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GPS based waypoint navigation for an
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GPS based waypoint navigation for an autonomous guided vehicle - Bearcat III

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Abstract

One of the major challenges in designing intelligent vehicles capable of autonomous travel on highways is reliable global positioning system (GPS) based navigation. GPS extends use, both as geographic information and navigational system for a ground based mobile robot, Bearcat III. Experiments were conducted in Bearcat III, for waypoint navigation using Garmin GPS 76. RS232 interface connects the GPS system to the main control computer. A mapping program defines a desired route and GPS information was used to update the control points of the mobile robot using a reinforcement learning method. Local position updates were used when found in the environment. Extended use of GPS to local vehicle control that requires more resolution that is available from the raw data using the adaptive control method was significant. The systems were tested in July 2003 at the International Ground Robotics Competition.

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Chapter 1

Introduction

1.1 Motivation

There has been a great amount of research devoted to the global positioning system based navigation for mobile robot platforms and intelligent vehicles. Any mobile robot that must reliably operate in an unknown or dynamic environment must be able to perform intelligent navigation. As road following and off road systems have become capable, more attention has been focused on GPS based navigation. The Center for Robotics Research at the University of Cincinnati has built an unmanned, autonomous guided vehicle named Bearcat III for the Annual Intelligent Ground Vehicles Competition conducted each year by the Association for Unmanned Vehicle Systems.

1.2 Organization of the Thesis

This thesis is organized into 5 chapters. Chapter 1 is an introduction and gives the motivation and organization of the thesis. Chapter 2 describes the Bearcat-III systems Design on which testing was done. Chapter 3 lights the literature overview of international ground vehicle competition – challenge, research goals, global positioning system, GPS mechanisms and navigational challenge problem. Chapter 4 describes the navigational solution approach, algorithm, implementation and test results. Chapter 5 presents the conclusion and directions for future research.

Chapter 2

The Bearcat III

Bearcat III is an Autonomous Guided Vehicle built at the University of Cincinnati, Center for Robotics Research basically for competing in Annual intelligent ground vehicle competition. It is capable of following line tracks and avoiding obstacles on the path as prescribed by competition regulations. It does have navigational capabilities using a global positioning system (GPS). The performance characteristics of Bearcat – III is shown in Table 1

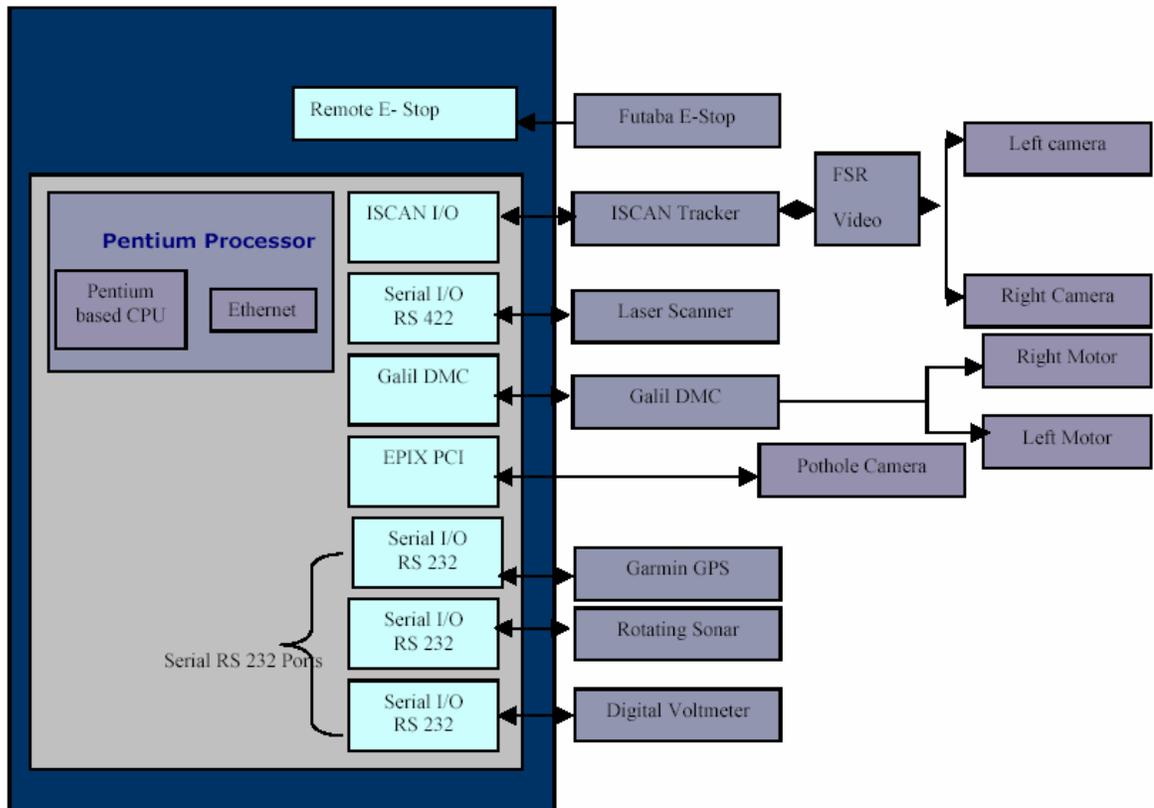
Table 1.1 Performance Characteristics of Bearcat - III

S.No	Task	Predicted Performance
1	Line Following	Tracks lines with an accuracy of 0.3 inches
2	Obstacle Avoidance	Detects obstacles 8 inches and higher in a range of 24 feet
3	Pothole Detection	Detects simulated potholes across the 10 feet track and a distance of 4 feet
4	Waypoint Detection	Navigates waypoints with an accuracy of 5 feet
5	Emergency Stop	Has a remote controlled emergency stop that can be activated from a distance of 65 feet
6	Dead End Detection	Detects dead ends and avoids traps by backing up and following alternative route
7	Turning Radius	Vehicle has a zero turning radius
8	Maximum Speed	5 miles per hour
9	Ramp Climbing Ability	Can climb inclines up to 10 %
10	Battery Life	3 hours of continuous operation
11	Braking Distance	Vehicle comes to a dead stop as soon as the power is cut off

2.1 System Design of Bearcat III

The major sub systems classified based on Bearcat III's functionality would be Vision, Motion control, Sonar, Laser scanner, Mechanical, Navigation, Electrical, Health and Safety systems.

Fig 2.1 Basic block diagram



2.2 Vision System

The Bearcat's vision system for the autonomous challenge comprises three cameras, two for line following and one for pothole detection. The vision system for line following uses 2 CCD cameras and an image tracking device (ISCAN) for the front end processing of the image captured by the cameras. ISCAN tracker is used to process the

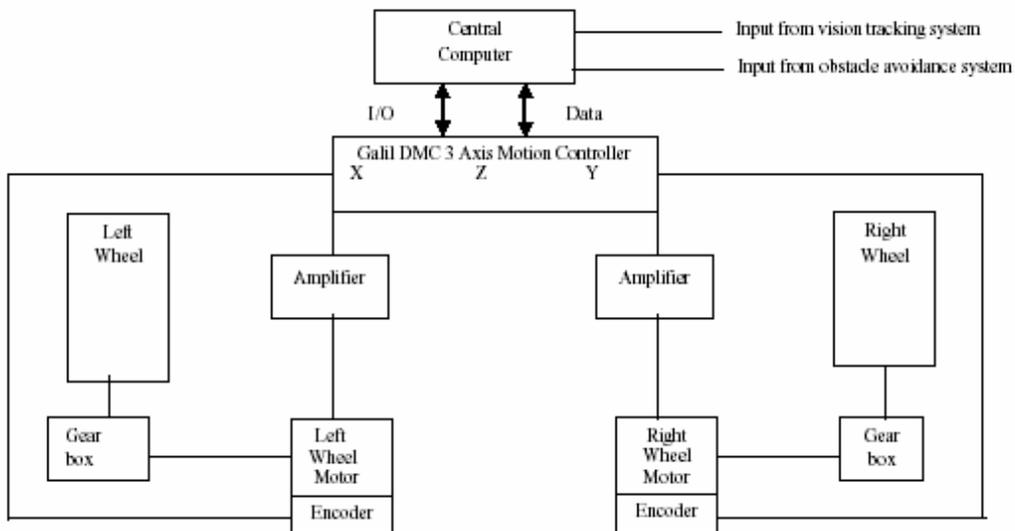
image of the line; the tracker finds the centroid of the brightest or darkest region in a captured image. The three dimensional world co-ordinates were reduced to two dimensional image coordinates as a result of the transformations taking place from the ground plane to the image plane. A novel four-point calibration system was designed to transform the image co-ordinates back to world co-ordinates for navigation purposes. Camera calibration is a process to determine the relationship between a given 3-D coordinate system (world coordinates) and the 2-D image plane a camera perceives (image coordinates). The objective of the vision system is to make the robot follow a line using a camera. At any given instance the Bearcat tracks only one line, either right or left. If track is lost from one side, then the central controller through a video switch changes to the other camera.

In order to obtain accurate information about the position of the line with respect to the centroid of the robot, the distance and the angle of the line with respect to the centroid of the robot has to be known. When the robot is run in its auto-mode, two ISCAN windows are formed at the top and bottom of the image screen. The centroids of the line segments are returned by the ISCAN tracker. These data-points help us to determine the angle and distance of the line with the robot. The calculated distance and angle work as inputs for the motion control system.

2.3 Motion Control System

The motion control system shown in the Figure 2.2 enables the vehicle to move along a path parallel to the track and to negotiate curves. Steering is achieved by applying differential speeds at the left and the right wheels. Manipulating the sum and difference of the speed of the right wheels, the velocity and orientation of the vehicle can be controlled at any instant. Two motors power the gear train. The motor torque is increased by a factor of 40 using worm and worm gear train. The power to each motor is delivered through an amplifier that amplifies the signal from the Galil DMC Motion Controller. The data from the vision and obstacle avoidance systems work as an input to the central controller to give commands to the motion control system to drive the vehicle.

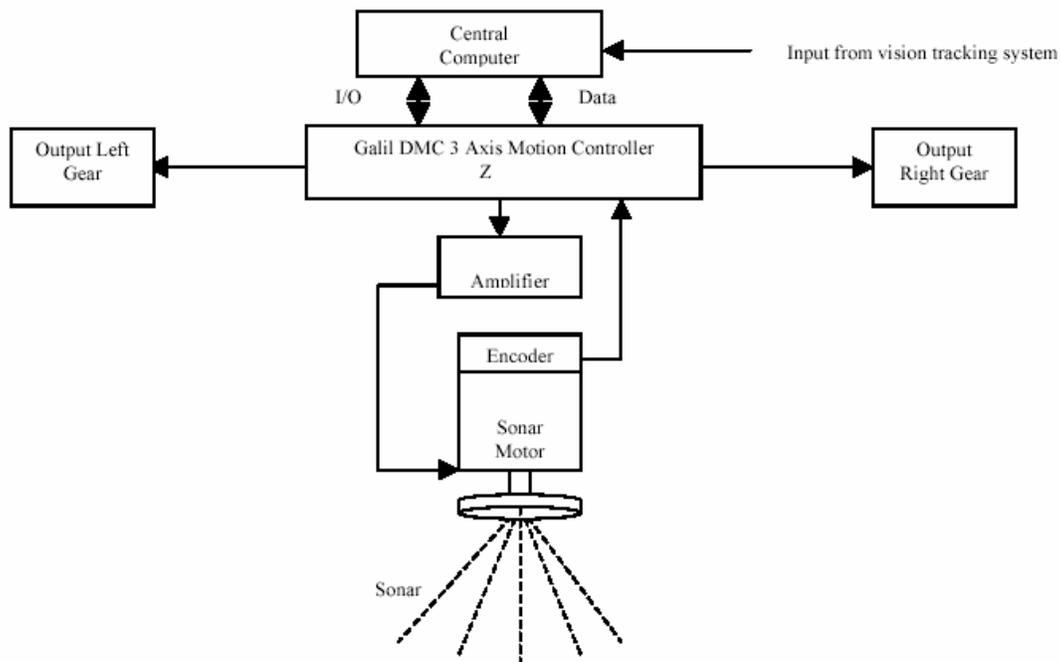
Fig 2.2 Motion Control System Block Diagram



2.4 Sonar System

The two main components of the ultrasonic ranging system are the transducers and the drive motor as shown in Figure 2.3. A 12 Volts DC, 0.5 Amps unit powers the sonar. A “time of flight” approach is used to compute the distance from any obstacle. The sonar transmits sound waves towards the target, detects an echo, and measures the elapsed time between the start of the transmit pulse and the reception of the echo pulse. The transducer sweep is achieved by using a motor and Galil motion control system. Adjusting the Polaroid system parameters and synchronizing them with the motion of the motor permits measuring distance values at known angles with respect to the centroid of the vehicle. The distance value is returned through an RS232 serial Port to the central controller. The central controller uses this input to drive the motion control system.

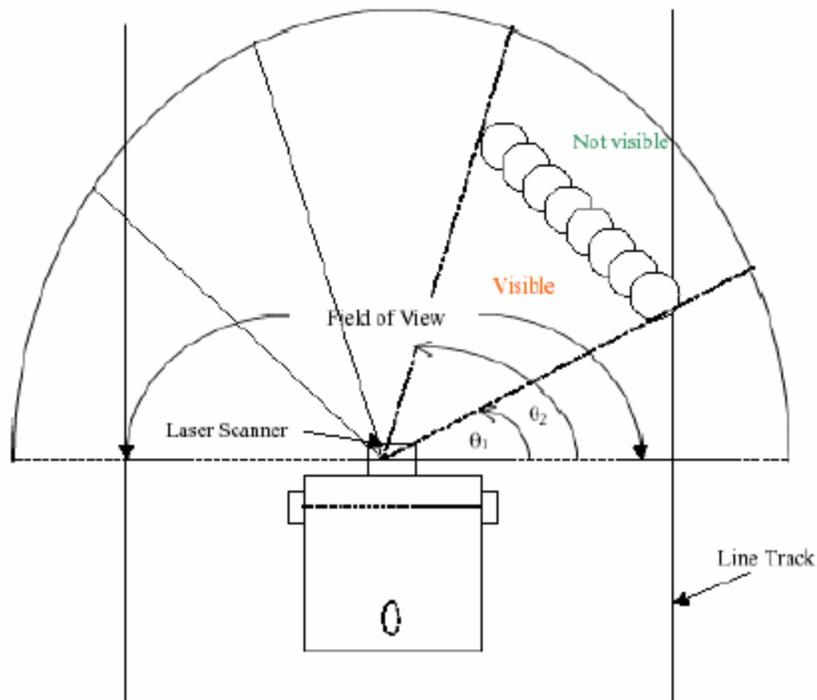
Fig 2.3 Sonar Obstacle Detection system



2.5 Laser Scanner System

The Bearcat uses the SICK laser scanner (LMS 200) for sensing obstacles in the path. The power supply to the unit is through a 24Volt, 1.8 Amp adapter. The unit communicates with the central computer using a RS422 serial interface card. The maximum range of the scanner is 32 meters. For the contest, a range of 8 meters with a resolution of 1° has been selected. The scanner data is used to get information about the distance of the obstacle from the robot. This can be used to calculate the size of the obstacle. The scanner is mounted at a height of 8 inches above the ground to facilitate the detection of short as well as tall objects. The central controller performs the logic for obstacle avoidance and the integration of this system with the line following and the motion control systems. The Figure 2.4 shows the field view with the laser scanner.

Fig 2.4 Laser scanner and range detection



2.6 Waypoint Navigation Using GPS

The methodology behind the Bearcat navigational challenge problem was to select a commercially available GPS unit and utilize the built in features of the unit to provide a solution to the GPS navigational problem. This approach relies on the GPS unit's navigational processing features and reduces the computational load that the robot CPU must perform to navigate the course. The basic criteria used in the selection of the GPS unit are WAAS (Wide Area Augmentation System) capability, RS-232 serial port input/output ability, external antenna, external power capability, and embedded navigation features. Based on these selection criteria the Garmin GPS 76 was chosen as the unit to provide GPS navigational ability to the robot. The major navigational features of the GPS unit used in the solution of the GPS navigational problem are the ability to input/output NMEA (National Marine Electronics Association) messages, set target waypoints, and calculate bearing/range information to the target waypoint. The physical implementation of GPS navigation feedback control loop consists of the Garmin 76 GPS unit, the robot motion control system, laser scanner, and the robot computer.

2.7 Mechanical System

The Bearcat III is designed to be an outdoor vehicle able to carry a payload of 100 pounds. Optimal design was arrived using good design practices during basic design and CAD software such as AutoCAD R14 and IDEAS Master series 7.0 were used in the final analysis phase for stress and load analysis. The basic structure goes with the aluminum extrusions, joining plates and T-nuts. The frame is designed with an extruded aluminum structure to hold the components of the vehicle.

Fig 2.5 Mechanical system



2.8 Power System

The Bearcat III's electrical system consists of a DC battery power system that supports an AC power system through an inverter. Three 12-Volt DC, 130 Amp hours, deep-cycle marine batteries connected in series provide a total of 36 Volts DC, 4680 Amp hours for the main electrical power. A 36-Volt, DC input 600-Watt inverter provides 60 Hz pure sine wave output at 115 Volts AC. The inverter supplies AC electrical power for all AC systems including the main computer, cameras, and auxiliary regulated DC power supplies. An uninterruptible power source (UPS) interfaces the robot main computer with the AC power system. The UPS provides 3 minutes of emergency power to the main computer during AC power system interruptions. The UPS allows the main computer to be properly shutdown or connected to an external power source if the

main robot AC power system is offline. The DC system provides 36 volts unregulated DC electrical power to the motors at a maximum of 10 Amps. The total power required by the Bearcat is approximately 735 Watts for the DC systems and 411.3 Watts for the AC systems. Thus, 1146-Watts total power is required to operate the Bearcat III. A loss of 10 percent was estimated for the required power to yield 1261 Watts actually required. A 10 percent loss can also be assumed for power supplied by the batteries to yield 4212 watt hours available. Based on these estimates the Bearcat III power system has an estimated endurance of 3.34 hours at full load.

2.9 Health Monitoring System

The Bearcat III is equipped with a self- health monitoring system. A RS 232 serial port is used to take input from a digital multi-meter, which can be accessed from C++ code to check the total DC voltage of the batteries. The health monitoring is implemented as a C++ class module that has methods that can monitor battery voltage and display warning messages to the computer screen. Two voltage threshold trip points can be set that will trigger a low voltage and a critical low voltage warning message. The low voltage warning indicates that the battery voltage is below the first threshold trip point and that preparations should be made to change or charge the batteries. The critical low voltage warning indicates that corrective actions must be taken immediately because robot power system shutdown is eminent. The voltmeter class can also be used in code to sound an audible alarm or activate the robot strobe light at the specified threshold point. The power system voltage display is visible to the operator and provides a constant indication of voltage.

2.10 Safety System

2.10.1 Manual Emergency Stop

The manual emergency stop unit consists of a red manual push button located on the easily accessible rear surface of the vehicle. When pressed, the power to the motors is cut off and the self-locking mechanism of the gearbox brings the vehicle to an instant halt. The self-locking mechanism ensures that the vehicle does not move when it is not powered and serves as a safety measure against any undesirable motion such as rolling when parked on a slope.

2.10.2 Remote Controlled Emergency Stop

The mobile robot can be de-activated by a remote unit from a distance of 65 feet in compliance with the rules for autonomous challenge of the international ground vehicle contest. The remote controlled emergency stop consists of a Futaba transmitter, a receiver, an amplifier, and a relay. The advantage of using this is that the transmitter need not be in line with the sight of the receiver. The Futaba transmitter uses a 6V DC and transmits FM signals at 72.470 MHz over a range of 65 feet. This amplified current activates the contacts of the relay that in turn activates the emergency stop solenoid and cuts power to the motors.

Chapter 3

Literature Review

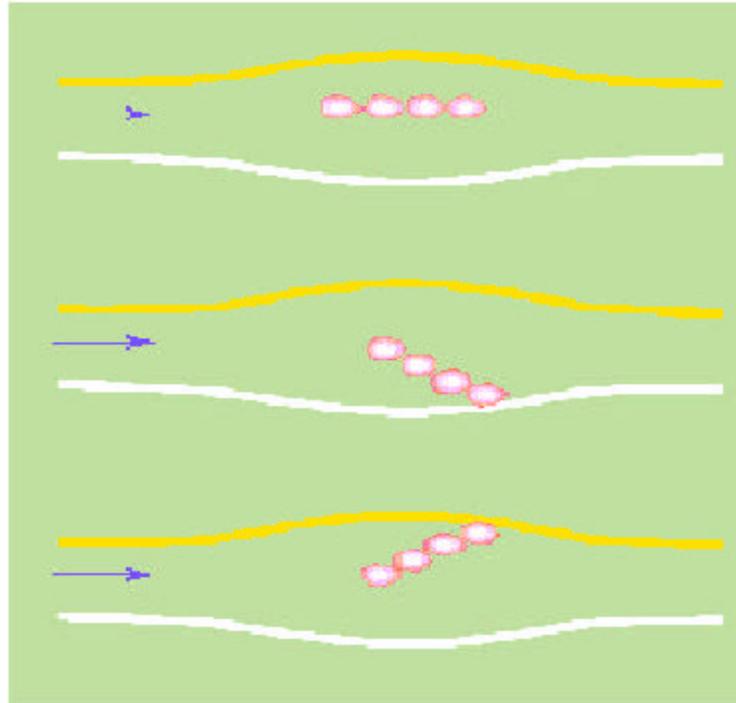
3.1 International Ground Vehicle Competition - Challenge

An autonomous vehicle needs a sophisticated system for analyzing the failures, storing the related information in an integrated repository and retrieving the same via standard user-friendly interface. The Center for Robotics Research at University of Cincinnati has been developing robots for the past 15 years. The Bearcat robot of UC Robotics team has undergone three major modifications till now. The latest version called Bearcat III. The Center for Robotics Research at the University of Cincinnati has been a participant in the Annual Intelligent Vehicles Competition competition for the last 10 years. The University of Cincinnati has so far used three versions of their Automated Guided Vehicles.

The competition requires a fully autonomous ground robotic vehicle to negotiate around an outdoor obstacle course under a prescribed time while staying within the 5 mph speed limit and avoiding the obstacles on the laid track. Unmanned, autonomous vehicles must compete based on their ability to perceive the course environment and avoid obstacles without human assistance in any form during competition. All computational, power, sensing and control equipment must be carried on board the vehicle. The course is out on grass, pavement, simulated pavement, or any combination, over an area of approximately 60 to 80 yards long, by 40 to 60 yards wide. The path of vehicle travel is marked by solid white lines (which can be dashed at certain regions).

Sometimes the lines may get obscure or change color from white to green. The road direction may change but the width of the road is always approximately 10 feet.

Fig 3.1 Obstacle course for Bearcat III



The obstacles block the path of the robot and the vehicle is expected to maneuver with enough clearance without touching or knocking. These obstacles may vary from 5 gallon buckets; construction barrels (aligned at an angle to the track) or it can be a sand trap and also a ramp (inclined at 10 percent or about 8 degrees). In short, the vehicle must be able to follow the changing track while avoiding obstacles at the same time. In order for this to happen, the vehicle must be designed in such a way that it can sense and deal with the issue of uncertainty and incomplete information about the environment in a reasonably short duration of time.

3.2 Research Goals

The ability to navigate in known and unknown environments belongs to the key skills of today's mobile robots. Especially in structured environments, characteristics of the robot's surroundings can be used to simplify the task. The University of Cincinnati Robotics Research Center has been working on improving the ability of the automated guided vehicles for several years. Each year, some new features are added to extend the robot functionalities. Navigation and positioning are crucial to mobile robot navigation and yet the process has always been quite cumbersome. Over the years the Cincinnati Robotics team has successfully developed vision systems and sonar sensors on their robot Bearcat III to trace landmarks so that the vehicle could understand where it is. However, this is highly unreliable as it is worked only in local area and also subject to movement or destruction by environmental factors. The quest for greater and greater navigation accuracy has spawned the idea of employing GPS technology to improve the robot navigation functionality. The goal of this research was to implement Garmin GPS 76 on Bearcat III for waypoint navigation in its environment.

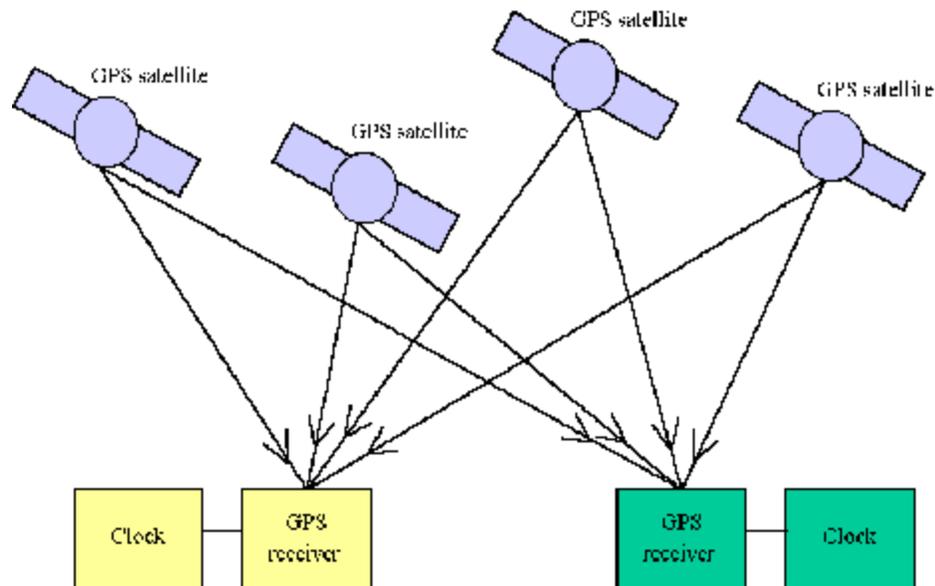
3.3 Global Positioning System Technology

Global Positioning Systems (GPS) provide navigational community with powerful tools for acquiring accurate and current digital data. Combined with high resolution remote sensing and GIS for land use studies, GPS can provide high accuracy data for navigation.

The Global Positioning System is a satellite-based radio navigation system initially developed and operated by the U.S. Department of Defense (DOD). In 1996, a

Presidential Decision Directive, later passed into law, transferred "ownership" from DOD to an Interagency GPS Executive Board (IGEB), co-chaired by senior officials of the Departments of Transportation and Defense to provide management oversight to assure that GPS meets civil and military user requirements. GPS permits land, sea, and airborne users to determine their three-dimensional position, velocity, and time 24 hours a day, in all weather, anywhere in the world with a precision and accuracy far better than other radio navigation systems available today or in the foreseeable future. GPS consists of three segments: space, control, and user.

Fig 3.2 Determination of coordinates from four coded time signals



The Space segment consists of 24 operational satellites in six 12-hour orbits 20,200 km (10,900 mi) above the earth at an inclination angle of 55 degrees. The satellites are spaced in orbit so that at any time a minimum of 4 satellites will be in view to users anywhere in the world. The satellites continuously broadcast a low power, one

way position and time signal to users throughout the world. There are currently 29 satellites in orbit, or five spares, which assure the availability of 24 operational satellites.

The Control Segment consists of a master control station in Colorado Springs, Colorado, with five monitor stations and three control up-link stations located throughout the world. Monitor stations track all GPS satellites in view and collect ranging information from the satellite broadcasts. This information is then sent back to the master control station, which computes extremely precise satellite orbits. The data is then formatted into updated navigation messages for each satellite. The updated information is transmitted to each satellite via the control up-link stations, which also transmit and receive satellite control and monitoring signals.

The User Segment consists of the receivers, processors, and antennas that allow land, sea, or airborne operators to receive the GPS satellite broadcasts and compute their precise position, velocity and time. GPS, formally known as the Navstar Global Positioning System, was initiated in 1973 to reduce the proliferation of navigation aids. By creating a system that overcame the limitations of many existing navigation systems, GPS became attractive to a broad spectrum of users.

GPS has been successful in virtually all navigation applications, and because its capabilities are accessible using small, inexpensive equipment, GPS is also being used in many new market applications today. There are five stations around the world (Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs.) monitoring the GPS satellites, checking both their operational functions and their exact position in space. The ground station transmits corrections for the satellite's ephemeris constants and clock

offsets back to the satellites. The satellites can then incorporate these updates in the signals they send to the surface of the earth and can be read by GPS receivers. It functions just like assigning each patch of land a unique address. GPS satellites provide specially coded signals that can be processed in a GPS receiver, enabling the receiver to compute altitude, longitude, height, velocity and time. Precise positioning could be achieved by using GPS receivers at different locations providing corrections and reference positioning data for remote receivers.

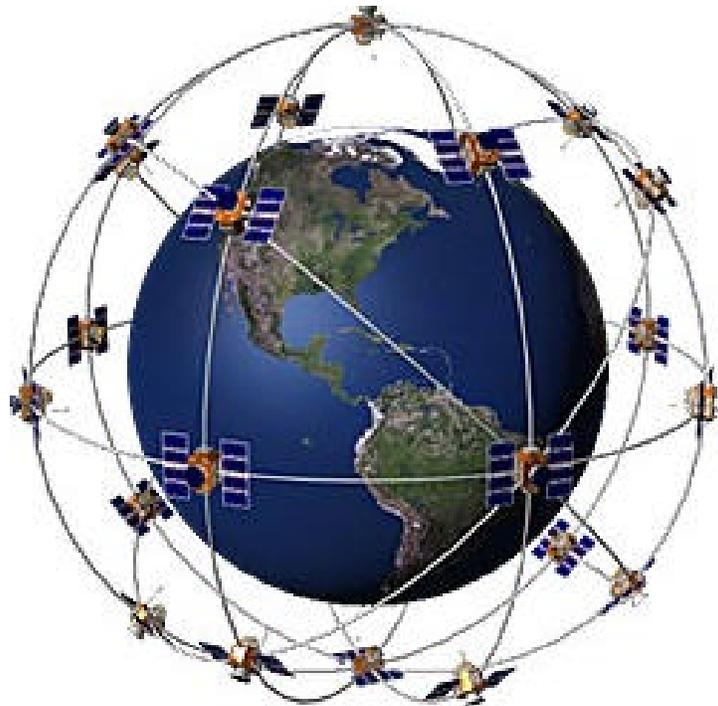
Time and frequency dissemination, based on the precise clocks on board the satellites and controlled by the monitor stations, is another use for GPS. Astronomical observatories, telecommunications facilities, and laboratory standards can be set to precise time signals or controlled to accurate frequencies by special purpose GPS receivers. Research projects also use GPS signals to weight atmospheric parameters. Generally, at least four satellite signals should be read to determine precisely of one position on earth. The determination of position and time from satellites is shown in Figure 3.2. Determination of coordinates from four coded time signals.

3.4 GPS Theory and Accuracy

GPS receivers collect signals from satellites in view. They display the user's position, velocity, and time, as needed for their marine, terrestrial, or aeronautical applications. Some display additional data, such as distance and bearing to selected waypoints or digital charts. The GPS concept of operation is based upon satellite ranging. Users determine their position by measuring their distance from the group of satellites in

space. The satellites act as precise reference points. Each GPS satellite transmits an accurate position and time signal. The user's receiver measures the time delay for the signal to reach the receiver, which is the direct measure of the apparent range (called a "pseudo range"), to the satellite. Measurements collected simultaneously from four satellites are processed to solve for the three dimensions of position (latitude, longitude, and altitude) and time. Position measurements are in the worldwide WGS-84 geodetic reference system, and time is with respect to a worldwide common U.S. Naval Observatory Time (USNO) reference.

Fig 3.3 GPS Constellation



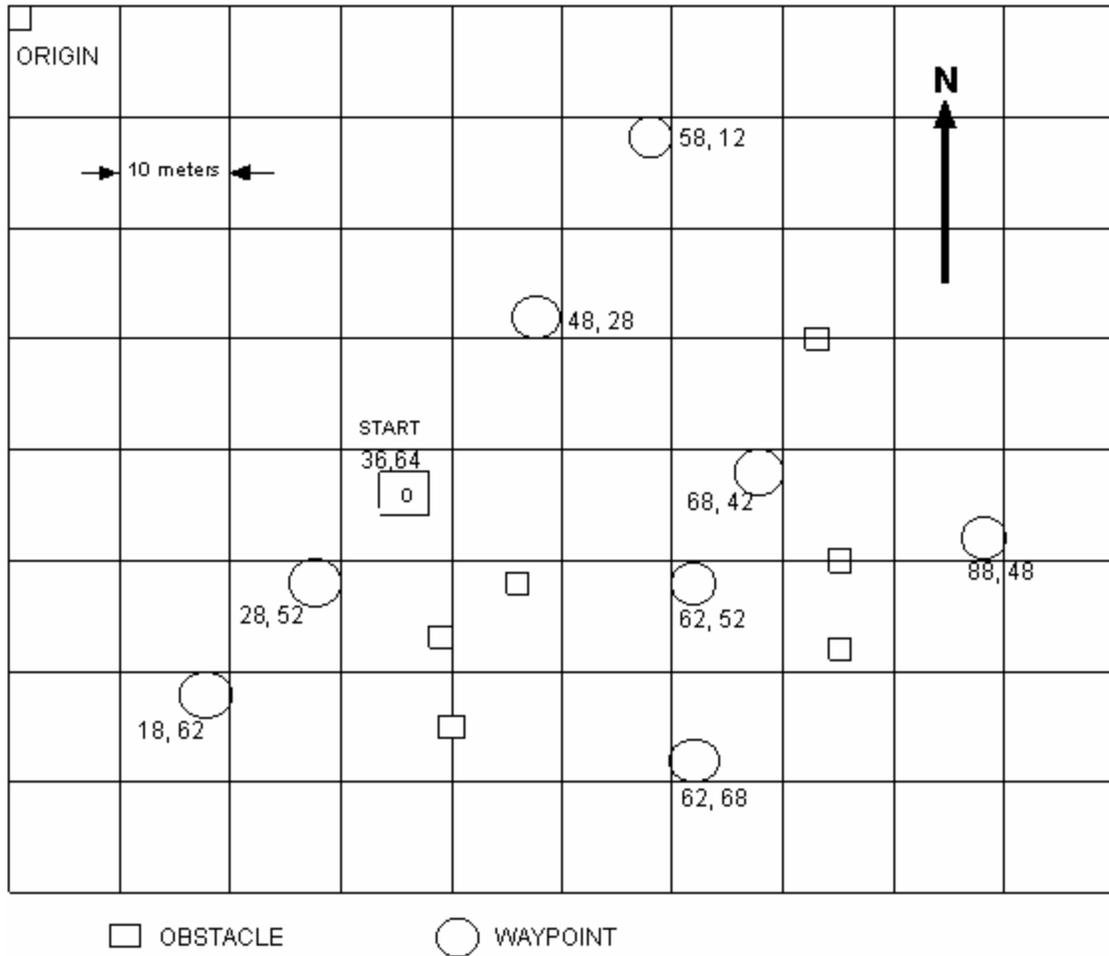
Accurate timing is the key to measuring distance to satellites. Receiver clocks do not have to be that accurate because an extra satellite range measurement can remove errors. The basic orbits of satellites are quite exact but in order to make it reliable the

GPS satellites are constantly monitored by the Department of Defense (DoD). They use precise radar to check each satellite's exact altitude, position and speed. The errors they're checking are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris." These errors are generated by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites. The errors are usually very slight but if you want high level accuracy they must be taken into account. Once the DoD has measured a satellite's precise position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals it is broadcasting. So a GPS signal is more than just pseudo-random code for timing purposes. It also contains a navigation message with ephemeris information as well. The ionosphere and atmosphere around the earth cause delays in the GPS signal that translate into position errors. Some errors can be factored out with mathematics and modeling. The configuration of the satellites in the sky can magnify other errors. Differential GPS can eliminate almost all errors.

3.5 Navigation Challenge

The challenge in this event 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. Coordinates of the targets will be given in latitude and longitude as well as in meters on an x - y grid. The contestants are expected to use Differential GPS, but non-differential GPS is allowed as well as dead reckoning with compasses, gyros, and wheel odometers. WAAS or any of the commercial suppliers of corrections are also allowed.

Fig 3.4 Typical course for navigational challenge



The map above shows a typical course for the Navigation Challenge used for practice during development. Coordinates on this map are in meters measured from the origin. The competition course would be run on a grassy field approximately 80 by 90 meters (1.8 acres), and the total travel distance on the course will be on the order of 275 meters depending on the route chosen for the vehicles. The exact target locations would be marked on the grass for use by the judges, but there will be no standup markers to

indicate those positions. Construction barrels and certain other obstacles would be located on the course in such positions that they must be circumvented to reach the waypoints.

The robot is supposed to navigate to each successive target point based on GPS satellite position data and arrival at a target point is defined as approaching within five feet of the target point. The GPS is used to get the original position, then tracking is used to move the robot from one point to the next, updating the new base with every pass. The GPS receiver outputs position (latitude, longitude, height) and velocity information at a rate of 1 second per output to 255 seconds per output. The accuracy of the output varies between 5 feet to 25 feet. The normal robot speed is about 5 feet /second, and the motion command delay is about 0.5 second.

The main issue in controlling with GPS feedback is to maximize the accuracy. In order to do this, several sample data should be accumulated and then the average and variance computed through a least squares method. Also, since the contest field has limited distance, errors due to the earth arc may be ignored. However, when the robot is in motion, the sampling historical data are taken not for a fixed spot. This could be fixed by adding shifts of the robot over time to the historical data, which could then be processed as if they are sampled at the same spot over a period of time.

Chapter 4

The Global Positioning System on Bearcat III

4.1 Approach

The approach is basically to choose commercially available GPS units which with its navigational processing features eliminate the need for computation in the main computer that can be conserved for obstacle avoidance and line following features during the contest. This method also eliminates the need for GPS navigational algorithms development as they are already loaded by GPS unit manufacturer in the kit. The GPS unit selected was also based on the criteria that its embedded software be upgradeable as newer versions become available from the manufacturer.

4.2 Selection of Commercial GPS system

A commercially available GPS unit was selected and its built in features are utilized to provide a solution to the GPS navigational problem. The primary reason for selection of the Garmin GPS 76 unit is Waas capability to improve the accuracy, RS-232 serial port input/output ability for ease of interfacing, and embedded navigational features which avoid fresh development. Waas capability improves the accuracy of the standard GPS signals to 3 meters which can be inferred from the table 4.1 Specifications of Garmin GPS 76 used in Bearcat - III. The RS-232 input/output capability allows the robot computer to interface with the GPS unit directly and process the navigational data from the GPS unit.

Table 4.1 Specifications of Garmin GPS 76 used in Bearcat - III

1	Size	1.2" x 2.7" x 6.2" (3.0cm x 6.9cm x 15.75cm)
2	Weight	7.5 oz (0.21 Kg)
3	Display	2.9" diagonal (6.0cm) high-contrast, 4-level gray LCD with backlighting (180 x 240 pixels)
4	Case	Fully gasketed, floatable, high-impact plastic alloy, waterproof to IEC 529-IPX-7
5	Temp. Range	5°F to 158°F (-15°C to 70°C)
6	Battery Life	16 Hours in Battery saver mode
7	Receiver	Differential-ready 12 parallel channel receiver
8	Acquisition Times	Approx. 15 seconds (warm start) Approx. 45 seconds (cold start) Approx. 5 minutes (First Time/Auto Locate)
9	Update Rate	1/second, continuous
10	GPS Accuracy	*<15 meters (49 feet) RMS 95% typical
11	DGPS (USCG) Accuracy	3-5 meters (10-16ft), 95% typical
12	DGPS (WAAS) Accuracy	3 meters (10-16 ft), 95% typical with DGPS corrections
13	Velocity Accuracy	0.1 knot RMS steady state
14	Dynamics	6 g's
15	Batteries	Two 1.5- volt AA batteries
16	Source	8-35V DC
17	Fuse	AGC/3AG – 2.0 Amp

The NMEA (National Marine Electronics Association) 31 data format interface was used for data exchange between the main computer and the GPS unit although the GPS unit is capable of other data interface methods. The main navigational features of the GPS unit used in the solution of the GPS navigational problem are the ability to input/output NMEA messages, set target waypoints, and calculate bearing/range information to the target waypoint. The powerful Garmin GPS 76 served the purpose albeit a lot of other additional other features were not utilized in the current navigation algorithm.

Fig 4.2 Garmin GPS 76



4.3 Algorithm

The classical closed feedback control loop was utilized in the modeling of the navigational challenge problem, with an input command, feedback signal, error signal, and output transfer function characteristics. The target waypoint destinations are specified as the input command and the feedback signal is provided by the Garmin GPS 76 based on its position with reference to satellite data. Now, using the present position co-ordinates, it plots bearing and range from the target waypoint to determine the error. Correction signals are generated to reduce the error to a certain tolerance based on the bearing angle error signal generated by the Garmin GPS 76 unit. The corrective signals are sent to the robot motion control system, which translates the commands into motor control voltages that steer and propel (right, left or stop) the robot on the course. Once the bearing angle error and target range have been reduced to the required tolerance, the

robot reaches its target destination waypoint. Now, the process continues until all target waypoints in the input file are navigated.

The navigational challenge field also has different kinds of obstacles which have to be avoided by the robot while navigating given waypoints. The Bearcat III uses a SICK laser scanner for obstacle avoidance which takes the routine in its control whenever there is an obstacle in the range. Also, obstacle avoidance has a similar classical feedback control loop used for the GPS navigation. Once the robot effectively evades the obstacles, the original target waypoint is restored and the navigational routine is resumed.

4.4 Implementation

The implementation of GPS navigation feedback control loop consists of the Garmin 76 GPS unit, Galil DMC motion controller, SICK laser scanner, and the main onboard computer. The input file of the target waypoints has the precedence of the waypoints records to be navigated by the robot. The records are then stored in the memory as an array. Each target waypoint is sequentially selected from the waypoint coordinate array and the target coordinates are formatted into a NMEA \$GPWPL (Waypoint Location) sentence that is transmitted to the Garmin 76 GPS unit via the RS-232 port interface. This message is sent to the Garmin 76 GPS unit and it sets the active target waypoint in the GPS unit's memory, this is the command signal. Once set, the waypoint coordinate is used by the GPS unit to calculate bearing and range to the target waypoint. The Garmin 76 unit must be set to NMEA interface mode and navigate to waypoint mode with the target waypoint name (ID) selected. Once in NMEA mode, the Garmin 76 unit transmits various NMEA sentences with GPS navigational data [32]. The feedback and error signal

information is transmitted in the NMEA \$GPRMB (Recommended minimum navigation information) sentence.

Garmin GPS 76 sends the \$GPRMB ASCII sentence to the main computer where it is parsed to obtain the bearing and range to destination waypoint data, which is the error signal. The main computer sends either turn left or turn right correction signal to the robot motion control system based on the bearing to target value. The robot turns to the commanded correction angle until the GPS unit bearing error feedback signal is within the selected tolerance. The process continues as the robot reaches the first waypoint for the next target waypoint record. The laser scanner sends correction signal when the robot is in obstacle avoidance mode to turn the robot until the obstacle is no longer obstructs the robot. The robot computer processes the digital feedback control algorithm code and sends correction command to the robot motion control system apart from interfacing all the systems involved.

The Garmin 76 GPS unit is represented in the navigation code by a C++ GPS class that has member functions into a single GPS object that can be used in the C++ code to implement the feedback control loop. The functions defined in the GPS class are:

1. void GPS::readGpsData(void){} - Reads gps data from serial port and returns a pointer to a string array containing the data.
2. void GPS::getGpsData(struct gpsdata* t){} - copies the contents of the private member variable N8MEA into a gpsdata structure and this function allows outside access to the private member variable NMEA by making a copy of the structure into the gpsdata structure pointed to by the gps data structure in the function parameter list.

3. void GPS::CreateWaypointFile(void) {} - a waypoints data file is created through user interface input waypoint data structure file written.
4. void GPS::SelectWaypoint(int select) {} - selects an active waypoint function and takes waypoint number as a parameter
5. void GPS::InputWaypoints(void){} - Reads the input values of waypoint information
6. void GPS::printInfo(void){} - Prints gps class data member contents to screen.

4.5 Experimental Test Setup and Results

Testing was done based on the outline given in the Annual Intelligent Ground Vehicle Competition navigational challenge guidelines. Extensive testing resulted in winning the third prize in Navigational challenge of IGVC 2003 with eight target waypoints points. Using the handheld Garmin GPS 76, the latitude and longitude of each marked position was determined and recorded in the input file. Firstly, the robot was subject to manual navigation testing. The angle and distance information from GPS navigation computer program was used to determine the steering direction information. The values were manually input into the robot steering command prompt which turns the robot in the direction specified. Once the turn angle was manually set, the robot was given the command to move a line distance equal to the range to the target waypoint as displayed by the GPS navigation computer program. The purpose of the manual testing was verification of GPS unit interface and output data. Extensive testing proved that GPS navigation algorithm worked satisfactorily albeit an error of twelve feet which almost equals the advertised accuracy of the GPS unit in Waas mode.

Fig 4.3 Team with III Prize in Navigational Challenge in IGVC 2003



Fig 4.4 Action during Navigational Challenge in IGVC 2003



Chapter 5

Conclusion and Directions for Future Research

The technology of the Global Positioning System is allowing for huge changes in society. The applications using GPS are constantly growing. The cost of the receivers is dropping while at the same time the accuracy of the system is improving. GPS will soon be at least as pervasive as the cell phone. As a matter of fact, GPS is now standard in every cell phone sold in the U.S. “The U.S. Federal Communications Commission has mandated that by October 2001, wireless carriers must be able to pinpoint and report the location of all 911 calls by integrating GPS systems into their cellular phones. Emergency crews can then use this information to reach their destinations more quickly.” The potential applications of GPS are vast.

GPS is often used in conjunction with a GIS (geographical information system) to provide location information and directions in personal automobiles. The potential for GPS in our personal transportation is much more extensive than driving directions. Once perfected, auto driving system would permit unimpeded traffic flow, significantly reduce traffic jams, and bring about an unprecedented increase in the safety of the automobile. However, the direct use of GPS on automated guided vehicles in manufacturing is currently limited. The biggest obstacle in direct GPS application is the accuracy of the GPS, which can be improved by also using two or more ground-based receivers. One receiver can monitor the variations in the GPS signal and communicate those variations to the other which can then correct its calculations for better accuracy. In the future, one can combine the GPS signal with local sensors such as the existing vision and laser

scanner signals to allow a robot to move from one point to the next and at the same time avoid obstacles on the course. If successfully tested, this has tremendous potential in manufacturing applications.

Manufacturing companies will benefit greatly from having better control of their supply chains by knowing the location of raw materials, processed goods and inventory. Managers can expect a steady increase in cohesion of not only the supply chain, but of the entire production and administrative processes, as new and better GPS related applications continue to bridge gaps in the current system, thus allowing cost containment and increased customer service to occur simultaneously. The use of GPS combined with local beacon should have a variety of application in material handling, storage and retrieval.

Airlines may one day be able to use GPS, along with autopilot, to choose to fly their planes without a pilot, thereby substantially reducing the risk of flight accidents. Farmers will be able to program their machinery to plant, fertilize, irrigate, or harvest their crops.

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