2003 Intelligent Ground Vehicle Competition
Design Report

"Grizzly"

Oakland University

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ABSTRACT

The goal of this project was to develop an autonomous robot capable of functioning in all 3 parts of the competition. It has an omni-directional camera system capable of seeing all the way around itself, a SICK laser rangefinder to detect hard obstacles, a positioning system that combines GPS and IMU (Inertial Measurement Unit) information, and a unique 4-wheel drive, 4-wheel steer drive system that gives the vehicle the capability of holonomic motion.

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ACKNOWLEDGEMENTS

We would like to thank the help of a few individuals that have helped us over the course of the year. First and foremost, Professor Ka C. Cheok who has helped us in almost every aspect of the competition and helped our team many times re-organize ourselves whenever we needed it. We would also like to thank Jim Zondag for the wonderful 4-wheel drive 4-wheel steer drive system. He gave his time to our team for no cost and has never once asked for anything in return. Finally, to Edzko Smid, Chandra Boopalam, Nithin Chandrababu, Gheorghe Galben and all the other in the engineering department that have helped our team in countless ways.

II Goals

This year, we wanted to have our robot be able to track the lane properly, and go at least partway down the course without hitting anything. For the navigation challenge, we hope to go to all of the targets this year. For the follow the leader competition, we would like to follow the tractors course reasonable accurately.

We wanted to rebuild the frame, since we felt we had met the limit with last years design. We wanted the new frame to be flexible in how we could use it, so we would be able to adapt to any problems that came up.

III Differences From Last Year

Last year, our robot consisted of plywood bolted to a base of a Power Wheels toy. Problems we had with that frame were that it could not support a large amount of weight without bending, and the 2 drive wheels utilizing skid steering did not respond well.

For this year's competition, we completely rebuilt the frame. It uses extruded aluminum, with plexiglass sheets acting as shelves to mount devices to. It uses 4 drive wheels; each of can be independently steered.

In addition, we have added additional sensors to our robot. We are utilizing an Inertial Measurement Unit (IMU), a SICK laser rangefinder, and replaced the USB web cam with a digital camera that takes still pictures.

Last year's software was designed utilizing a Visual Basic front end, which would load Dynamic Link Libraries written in C++. We have eliminated the Visual Basic front end, using C++ code to handle the user interface. We have not used Dynamic Link Libraries this year, instead using C++ classes internal to the code to subdivide the program into smaller parts, keeping it easy to maintain.'

III Subsystems

Electrical

The electrical subsystem consists of a 24V bus and a 12V bus. The 24V bus is solely for the SICK laser rangefinder, and the 12V bus is for all other electrical elements, which include the motors, the sensors, and the computing equipment. Two sealed lead acid 12V 26 Amp-Hour batteries are used along with both 30-second delay circuit breakers and ordinary automotive fuses for added protection.

All sensors onboard the vehicle are self-sufficient and only require a power source to operate. The IMU, which consists of 3 orthogonal rate gyros and 3 orthogonal accelerometers, is placed as close to the vehicle's center of mass as to limit its false measurement of rotational accelerations. Communication with the IMU is done through an asynchronous serial line. The SICK laser rangefinder is placed in the front of the vehicle so that all oncoming obstacles are within its FOV. It has the ability to take a total of 361-distance measurement within a 180 degree FOV with a 15 mm resolution and a 10-meter range. Communication with the SICK is done through an asynchronous serial line. For the vehicle's vision an omni-directional camera system is used to see a complete 360 degrees around. This is accomplished with a parabolic convex mirror and an Olympus digital camera. Communication with the camera is done through a USB link. The final sensor onboard the vehicle is a NovAtel 12-channel GPS unit. In stand-alone mode it has the ability to calculate a position with an accuracy of 1.8 meters in both latitude and longitude. Communication with the GPS unit is done using an asynchronous serial line.

Mechanical

The vehicle has a total of 8 off-the-shelf motors that are used to control the motion of the vehicle. The vehicle has 4-wheel drive along with 4-wheel steering capabilities. This system requires 8 amplifiers and 8 feedback sensors so that each motor is properly controlled. For the 4 drive motors, which are off Fisher-Price kid toys, 4 optical quadrature encoders are used to measure the rotational speed of each wheel. For the 4 steering motors, which are automotive window lift motors, 4 smart position sensors (non-contact potentiometers) are used to measure the angle of rotation of each wheel. To properly utilize the above equipment 8 closed-loop proportional-integral digital controllers are used to get the desired responses. A MPC555 microcontroller is used to measure all 8-sensor values, to read in, and/or calculate, the desired set points for each motor sub-system, and to calculate the control output that will be sent to the motor amplifier through a PWM (Pulse Width Modulation) signal.

One of the new and unique things about this vehicle is its drive system. The proper term for this type of drive system is holonomic, in that it has the ability to move to a new point in 2D space immediately. Unlike a car-like drive system where, for example, to move sideways it would have to first backup, then turn the front tires, and then drive forwards to get to the desired location. Due to the unique drive system, our vehicle has the capability to perform any maneuver in a 2-axis domain. The only downside to this configuration is the complexity in calculating the correct wheel angles and speeds.

Computing

For on board processing, we have 2 devices. The first is a Stealth LPC-301 mini PC. It has an Intel Pentium 3 processor, 256 MB of PC133 RAM, running Microsoft Windows 2000 Professional. We choose this computer since it was small (10 inches by 5.7 inches by 1.6 inches) and relatively powerful. We use the LPC-301 computer to handle communication with the sensors, image processing, and path planning.

The other device is an Axiom MPC555 Evaluation Board. This microprocessor handles communication with the wheels sensors, and controls the motors. It drives whatever course the LPC-301 sends to it.

Most of the sensors communicate through the RS-232 protocol. In order to have enough communication ports on the PC, we used a converter with 4 RS-232 ports on it that attaches to the PC through the USB bus. The PC and the MPC555 microprocessor are connected through a RS-232 link.

V. Software

This year, the software is divided into two parts, one that runs on a MPC555 microprocessor, and the other which runs on an Intel x86 computer. The MPC555 microprocessor handles driving the robot, the Intel x86 computer handles gathering information from the sensors, interpreting that information, and deciding where to go. The program running on the MPC555 microprocessor is written in C. The program running on the Intel x86 is written in C++.

The main part of the program running on the Intel x86 is divided up into many different C++ classes. Each class has a specific purpose. This division helps keep the program easy to manage, and assists in the design of the program.

Sensor Communication

The program obtains data from the sensors using both USB and asynchronous serial ports. We have a class written for each of the 4 major sensors (GPS, IMU, Camera, Laser rangefinder). This data is then passed to another set classes, which interpret the data, and then combine information from the sensors to provide a better representation of the environment. These two classes are Internal World (GPS, IMU) and External World (Camera, Laser Radar).

Vehicle Positioning

A Kalman filter is used to increase the vehicle's ability to calculate its own position. Using GPS by itself assures us 1.8 meter accuracy, and perhaps lower for shorter time durations, however, to be competitive during the competition and to broaden our horizons as students, we have decided to attempt to fuse the GPS information with the IMU information to obtain a position accuracy of less than 1 meter. What a Kalman filter, or an Optimal Estimator, does is estimate a system's internal states, in this case the position of the vehicle, while using different sources of information that have been corrupted with white noise. A Kalman filter calculates the best mix of the two sources and then combines them in a way. The end result is a position value that has the long-term stability of GPS and the short-term accuracy of the IMU.

Obstacle Detection

For the laser rangefinder, a large array with values indicating how for out a solid object was found is processed. To distinguish between different objects, we check for large differences between each element of data. With the assumption that obstacles on the course are circular, we take the right most point, the left most point, and the closest point of the object found. These are used to make an estimate of the objects center location and radius. This is then stored in a linked list of known obstacles.

As mentioned previously, an omni-directional camera system is used to obtain the vehicle's visual point-of-view. The image that is produced with such a system is an image that shows all surrounding scenery in a normal rectangular image. The convex mirror transforms the image and produces a "warped" image. Due to the fact that the mirror is parabolic it is possible to "unwarp" the image and make it look like an ordinary camera with any desired position and orientation took it. The approach taken for this year's competition is to use the image in its "warped" state. This will make the loop time of the image processing algorithm shorter, along with being able to use the fact that the image is "warped" to our advantage.

The image processing techniques used are simple and straightforward. The first step is to transform the RGB image produced by the digital camera into a HSV (Hue, Saturation, Intensity) image. The second step is to calculate both a hue histogram and an intensity histogram. Assuming that one of the two histograms has a bi-modal distribution, it is possible to calculate a threshold so that a binary image (black and white) can be produced. Once the binary image is produced a simple set of filtering algorithms will be used to clean up the binary image. The final step is to take the filtered binary image and calculate where the obstacles lie around the vehicle. The actual calculation of the positions has not been accomplished yet.

Navigation

Like last year, we are using a path-planning program called A* (A star). This works by representing the area around us as a 2 dimensional array of cells. Cells are marked either impassible or passable, depending upon what the sensors have found. A start point and a destination point are marked. The routine evaluates cells by taking the distance required to get there, (the sum of the cells to get to that point), and the distance it takes to go directly to the target. Impassible cells are not evaluated. Once the destination has been reached, the path to it is then traced, and is used as the result of the A* routine.

Applying this to the Navigation Challenge is fairly simple. The start point is the current destination, and the destination is the closest waypoint. Circles are marked as impassible on the array, representing barrels found. Once we reach within distance of the target, the target is removed from the list, and a new target is selected based upon proximity.

For the Autonomous Challenge, barrels are again marked as impassible circles on the array in the A* routine. We also mark down the lines as impassible. The current location is set as the start point, and the destination is set as a point ahead in the direction of the lanes.

For the Follow The Leader competition, a continually updated list of targets is made. Each target is constructed based upon the robots location taken from the GPS, combined with the tractors location taken from the laser rangefinder. A simple routine is used to find the current target, which is the position 3 meters behind the tractor.

VI Production Costs

Item	Estimated Price
Crossbow IMU300CC-100	$300
NovAtel OEM Euro4	$3,000
Stealth LPC-301	$895
SICK LMS200-6	$6,000
Sealevel SeaPORT+4/232 2401	$200
Axiom MPC555 Evaluation Board	$1,000
12 Volt Batteries	$80
OneShot 360 Immersive System	$500
Olympus C330 Zoom	$500
Victor 833 Control Units	$125
AC Power Inverter	$100
Linksys Wireless Ethernet Bridge	$100
Metal	$600
Total	**$13,400.00**

VII Conclusion.

In conclusion, our team feels very confident that all the hard work and new knowledge learned will help Grizzly compete with the best at this year's competition. Many sound technical topics were utilized throughout the year, such as closed-loop control of DC motors, Kalman Filtering, image processing techniques, microcontroller programming, plus many others. Even if Grizzly doesn't win the competition we feel that the knowledge learned over the course of the last year is more than enough reward for the time and effort we put in.