research in the same field along with all the top automobile makers. Other countries in Europe and Japan (predominantly Toyota) have also been working along similar lines.

Autonomous transportation is one of the way's in which vehicle technology is developing. Autonomous vehicles are a reality for the future. It is how they will develop and be used that is still unknown. The reasons for the development of autonomous vehicles are clear: personal convenience, increased safety, reduced congestion, and environmental benefits. The implications of this development on our society are not completely known.

In this chapter, we look at passive and active safety, introduce Intelligent Transportation Systems and look in detail in one of them – Automotive Collision Avoidance System

6.2 Passive safety v/s active safety

Since the mid-1960s there have been significant advancements in vehicle safety. Passive safety features such as seat belts, air bags, crash zones and lighting have dramatically reduced accident rates, injury severity and the number of fatalities. For example, the fatality rate per hundred million vehicle miles traveled has fallen from 5.5 to 1.7 from the mid-1960s to 1994. In spite of these impressive improvements, each year in the United States, motor vehicle crashes still account for a staggering 40,000 deaths, more than three million injuries, and over $130 billion in financial losses. Significant further gains in reducing crash costs will prove more difficult to achieve by proceeding with the current passive safety technologies alone. Consequently, there is merit to investigate other promising technologies in an attempt to reduce the severity of crashes or even complete mitigation of all collisions. Air bags and seat belts save tens of thousands of people a year. Supercomputers now let designers create car frames and bodies that protect the people inside by absorbing as much of the energy of a crash as possible. As a result, the number of fatalities per million miles of vehicle travel has decreased. But the ultimate solution, and the only one that will save far more lives, limbs, and money, is to keep cars from smashing into each other in the first place.

Increased safety is an important concern. Air bags and anti-lock brakes are seen as necessities in cars. The use of air bags and seat belts only helps drivers after they have gotten into an accident situation. Things like brake lights and anti-lock brakes help the driver prevent accidents. These measures help to improve safety, but something more needs to be done to prevent the accident from happening.

Driver error needs to be reduced, as it is one of the biggest creators of traffic accidents and incidents. Active safety includes warning as well as avoidance systems.

The introduction of Automotive Collision Warning Systems potentially represents the next significant leap in vehicle safety technology. Such systems attempt to actively warn drivers of an impending collision event, allowing the driver adequate time to take appropriate corrective actions to mitigate, or completely avoid, the event. Crash statistics and numerical analysis strongly suggest that such collision warning systems will be effective. Crash data collected by the U.S. National Highway Traffic Safety Administration (NHTSA) show that approximately 88% of rear-end collisions are caused by driver inattention and following too closely [13]. This number can be significantly reduced if not eliminated.

In NHTSA's vision of the future driver-vehicle-highway environment, a wide variety of innovations will appear within and outside of the motor vehicle to supplement the driver's efforts at vigilance and control. Among the systems envisioned, new products will monitor the driver's own state of fitness, enhance driver situational awareness on a continuous basis, provide advance warnings of potential danger, intervene and assist with emergency control if a crash is imminent, and perhaps eventually automate the driving process on specialized roadways of the future. The next generation cruise-control system, for example, will automatically maintain a safe distance from vehicles ahead. With a lane tracking system, imminent departure from the roadway will be predicted by on-board electronics, and the driver will be alerted in time to recover. A cooperative intersection will communicate data on the state of the traffic signal and warn of the presence of conflicting traffic to further reduce the risk of intersection collisions.

California is leading the way in smart highway research and public-private partnerships in the United States [14]. Pathfinder is a leading project being carried out by the California Department of Transportation, General Motors and the Federal Highway Administration. Also research is being done on smart highways that will allow a driver to program a destination on a dashboard computer, then sit back and enjoy the ride.

In Europe, auto makers, electronics experts and university researchers took part in PROMETHEUS - the Program for European Traffic with the Highest Efficiency and Unprecedented Safety. In Japan, where traffic congestion is a major problem, there are two major research and development programs: AMTICS, the Advanced Mobile Traffic Information and Communication System, and RACS, the Road-Automotive Communication System.

6.3Intelligent Transportation System (ITS)

At this point the plan for the development of ITS has five functional areas [15].

- Advanced Traffic Management Systems (ATMS)
- Advanced Traveler Information Systems (ATIS)
- Advanced Vehicle Control Systems (AVCS)
- Commercial Vehicle Operations (CVO)
- Advanced Pubic Transportation Systems (APTS)

The Advanced Traffic Management Systems are the base of ITS. They will collect and distribute information about road and driver conditions. They will also control traffic lights and metering ramps in order to better manage the flow of traffic. At some point in the future they could even control driver routes. Advanced Traveler Information Systems provide information to the traveler, probably via onboard navigation systems. Advanced Vehicle Control Systems increase safety by enhancing the vehicles controls in dangerous situations. This included collision avoidance systems and eventually the use of autonomous vehicles. Commercial Vehicle Operations is just the continuation of information gathering from the commercial sector. Advanced Pubic Transportation Systems will be an improved mass transit system that will use all of the other ITS technologies, to make mass transit a viable option.

The integration of all of these systems should be greater than the sum of its parts. It will allow for better transit due using some existing and some yet to be developed technology.

6.4 Automotive Collision Avoidance System (ACAS) Program

The introduction of automotive collision warning systems potentially represents the next significant leap in vehicle safety technology by attempting to actively warn drivers of an impending collision event, thereby allowing the driver adequate time to take appropriate corrective actions in order to mitigate or completely avoid the event. With this as an impetus, the Automotive Collision Avoidance System (ACAS) Program was launched.

The combined activities and accomplishments achieved under the Automotive Collision Avoidance Systems Development Program have been partially supported by funds generously provided by the U.S. Government, through the Defense Advanced Research Project Agency (DARPA). The program has been administered by National Highway Traffic on behalf of DARPA. [16]

The Automotive Collision Avoidance System Program was conducted by a consortium led by Delphi-Delco Electronic Systems. Other members of the consortium were - General Motors Corporation, NAO Safety and Restraint Center, Hughes Research Laboratories, ERIM International, UC Davis, and STI.

The accelerated development of strategic technologies/systems that are the essential building blocks for a fully integrated comprehensive collision warning system, has mainly focused on the following three areas: (a) sensors (i.e., forward-looking radars and lasers, side detection radars, and lane tracking vision), (b) systems (i.e., path estimation, in-path target selection, and threat assessment), and (c) human factors (i.e., driver-vehicle interfaces, and understanding the effects of warning cues on drivers). The primary goal of the ACAS Program is to provide a highly focused effort to accelerate the development of active crash avoidance systems for the automotive industry.

It is envisioned that the ACAS Program will assist in the development of a comprehensive collision warning system, which is capable of detecting and warning the driver of potential hazard conditions in the forward, side, and rear regions of the vehicle. The system will incorporate the use of long range radar or optical sensors that are capable of detecting potential hazards in the front of the vehicle, short range sensors to warn the driver of nearby objects when changing traffic lanes or backing up, and a lane detection system that alerts the driver when the vehicle is changing traffic lanes. The current program effort is focused on providing warnings to the driver, rather than take active control of the vehicle.

Conceptual Architecture behind the system.

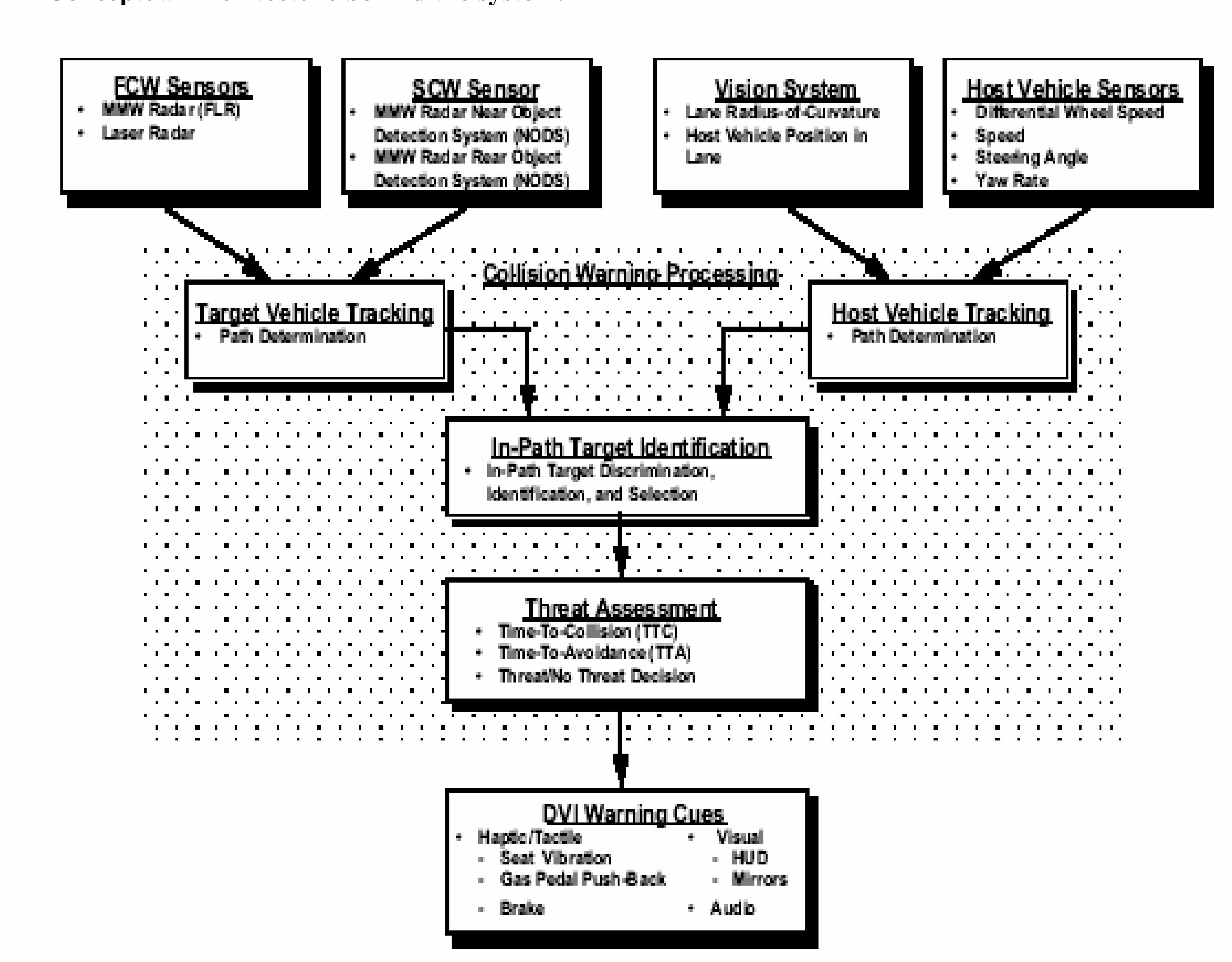


Fig-6.1 Conceptual architecture behind the collision warning system [16]

Forward Collision Warning (FCW) Sensors along with Side Collision Warning (SCW) sensors would provide information regarding the target vehicle, while other systems like Vision and sensors from the host vehicle itself will help in ascertaining the position of and the path being followed by the host vehicle. The radar, other sensors and the cameras work together to track the car ahead and distinguish it from extraneous nonmoving objects more rapidly than would be possible with either alone These inputs together will form input for the target vehicle identification, differentiating it from obstacles or other stray data. This information will be fed to the collision warning processor which will process the data for evaluating time to collision, time to avoidance. The vehicles computer already has data regarding the vehicles capacities with regards to speed, braking and such factors. Then the collision warning system will take a decision regarding the existence of a threat. It will have a capability of both passive warning systems like tactile, audio and visual warnings with suggestion on what to do like change lane or reduce speed as well as active safety features like braking and reducing speed of the vehicle via the computer directly in case of emergency.

6.5 Currently available adaptive cruise control (ACC) systems

They have already started equipping high-end vehicles with sensors that detect motion and obstacles, coupled to processors that respond instantly to whatever is detected.

These ACC systems, which add $1500 to $3000 to the cost of a car, use laser beams or radar to measure the distance from the vehicle they are in to the car ahead and its speed relative to theirs. If a car crosses into the lane ahead, say, and the distance is now less than the preset minimum (typically a 1- or 2-second interval of separation), the system applies the brakes, slowing the car with a maximum deceleration of 3.5 m/s^2 until it is following at the desired distance. If the leading car speeds up or moves out of the lane, the system opens the throttle until the trailing car has returned to the cruise control speed set by the driver.

In May 1998, Toyota became the first to introduce an ACC system on a production vehicle when it unveiled a laser-based system for its Progress compact luxury sedan, which it sold in Japan. Then Nissan followed suit with a radar-based system, in the company's Cima 41LV-2, a luxury sedan also sold only in Japan [12]. In September 1999, Jaguar began offering an ACC for its XKR coupes and convertibles sold in Germany and Britain. Like many ACC systems, it is the result of a group effort: Delphi Delco Electronic Systems supplies the radar sensing unit; TRW Automotive Electronics, the brake control; and Siemens, the assembly that manipulates the throttle.

Last fall, Mercedes-Benz and Lexus joined the adaptive cruise control movement. Lexus offers an ACC option for its top-of-the-line LS430; at the moment, it is the only ACC system available in the United States. Mercedes' system is an option on its C-Class and S-Class models, which are available in Europe; it was developed by M/A-Com, Lowell, Mass., and uses a radar made by Filtran Microcircuits Inc., in West Caldwell, N.J.

Although conventional cruise control is a much more popular option in North America than it is in Europe and Asia, none of the Big Three U.S. automakers has an ACC system in production yet. General Motors (GM) and Ford, however, are collaborating on a Collision Avoidance Metrics Project, whose results are expected to influence the companies' early ACC offerings. Both plan to introduce ACC systems for calendar year 2002, GM in a Cadillac, and Ford in a Lincoln. By then, Opel, Saab, and Volvo will have also made systems available as options on some of their cars, according to Raymond Schubert, a researcher at Tier One, a Mountain View, Calif.-based automotive electronics market research firm.

6.6 Cooperative collision avoidance

Though conventional ACC is still an expensive novelty, the next generation, called cooperative adaptive cruise control, or CACC, is already being tested in California and elsewhere. While ACC can only respond to a difference between its own speed and the speed of the car ahead, cooperative systems will allow two or more cars to communicate and work together to avoid a collision [17]. Ultimately, experimenters say, the technology may let cars follow each other at intervals as short as a half second. At100 km/h that would amount to a distance between cars of less than 14 meters (roughly two car lengths).

California PATH, in Berkeley, [18] is experimenting to develop systems that allow cars to set up platoons of vehicles in an ad hoc fashion. The cars communicate with one another by exchanging radio signals, much as portable electronic devices talk to each other using the Bluetooth wireless protocol. When one car pulls up behind another, the two will scan to determine whether the other is equipped for CACC. The cars will then work out a safe following distance on the basis of their actual performance characteristics--for example, the condition of the brakes of the trailing vehicle.

6.7 Conclusion

Currently prototypes of vehicles with dashboard computer terminals are already being built. The drivers will get up-to-date information about traffic conditions on stretch of the road in front of them for miles. And they'll be advised on alternate routes to avoid accidents, traffic jams or fog.

The next step is the Adaptive/Intelligent Cruise Control (available in modified form on some cars). While fully automated highway systems may be several years away, many applications are already road-ready or near ready. These near term systems include: **Adaptive/Intelligent Cruise Control** that senses vehicles ahead/behind and alters speed accordingly. **Obstacle/Collision Avoidance** that detects obstacles/other vehicles in the road and safely adjusts course. **Lane Keeping** with sensors that track markers in/on the highway, ensuring that the lanes are followed precisely [19].

Far future research possibilities include the fully automated Smart Highway/Smart Car system where once the Smart Car enters a specific stretch of the road the computer assumes complete control. The car drives itself following lanes and it can communicate with the highway computer. It takes the car to designated exit and control is handed back to the driver. It can also communicate with other cars on the road using similarly encoded sensors and help in maintaining very short distances at high speeds.

Advantages

More vehicles can be accommodated on the highway. Driving safety will be significantly greater. High performance driving can be conducted in adverse weather and environmental conditions. All ITS drivers can be safe and efficient drivers. Fuel consumption and emissions can be reduced. Land can be used more effectively. It will also more efficient commercial and transit operations.

And lastly, an important impact of these technologies is also an increase in the productive time of the users. If a car can drive itself on the highway, the person can utilize the time for other work, other than already reduced time between destinations.

Restrictions yet to be overcome

There are major restrictive factors which need to be taken into account. The primary among these are safety, reliability, and price. For such a system to gain acceptance by consumers, it must be reasonably priced, possess sufficient and effective functionality, and provide highly reliable performance. False alarms & missed detections should be non existent or kept to the minimum. And as with any scientific progress, more and more practical problems come up with real life implementation which cannot be predicted in the simulation exercises carried out.

Communication among sensors and processors embedded not only in vehicles but in roads, signs, and guard rails are expected to let cars race along practically bumper to bumper at speeds above 100 km/h while passengers snooze, read, or watch television.

Thus such technologies as Collision Warning Systems along with other rapidly developing and developed technologies like GPS will be the integral part of the forthcoming cars. So one can be very sure that like electric vehicles, smart vehicles are a sure thing of the future.

REFERENCES

[1] Center for Robotics at University of Cincinnati: { HYPERLINK "http://www.robotics.uc.edu/" }

[2] Center for Robotics, Bearcat III Design Report, University of Cincinnati, 2002: { HYPERLINK "http://reeses.mie.uc.edu/IGVC2002/DesignReport/DReport2002.pdf" }

[3] Aravind Muralidharan, ‘Sonar Based Navigation: Follow The Leader Solution for Bearcat III’, MS Thesis, University of Cincinnati, 2001

[4] International Ground Vehicle Competition: { HYPERLINK "http://www.secs.oakland.edu/SECS_prof_orgs/PROF_AUVSI/" }

[5] Mayank Saxena, Obstacle Avoidance using Laser Scanner for Bearcat III , MS Thesis, University of Cincinnati, 2001

[6]{ HYPERLINK "http://spie.org/scripts/search.pl?qs=spie&db_key=INST&aut_xct=YES&author=Chandak,%20Pravin" }, Chandak, Ming { HYPERLINK "http://spie.org/scripts/search.pl?qs=spie&db_key=INST&aut_xct=YES&author=Cao,%20Ming" } and Ernest L. Hall, Proc. SPIE, Intelligent Robots and Computer Vision, Vol. 4572, Boston, 2001, pp. 81-92

[7] Galil Inc, “DMC 1000 Technical Reference Guide V1.1”, Sunnyvale, CA, 1993

[8] W.S.H. Munro, S. Pomeroy, M. Rafiq, R. Williams, M.D. Wybrow, and C. Wykes, ‘Ultrasonic Vehicle Guidance Transducer’, Ultrasonics, 28, pp. 350-354

[9] Sick Inc.: { HYPERLINK "http://www.sickoptic.com/" }[10] { HYPERLINK "http://webopedia.internet.com/TERM/s/serial_port.html" }

[11] J.L. Martinez, A. Pozo-Ruz, S.Pedraza, and R. Fernandez, ‘Object Following and Avoidance Using a Laser Scanner in the Outdoor Mobile Robot Auriga -α’, Proc. Of IEEE, International Conference on Intelligent Robots and Systems, Canada, 1998

[12] { HYPERLINK "http://www.ben2.ucla.edu/~karna" }, ‘{ HYPERLINK "http://www.karnajean.com/html/thesis.html" }’, MS Thesis, Princeton University, 1996

[13] National Highway Traffic Safety Administration: { HYPERLINK "http://www.nhtsa.com/" }

[14] California Alliance for Advanced Transportation Systems (CAATS): { HYPERLINK "www.caats.org%20" }

[15] U.S. Department of Transportation- ITS: { HYPERLINK "http://www.its.dot.gov/" }

[16] Final Report - Automotive Collision Avoidance System (ACAS) Program, 2000: { HYPERLINK "http://www.nhtsa.dot.gov/people/injury/research/pub/ACAS/Ch1.htm" }

[17] Willie D. Jones, Keeping Cars from Crashing, IEEE Spectrum, Sept. 2001

[18] Partners for Advanced Transit and Highways (PATH): { HYPERLINK "www.path.berkeley.edu" }

[19] { HYPERLINK "http://www.tfhrc.gov/pubrds/july97/demo97.htm"}

[20] ITS America: { HYPERLINK "www.itsa.org%20" }

[21] Ernest L. Hall, Krishnamohan Kola and Ming Cao, “Fundamentals of Digital Motion Control,” Handbook of Industrial Automation, Marcel Dekker, New York, 2000, pp. 157-175

[22] Ming Cao, ‘Development of Motion Control Systems for an Autonomous Vehicle’, MS Thesis, University of Cincinnati, 1999

[23] C. Canudas-de-Wit, A.D. NDoudi-Likoho, ‘Nonlinear control for a convoy-like vehicle’, Automatica, 2000, pp 457-462

[24] T. Fraichard, P. Garnier, ‘Fuzzy control to drive car-like vehicles’, Robotics and Autonomous Systems, 2001, pp 1–22

APPENDIX: Problems with tuning and creating a new solution using gearbox

A. Introduction

In this chapter we look at the implementation part of the rotating sonar solution. A comparison is made of the methods for compensating the rotating sonar sensor motor [6]. These include analytical modeling, simulation and experimental approaches. Finally the addition of a new gearmotor and final results observed are described.

The idea of rotating sonar proposed was implemented on the Bearcat but did not work satisfactorily. After few cycles of rotation the motor would display unpredictable behavior. For rotating sensors, the motion control is critical for precise positioning of the sensor at a given location while a measurement is taken. Selecting the right parameters for the compensator portion of a controller is the most challenging step for in this motion control system design.

System Modeling

The position-controller system comprises a position servomotor with (Electrocraft Brush type DC motor) an Encoder, a PID controller (Galil DMC 1030 motion control board) and an amplifier (Galil MSA 12-80). The sonar system is driven by an Electrocraft brush-type DC servomotor. An encoder provides position feedback for the system. The drive motor is operated in current loops mode using a Galil MSA 12-80 amplifiers. The main controller card is the Galil DMC 1030 motion control board and is controlled through a computer.

Sonar motor and tuning requirements

The current algorithm requires the sonar to be positioned at five equiangular points with the center being exactly in front of the robot. Also the movement needs to be rapid as the robot moves forward at quite a high speed and should foresee obstacles as early as possible. At each point the motor stops for a very short time for the sensor to give accurate readings.

Thus following characteristics are required of the sonar motion

a) Fast response – the sonar should be rotated to the desired position at the fastest speed.

b) Least error – the stops should be accurate without overshoot or undershoot as the errors will become cumulative considering the cycle, and even a small error would render the obstacle avoidance program useless.

Considering the small load - the only load mounted on the sonar motor is the sonar, which is less than a quarter of pound and taking into account the above features, we selected Electro-Craft 0260-06-018 servomotor. The encoder of this motor is 2000 counts/revolution.

B. Analytical model

Amplifier mode settings - there are generally 3 modes of configurations for each amplifier, the current mode (torque mode), voltage mode and velocity mode. The current mode will provide large torque while the voltage mode will provide fast speed. During the field test, the robot will always have to climb ramps, high friction grassland, etc. So the two wheel motors were configured as current mode. The only load of the sonar motor is the quarter-pound sonar head. So, the load for the sonar amplifier is small. Voltage mode is selected to support a prompt response.

Control board and amplifier configuration

The Galil motion controller plugs into the PC bus and accepts several high level, ASCII commands. The Galil board is the main interface to transfer data to the computer and also the commands to the amplifier. It gets motor status information via encoder and then reports the data to the computer. The computer command is first sent to the Galil board and then transferred into analog control signal, which is between +/- 10 V via a 16 bit D/A converter (resolution 0003 Volts). This signal is a reference voltage which is applied to the amplifier reference in +/- pins to control the motor direction and speed. Depending on the amplifier mode, the control signal controls current, voltage or speed. These amplifiers get control signals from Reference in + and Reference in -, then provide output voltage or current power to the motor accordingly. The variation of the reference in error will determine the strength of the power output to the motor.

The encoder attached to the motor reads and gives negative feedback information of motor motion status. The negative feedback causes a difference between the command signal and feedback signal. This difference is called the error signal. The amplifier compares the feedback signal to the command signal to produce the required output to the load by continually reducing the error signal to zero.

Amplifier tuning

There are 4 potentiometers to be adjusted built into the amplifier, loop gain, current limit, reference gain and offset - the loop gain adjustment in voltage & velocity modes; voltage to current scaling factor adjustment in current mode. The current limit adjusts both continuous and peak current limit by maintaining their ratio (50%); the reference gain adjusts the ratio between input signal and output variables (voltage, current, velocity); the offset/test is used to adjust any imbalance in the input signal or in the amplifier. Before operation, these potentiometers need to be tuned to gain an optimum performance.

Sonar motor amplifier

Since the sonar rotation is a light load. A Miniature Brush type Servo Amplifier, MSA-12-80, was selected. It is low-cost, easy to use amplifier for driving brush type servo motors at high switching frequencies. The amplifier utilizes power MOSFETs and surface mount technology to produce high power in a small package. The MSA-12-80 accepts a +/- 10V range input signal directly from Galil control board, or it can be configured as a stand-alone drive. An unregulated DC power supply is required to drive the MSA-12-80.

The amplifier can be configured in three modes namely, voltage loop, current loop and the velocity loop. The transfer function relating the input voltage V to the motor position P depends upon the configuration mode of the system.

a. Voltage Loop

In this loop, the amplifier acts as a voltage source to the motor. The gain of the amplifier will be $K_{v.}$ And the transfer function of the motor with respect to the voltage will be

$$\frac{P}{V} = \frac{K_v}{[K_t s(s\tau_m + 1)(s\tau_e + 1)]}$$

where ,

$$\tau_m = \frac{RJ}{K_t^2}\ (s) \quad and \qquad \tau_e = \frac{L}{R}(s)$$

The motor parameters and the units are:

K_t : Torque constant (Nm/A)

R : Armature resistance

J : Combined Inertia of the motor and load (kg-m^2)

L : Armature Inductance

b. Current Loop

In this mode the amplifier acts as a current source for the motor. The corresponding transfer function will be as follows

$$\frac{P}{V} = \frac{K_a K_t}{Js^2}$$

where, $K_{a-=}$ Amplifier gain

c. Velocity Loop

In the velocity loop, a tachometer feedback to the amplifier is incorporated. The transfer function is now the ratio of the Laplace transform of the angular velocity to the voltage input. This is given by

$$\frac{\omega}{V}=\frac{\frac{K_aK_t}{J_s}}{1+\frac{K_aK_tK_g}{J_s}}=\frac{1}{[K_g(s\tau_1+1)]}$$

where,

$$\tau_1=\frac{J}{K_aK_tK_g} \quad \textit{and therefore}$$

$$\frac{P}{V}=\frac{1}{[K_g s(s\tau_1+1)]}$$

Encoder

The encoder is an integral part of the servomotor and has two signals A and B, which are in quadrature and 90 degrees out of phase. Due to the quadrature relationship, the resolution of the encoder is increased to 4N quadrature counts/rev. N is the number of pulses generated by the encoder per revolution.

The model of the encoder can be represented by a gain of

$$K_f=\frac{4N}{2\pi}\ [counts/rad]$$

Controller

The controller in the Galil DMC 1030 board has three elements, namely the Digital-to-Analog Converter (DAC), the Digital Filter and the Zero Order Hold (ZOH).

a. Digital-to-Analog Converter (DAC)

The Digital-to-Analog Converter (DAC) converts a 14-bit number to an analog voltage. The input range of numbers is 16384 and the output voltage is $\pm$10V

For the DMC 1030, the DAC gain is given by K_d=0.0012 [V/count]

b. Digital Filter

The digital filter has a discrete system transfer function given by

$$D(z)=\frac{K(z-A)}{z+\frac{Cz}{z-1}}$$

The filter parameters are K, A and C. These are selected by commands KP, KI and KD, where KP, KI

$$K = K_p + K_d$$
$$A = \frac{K_d}{(K_p + K_d)}$$
$$C = \frac{K_i}{8}$$

and KD are respectively the Proportional, Integral and Derivative gains of the PID controller. The two sets of parameters for the DMC 1030 are related according to the equations,

c. Zero Order Hold (ZOH)

The ZOH represents the effect of the sampling process, where the motor command is updated once per sampling period. The effect of the ZOH can be modeled by the transfer function,

$$H(s) = \frac{1}{\left(1 + s\frac{T}{2}\right)}$$

In most applications, H(s) can be approximated as 1.

Having modeled the system, we now have to obtain the transfer functions with the actual system parameters.

System Analysis

The system transfer functions are determined by computing transfer functions of the various components.

- Motor and the Amplifier

  The system is operated in a current loop and hence the transfer function of the motor-amplifier is given by

$$\frac{P}{V} = \frac{K_a K_t}{Js^2}$$

- Encoder

The encoder on the DC motor has a resolution of 500 lines per revolution. Since this is in quadrature, the position resolution is given by 4*500=2000 counts per revolution.

The encoder can be represented by a gain of

$$K_f = \frac{4 \times N}{2\pi} = \frac{2000}{2\pi} = 318$$

- DAC

From the Galil manual, the gain of the DAC on the DMC 1030 is represented as

K_d = 0.0012 V/count

- ZOH
  The ZOH transfer function is given by

$$H(s) = \frac{1}{1 + s\frac{T}{2}}$$

Where, T is the sampling time. The sampling time in this case is 0.001s. Hence the transfer function of the ZOH is:

$$H(s) = \frac{2000}{s + 2000}$$

The design objective is set at obtaining a phase margin of 45 degrees.

We select the filter function of the form G(s)=P+sD;

such that at crossover frequency of 200, it would have a magnitude of 66 and a phase of 50 degrees.

$$|G(j200)| = |P + (j200D)| = 66$$

and

$$Arg\left[G(j200)\right] = \tan -1\left[\frac{200D}{P}\right] = 50^\circ$$

Solving the equations, we get,

P=42;

D=0.25

The filter transfer function is given by G(s)=0.25s+42.

C. Simulation and Optimization

The basic model of the control system was setup-using MATLAB. For this purpose the SIMULINK toolbox was used. This toolbox allows the modeling of the various systems on the control system. Optimization was done using the OPTIMIZATION toolbox.

The objective of the model was to attain a stable control system. One of the main requirements was that the phase margin should be less than 45 degrees and a gain margin more than 10 decibels with the percentage overshoot not exceeding 20%. The Galil DMC 1000 controller has a proportional integral and derivative controller to provide the necessary compensation. The simulation involves three steps – i.) a Matlab file that has the model of the transfer function; ii.) a second Matlab source file converts the digital gains to analog gains; iii.)a Simulink graphics model which takes the analog values of the gains and simulates the system step response.

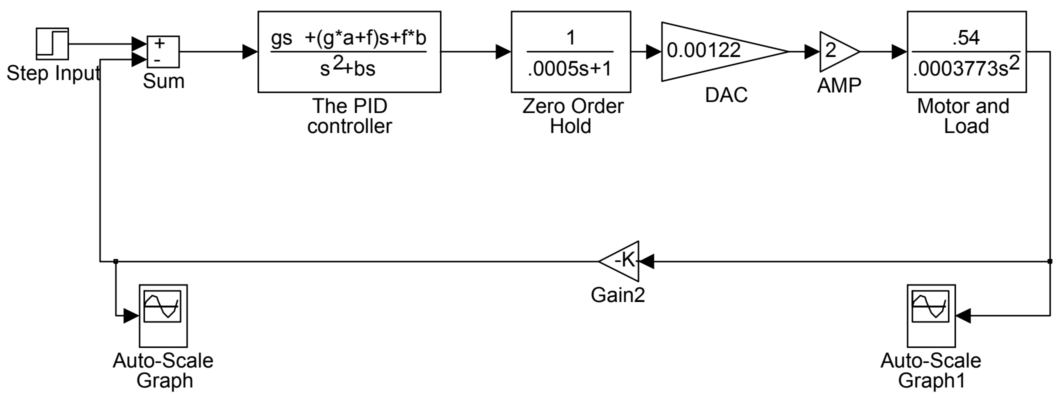


Figure-i. Simulink model of the

The model consists of a step input signal fed to a summation block. The constant values to be used in the PID block are calculated using a separate M-file. These values calculate the analog gains for the various digital gains. The calculated analog values are stored in the Matlab kernel and, are read automatically when the model file is run. Analog values in the PID controller adjust the input signal and feed it to the Zero order hold. The zero order hold holds the input level until the next input is given in order to smoothen the input wave. Sampling time for this is modeled in the block. The signal is then fed into the DAC (digital to analog converter) and then to the amplifier. The amplifier gain is set at 2 but could be changed on the actual device to suit the amplification needed. The amplified signal is fed to the load which in our case is the overall system including the motor and drive train. The motors have encoders that give the position feed back signal, which is fed to a summation block for correction. From the simulation it was found that the phase margin was within tolerable limits and the overshoot was less than 15%. These are observed in the magnitude and phase of the Bode plots.

Optimizing the control system to obtain PID values

The control parameters in the model above are optimized using a solver. This is a non-linear model to be optimized. This would enable the system to track a unit step input to the system with minimum error. MATLAB's optimization toolbox is used to solve the non-linear problem. The way this problem is tackled is in two steps. 1. The first method minimizes the error between the output and the input signal using *'lsqnonlin'* function. The routine lsqnonlin is used to perform a least square fit on the tracking of the output. 2. The second method uses the *'fminimax'* function. In this case, rather than minimizing the error between the output and input the function minimizes the maximum value of the output at any time. The variables are the parameters of the PID controller. If the error needs to be minimized only at one time, it would be a single objective function. But, we need to minimize the error for all time steps so it becomes a multiobjective function.

First the variables Kp, Kd, Ki are all defined and initialized before calling 'lsq'. When the 'optroutine' file is run the model is loaded and function 'lsq' does the optimization based on the initial values of specified for the parameters and, constraints. A solver called simset is chosen and the simulation is run.

Finally the optimization gives the solution for the Proportional, Integral, and Derivative (Kp, Ki, Kd) gains of the controller after 55 function evaluations. The result from Matlab is shown below.

Pid ( ) =   1   5   10

Iteration	Func-count	Residual	Step-size	Directional derivative	Lambda
1	3	4.76719e+012	1	-4.91e+012	
2	10	4.70723e+012	0.375	-1.51e+011	1.32032e+012
3	17	4.65431e+012	0.253	-2.33e+011	8.77204e+011
4	24	4.58281e+012	0.293	-8.38e+010	1.68981e+012
5	31	4.56367e+012	0.0868	8.32e+010	2.02202e+012
6	39	4.53102e+012	0.119	-1.63e+011	2.60576e+012
7	55	4.53102e+012	3.28e-007	-3.27e+011	1.07078e+018

Optimization terminated successfully:

Search direction less than tolX

pid = 0.7234 4.9399 10.0233

The final optimized parameter values are Kp = 0.7235; Ki = 4.9399; Kd = 10.0233

E. WSDK Method

The Windows Servo Design Kit (WSDK) software helps us in the configuration, tuning, testing, and analysis of the Galil Motion Controllers. WSDK has a number of functions that simplify and aid in setting up and evaluating a complete servo system. These include tuning the servo system, monitoring and recording data using the storage scopes and evaluating system performance.

As stated, when operating a Galil Motion Controller with servo motors, the system parameters for each axis must be established to provide optimal servo operation. The main parameters to be determined for optimal performance KP, KD, and KI can be determined manually or automatically through the tuning section of the WSDK software.

Setup & Running WSDK

To communicate with the Galil controller we need to first set it up. This involves registering it in the Windows registry. We need to setup the appropriate parameters for the controller. We have used a DMC-1000. We select an I/O port address (default 1000) and an interrupt (IRQ). We can use WSDK with multiple controllers at the same time.

Communication with the controller can be done using the terminal to send commands.

Tuning Methods

There are 4 built-in tuning methods available with the WSDK - Auto Crossover Frequency, Crossover Frequency, General Tuning, Conservative Tuning, along with an option for manual tuning. A brief description of the four tuning methods provided by the Galil kit is as follows -

General Tuning

This routine tunes the system by increasing each gain until instability occurs, then decreases the gain. The WSDK finds the best KP for a given value of KD. Once the best KP is found, KD is increased and WSDK finds the best KD for that KP value. This process is repeated until KD cannot be increased further without causing instability in the system. WSDK then decreases KP and KD to stable values. It then determines the highest value of KI which does not cause instability.

Automatic Crossover Frequency

This method attempts to determine the PID parameters that correspond to the crossover frequency of the system. This routine is used if the system's bandwidth is unknown.

Crossover Frequency

The Crossover Frequency routine allows defining a crossover frequency (rad/sec), and then attempts to tune the axis to provide the best system response at that frequency. Lower frequencies tend to over damp the system, resulting in a slower and more sluggish response. The higher frequencies produce faster system response, but because it tends to under damp it may cause the system to overshoot.

Conservative Tuning

The Conservative Compensation routine tries to find a gain setting that will not cause "buzzing" or overdrive the system. As the name suggests, the PID parameters are chosen to avoid any instability in the system but still provide a responsive system.

About the Manual Tuning

The Manual Tuning method provides a means of testing the responsiveness of your system. This method allows to choose the gain and damping of your system. Unlike the other tuning methods, this is not an automatic routine. All tuning parameters may be adjusted with sliders or by entering a value. The changes are in real-time which results in instant feedback regarding the effect of the parameters on the system's stability. We can test the system after any change.

Running the Tuning Methods

To run any method, we select a tuning method and the axis to be tuned. We also select to show a step response based on the current PID filter settings to provide a visual indication of how well the system is tuned. We can change most of the parameters involved in the tests. The Auto-Crossover Frequency and Crossover Frequency tuning methods send pulses or offsets to the diagnosed axis. The values of the Pulse Magnitude (Volts) and the Pulse Duration (msec) can be varied.

WSDK also provides storage scopes to record the actions of your controller and display them on the screen. It is also possible to display a derivative of the data you have recorded.

System Evaluation

WSDK provides a section on system evaluation which allows us to check the response characteristics of the system. This can be done in different ways. The first method relies on evaluating the step response which is displayed as part of the tuning procedure. The second method requires that the user write a program, run it, and evaluate the system by comparing the actual profile to the commanded profile. Another way would be to directly use the System Evaluation section of WSDK There are three tests that can be performed by the System Evaluation Section of WSDK.

Absolute Stability Test

The Absolute Stability test saturates the system to determine if it is conditionally unstable. The system is subjected to a pulse at the maximum output voltage of the controller (10V). If it is not unstable, it will remain stable unless under extreme or unusual conditions. The test displays the actual position and the requested torque on separate scopes. Typically, a well-tuned system will generate a position profile that consists of a single overshoot on the trailing edge. Excessive ringing on the trailing edge is a sign of instability and reveals that the PID parameters are not optimal. If the position profile shows no overshoot, the system is over damped; in which case, it is not tuned for the maximum bandwidth.

Frequency Response on Open Loop and Frequency Response on Closed Loop

The system is subjected to a range of open loop/ closed loop frequencies in order for the user to analyze the response of the system. The actual position and positional error are plotted in the upper scope. The lower scope displays the system gain as a function of frequency. This data can aid the user in determining whether further tuning or refining is necessary.

Step Response Test

This test displays the actual position so the user can determine whether further tuning or correction to the system is necessary.

We use both the frequency response tests along with the step response test results to aid us in manually tuning the motor as per our requirements.

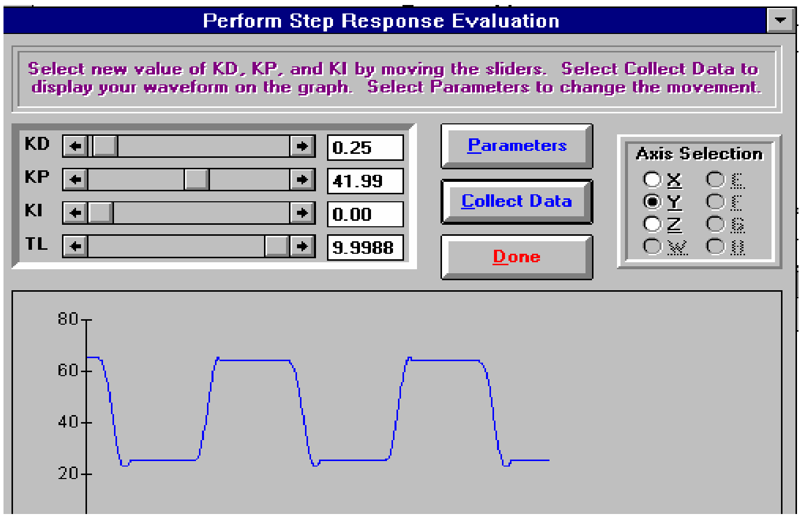


Figure-ii. Step Response Plot from the Galil servo design kit

E. Comparison of the three methods

All the tuning methods have been used variedly over a period of time on the motors driving the wheels as well as to tune the sonar motor. The values from WSDK tuning were used in the last two years contests and provided good performance. It is difficult to incorporate the load factor on motor in the simulation and optimization methods whereas WSDK carries it out in real environment. That's because it's difficult to model precisely each component such as time delay. On the other hand simulation method offers more independence with the variables. Now WSDK offer manual tuning option which can be used to test calculate values on the motor.

F. Addition of new gearmotor

Even after tuning the motor, the motor was displaying erratic behavior after few cycles such as exceeding the stopping points and stopping or rotating randomly. Initial analysis showed that one of the causes was overrun of the buffer memory in Galil Control Board. This was taken care of by introducing a programming constraint where the next command would not be sent till the previous command had been executed and Galil responded with a ready signal.

Though this solved the problem partially, inaccurate behavior persisted. It was observed that the motor started chattering or vibration was introduced. The reason for this was that the motor speed is very high (approximately 400 rpm) at normal settings. We were trying to rotate this motor for less than half a revolution and back which made the control very difficult. The control and positioning was difficult because we had to provide a very small value in the program and the response was not accurate for small values. Even reducing the speed did not make any change.

It was decided to add a gearbox to the motor to reduce the speed and give more control. After extensive search no gearbox was found which could be added to the existing motor. So the motor was replaced by an Electrocraft gearmotor model no. 284-001-103 which was the closest model to existing motor. It is essentially the same motor with sold with a pre-attached gearbox of ratio 50:1 sold by the same manufacturer. Thus it could be fitted easily in place of the existing motor. Both the encoder and power connections were similar. Installing the new motor solved the problem of chattering completely. The new motor was tuned using WSDK. Appropriate changes were made in the program as per the new gearbox. They included changing the counts give for rotation and setting the speed and acceleration values.

Simple logic helps us explain the more control offered by the gearbox -

Earlier to rotate the sonar by 15° we had to give a command to Galil of 70 counts which now is increased to 3500 counts. Thus we have a much wider range available to us for precise positioning.

The same ratio helps us in reducing the variations. Say earlier command was given to rotate the sonar by 15°, we had to rotate the shaft of the motor by 15°. If actual movement was 0.5° offset it would show in the sonar position as sonar was connected to shaft of motor.

Now the actual motor rotates by 750° which is more than 2 revolutions. So if the error is 0.5° the sonar position would not be affected as any error in the shaft is reduced further by a ratio of 50 in actual sonar displacement which is connected to the shaft of gearbox instead of being connected directly to motor.

Also allowing the motor to rotate some distance before stopping and changing direction has made tuning easier. Damping a motion of 100° to stop with less than 1° error is easier than damping a motion of 1° with less than 0.01° error.

G. Conclusion

The new tuned gearmotor has provided proper implementation to the rotating sonar idea. The resulting motion is much smoother and accurate. It was run for 500 cycles and displayed accurate positioning of sonar in the exact 5 positions.

It is expected to improve the results in both obstacle avoidance and follow the leader areas. It provides us with a low cost alternative to the more expensive laser scanner. Also it can be combined along with the laser scanner to give us more accurate obstacle avoidance data using a combination of both sources.

Filename: Thesis_Final
Directory: C:\WINWORD\Theses\Praveen
Template: C:\Documents and Settings\Administrator\Application Data\Microsoft\Templates\Normal.dot
Title: Study and Implementation of Follow the Leader Technology
Subject:
Author: Pravin Chandak
Keywords: system robot vehicle sonar motor
Comments: - Sonar System
System Modeling
2.1.3 Vision System
2.1.5 GPS System
2.1.4 Mechanical System

Creation Date: 8/8/2002 7:56 PM
Change Number: 2
Last Saved On: 8/8/2002 7:56 PM
Last Saved By: Administrator
Total Editing Time: 3 Minutes
Last Printed On: 8/8/2002 7:57 PM
As of Last Complete Printing
Number of Pages: 65
Number of Words: 15,364 (approx.)
Number of Characters: 87,580 (approx.)