The 19th Annual Intelligent Ground Vehicle Competition
June 3 - June 6, 2011

Bearcat Micro
University of Cincinnati

Introduction

This year marks the 19th consecutive year that the University of Cincinnati Robotics Team has participated in the IGVC. The robot, which is a compact version of our 2009 platform, has been developed by a collaborative effort from a multidisciplinary team. It has undergone major changes in its software along with changes in the support structure from the previous year's entry into the competition, mostly to adapt to the new rules for this year. This report describes the various aspects of Bearcat Micro's design, design tradeoff considerations and improvements over the past IGVC entries by the UC Robotics team.

Design Innovations

The Bearcat Micro this year went through major revisions in software and hardware, which were triggered both by changes in this year's rules and by areas in which the robot's performance last year could be improved. These areas were prioritized and assigned to team members to solve. A safety light has been added, which uses a parallel port to toggle it between solid and flashing. The E-stop antenna has been modified to increase range. The code was modified to allow for GPS navigation to be started in a standby mode in which the robot begins GPS navigation only when it comes within a few meters of a specified start waypoint. Other modifications have been made to improve performance and correct problems that have occurred in previous competitions. The vision processing has been rewritten to improve the performance of recognizing grass, lines, etc. Stereovision has been integrated into the code. GPS filtering has been improved as well.

This report is divided into the following sections:

1. Hardware Design: This section describes the basic platform along with the hardware components which includes the framework, power system, the emergency stop and the motion control system.
2. Electrical and Electronics system: The section lists out in brief the computer system and the various sensors with schematics of its integration.
3. Software design: Describes in detail the algorithm used for mapping, lane detection, the vector field approach and path planning.

1. Hardware

Frame

The load bearing chassis of the Bearcat Micro is made of 80/20 aluminum extrusion which is light and can be used without compromising the strength of the frame structure. The advantage of using this modular type frame comes in the ease of reshaping, and the ability to quickly mount new components as they are brought into the design.

The aft shelving support uses aluminum window shade track which weighs less than 1/6th the equivalent length of 80/20. Despite this reduction in weight, the shelving is still able to support at least 135lbs of distributed load. The profile of this material also enabled us to use the top shelf as a convertible desk.

Compacting the Bearcat Cub into the Micro

Over its history, the Bearcat Micro has undergone incremental improvements in design from the first generation golf cart, the second and third generation cubes, to the fourth generation robot. Our newest model, the Bearcat Micro is perhaps the most extensive revision yet due to its significantly smaller size.

The frame of the Bearcat Cub IV was stripped completely and cut to size around our battery dimensions. Planning for this involved using a SolidWorks® CAD model that proved the feasibility of overlapping our 2hp brushless servo motors and using every bit of available space. During construction, numerous additional improvements were made particularly through tight wiring and unconventional placement of power electronics and motion control boards.

Bearcat Cub IV		Bearcat Cub Micro	
Pros	Cons	Pros	Cons
-Ample space -Easy to access -Instant energy replenishment	-Easily broken caster wheels -Weighs 300 lbs -Too large -Disorganized -Difficult to transport -Gasoline fueled -Vibrations, loud	-Half the volume -Weighs 180lbs -Easy to remove sensor tower -Well utilized space -Organized, more presentable -Sturdier design -15 hr mean run time before recharge -Quiet operation -Top slides to convert into a desk	-Hard to access -Limited run time -11 hr recharge

Figure 1: Bearcat Micro design comparison

While most of the frame is based on 80/20 aluminum extrusion, the aft shelving uses aluminum window shade track which weighs less than 1/6th the equivalent length of 80/20. Despite this reduction in weight, the shelving is still able to support 135lbs.

Drive Train

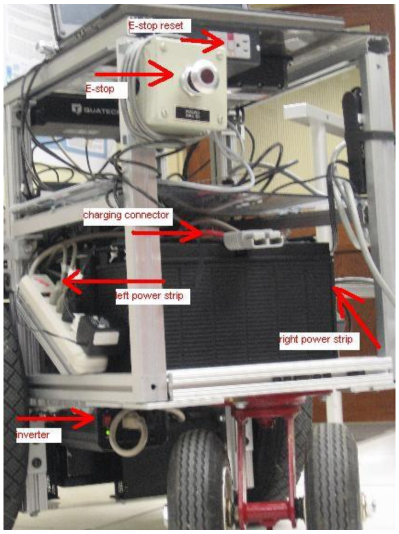
The Micro has two types of wheels – two main drive wheels and two rear castor wheels. The 19 inch drive wheels are enhanced traction wheels designed by Michelin. They consist of a forged steel wheel hub with a glass reinforced thermoplastic rim. The tires are made of a silica compound, which provides good traction even on wet surfaces.

The 10” rear castor wheel provides the stability needed for the Micro to perform zero turning radius turns. The robot is designed to run at a maximum speed of 5 miles/hour. A Pacific Scientific PMA43R0011200, 2H.P brushless servo motor has been installed on each drive wheel with a gear box of ratio 25:1. The gearbox and motors have been selected based on the design calculations taking frictional coefficient of 0.125 and 70% gearbox efficiency. This design incorporates the gearbox inside the hub of the wheel resulting in a compact and robust design.

During testing it was found that the robot can run more than 5 mph but for safety reasons the speed has been limited to 5 mph. The robot successfully climbed a 30 degree incline ramp.

Power System

The robot is powered by two 12v deep cycle marine lead acid batteries connected in parallel for total energy storage of 2064Wh. Power from the battery is sent to an 800W 120v inverter which powers all electronics including the motor amplifiers. When idle, the battery can run all electronics for up to 15 hours. When driving, the robot can run for 6 hours. Using batteries allows for silent, vibration and smoke free operation compared to a compact generator.



Emergency Stop

The robot stops using electronic dynamic braking that dissipates heat through a resistive load shunt. A manual E-stop button is located on the rear of the vehicle more than 2 feet above the ground which activates the brakes. The E-stop circuit uses an industrial grade GFCI based, which is light and takes up little volume. A Futaba remote control radio E-stop can also apply the brakes from a distance of 100 feet.

As part of our emphasis on having a compact robot, the e-stop circuit has been totally redesigned into a much smaller package.

Motion Controller

The Galil DMC 2130 motion control board is used for the Micro and is controlled through commands sent via an Ethernet connection from the laptop. Copley amplifiers deliver power to the motors after amplifying the signals they receive from the motion controller. Steering is achieved by applying differential speeds at the right and left wheels. The Galil motion controller was chosen because it is Ethernet based, has PID and Bode plot tuning software, and is compact and enclosed in a durable package. The controller can accommodate up to 4 axis and can control stepper or servo motors on any combination of axes. The Bearcat Micro has the ability to turn about its drive axis effectively performing a Zero Turning Radius (ZTR) pirouette. The block diagram of the system is shown in Figure 2.

Covering

In previous years, preparing for rain was never made a priority and was treated on an ad-hoc basis. This year, a semi-permanent covering was constructed from laminated poster board and Velcro which it is believed will provided adequate water-resistance. This has advantages over other materials, such as sheet aluminum, in weight, cost, flexibility, ease of installation\removal, which also makes it possible to use custom coverings for different events.

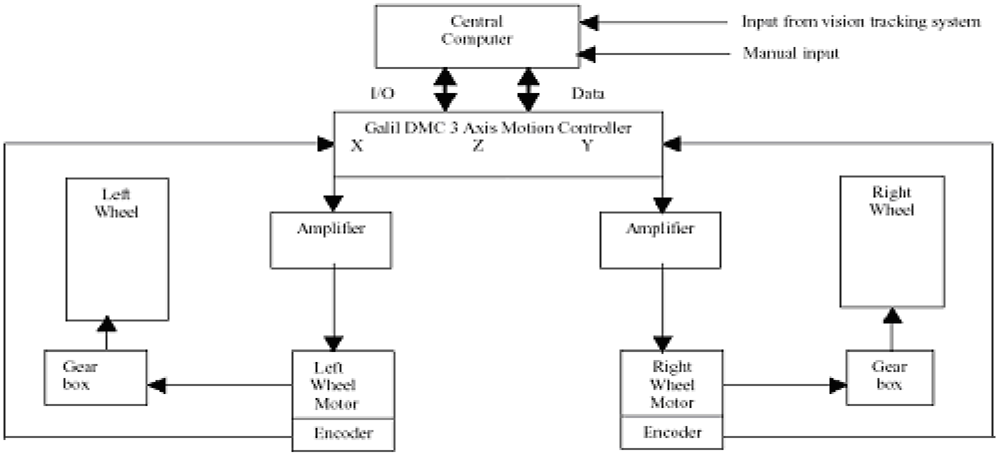


Figure 2: Motion control system

2. Electrical and Electronic Systems

The electrical systems of the Bearcat Micro consists of a motion controller, 2 amplifiers, 2 DC brushless motors, 2 digital cameras, a laser scanner, GPS unit, electronic compass, Bumblebee stereovision camera, safety light and an emergency stop. All power is provided by two lead acid batteries. The 12V components, including the GPS, E-stop, safety light, etc run directly off the batteries, while an AC inverter is used to provide power to other components, like the laptop and camera chargers, and the motion controller and amplifiers. This allows the Bearcat Micro to be outfitted with any set of sensors very easily since there is no need for the end user to customize any power supplies. The system acts like a hardware equivalent of software plug and play. Figure 3 below shows the data communication layout.

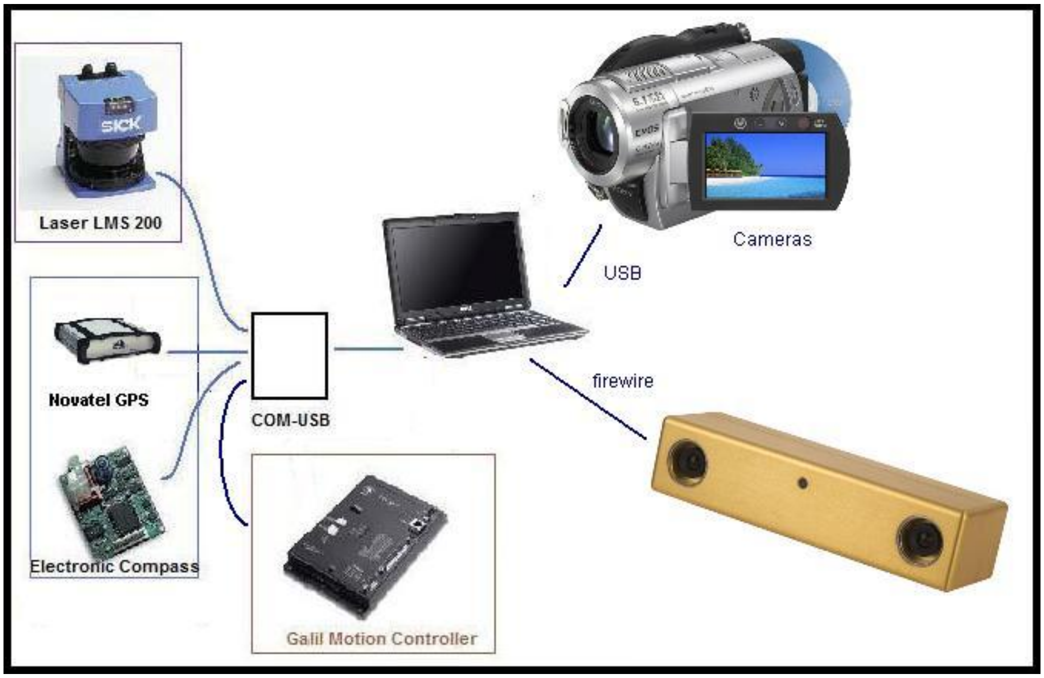


Figure 3: Bearcat Micro signal diagram

Computer System

A Dell Latitude D830 laptop is the central processing unit of the Bearcat Micro. It has a 2.6 dual core Intel processor with 3.5GB RAM. It processes data from the laser scanner, GPS, motion control system and image processing system. All control programs have been made in C++ taking advantage of open source libraries like openCV and openJAUS where possible. A user friendly GUI was developed to track the Bearcat Micro’s movement and position. A series of initialization files hold all calibration values and initial values for the system parameters.

Sensors

Laser Measurement System

The Sick LMS 200 scans a 2-dimensional plane of 180 degrees and returns obstacle distance measurements for up to 8.191 meters with a infrared laser beam (835 nm wavelength) based on it’s time of flight. The resolution of scan is 0.5 degree. It is communicating with the computer using a RS 232 ports with a data transfer rate of 38,400 bauds.

Global Positioning System (GPS)

A NovAtel's ProPak-V3 is a durable, high-performance receiver with advanced capabilities using a USB communication. The accuracy achieved with this unit is 0.6m using SBAS channel.

Cameras

Two Sony DCR-TRV118 video cameras provide the images that are used by the line detection system. Wide angle lenses and built in image stabilization improve image quality.

Compass

Honeywell HMR3200 digital compass is a 2 axis precision compass. The compass is oriented horizontally on the rigid body of the Micro. It provides 1 degree accuracy and operates at 19200 baud rate providing fast and accurate heading information to the robot for accurate path planning.

PointGrey Bumblebee

The Bumblebee contains two color cameras in an integrated stereovision system, with all calibration and coordinate transform functions provided, as well as an algorithm for calculating disparity between the two images.

3. Software

Image Classification

Images from the cameras are converted into HSV space and then thresholded to separate grass, lines, ramps, red\green flags, etc (see top 4 of figure 4). Thresholds are intended to be constant for all conditions, but in practice, must be modified.

Lane Detection Algorithm

Lane detection involves running a Hough transform on a binary image corresponding to the areas identified as lines by the image classification algorithm (see bottom of figure 4 for sample output. All image processing is performed with OpenCV; the Hough transform used is the one built into that library.

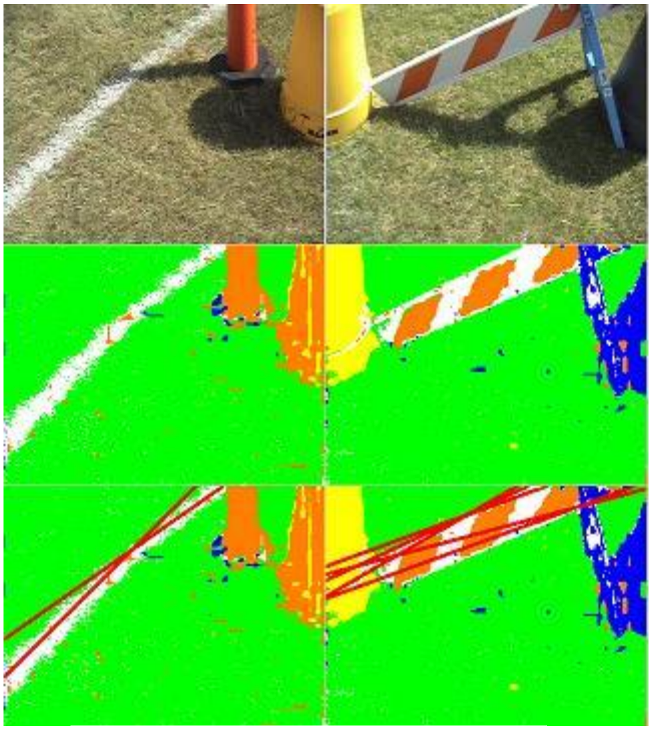


Figure 4: Image processing demo

Path Planning

Our approach builds on general vector field theory. In this theory obstacles apply force on the robot that pushes the robot away from the obstacles. The sum of all the forces will dictate the direction the robot chooses. The force applied to the robot from a particular obstacle is proportional to the distance the robot is from the obstacle[4].

Vector field general theory

In the vector field concept (VFC)[1][2][3] the robot is considered to be in a force field where all the obstacles push the robot away and the target pulls the robot to it.

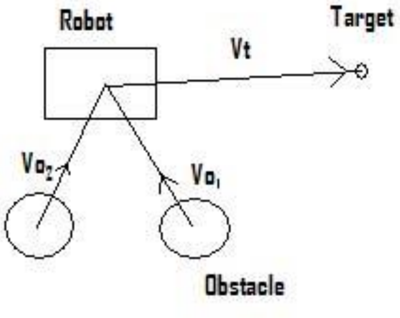


Figure 5: Robot with two obstacles and a target location

The resultant force acting on the robot is the sum of the repulsive force from the obstacles and the attractive force from the waypoint target as shown in Equation (1).

$$\overrightarrow{V_p} = \overrightarrow{V_r} + \frac{1}{n}\sum_{i=1}^{n}\overrightarrow{V_{0i}} \qquad (1)$$

where n is the number of obstacles in range and Voi is the force exerted by them on the robot. VT is the pulling force exerted by the target on the robot. Note that the magnitude of the force exerted by the obstacle decreases with distance from the robot. The magnitude of the waypoint or target vector remains constant irrespective of the magnitude of force exerted by obstacles.

Modified Vector field Concept

Since vector field based navigation can lead to singularities and result in a robot that is stuck in a corner or other trap, the obstacle information is preprocessed to attempt to remove such traps by rounding out corners and closing gaps too small for the robot to fit through. This has demonstrated some improvement in testing, but has not completely eliminated the problem.

The force vector field takes inputs from the laser scanner, cameras, and stereovision system. This means that lines can be considered as obstacles to be avoided, as well as obstacles that are transparent to the laser (either too high, like tables or mesh-like, like fences or bushed). This provides more robustness to obstacle detection. Also, treating lines as obstacles as well as using the Hough transform to determine the lane direction provides robustness for following lines. The speed of the robot is adaptive, driving more slowly the nearer obstacles are, which improves safety by forcing it to slow down when people are near, and by making it more immediately obvious that it has seen something.

Navigation

Navigation is accomplished by using a Kalman filter to integrate data from a digital compass and one or more GPS devices. This data determines a heading, subject to obstacle avoidance. After the position estimate is within a critical radius of the target waypoint, the robot will spiral out to a variable radius, making the system more robust to GPS errors. The heading computed between the estimated and target positions is then modified by the obstacle avoidance algorithm.

In the 2010 competition, the robot’s performance in the GPS challenge was lower than anticipated. This year’s team has detected and corrected errors in that code.

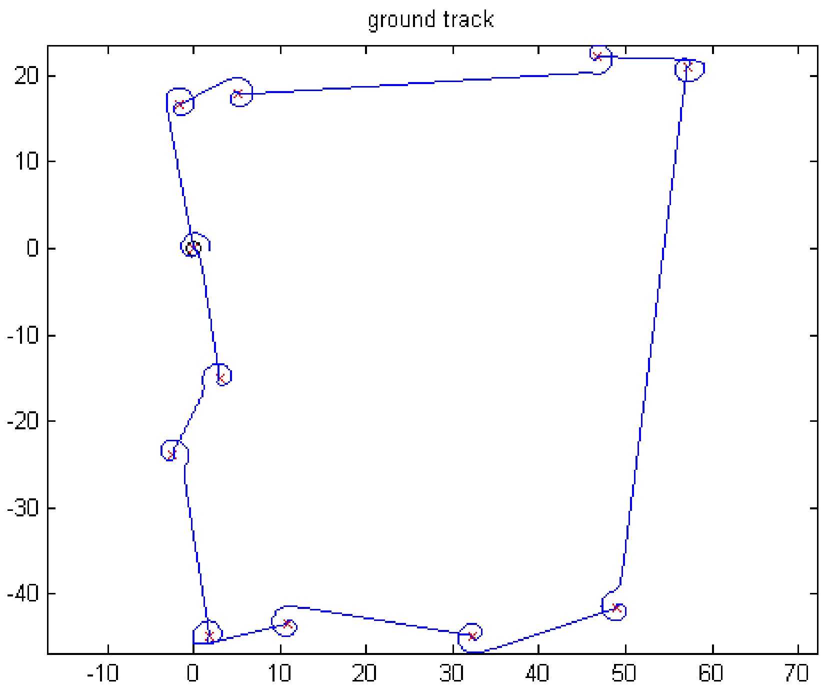


Figure 6: Navigation simulation showing spirals around waypoints

JAUS

Due to the JAUS protocol being rewritten, we have scrapped the JAUS library we wrote for previous competitions, and are now trying to use the open JAUS library. Currently no released versions support the features of JAUS required by the IGVC. A beta version is available, but has not yet been shown to be adequate.

Conclusions

The Bearcat Micro continues to evolve each year into a more robust research vehicle. This year every module of the robot was tested constantly for durability and predictable behavior before their integration into one system. Various control algorithms were developed during the development stages which evolved with repeated testing in simulated and real world environment. The algorithms are expected to significantly improve the Micro’s performance this year.

References

[1] J.C. Wolf, P. Robinson and J.M. Davies “Vector Field Path Planning and Control of an Autonomous Robot in a Dynamic Environment,” FIRA Robot World Congress. 2004.

[2] I. Ulrich, and J. Borenstein, "VFH+: Reliable Obstacle Avoidance for Fast Mobile Robots," IEEE Int. Conf. on Robotics and Automation, May 1998, pp. 15721577.

[3] I. Ulrich, and J. Borenstein," VFH*: Local Obstacle Avoidance with LookAhead Verification." IEEE Int. Conf. on Robotics and Automation, April 2000, pp. 25052511.

[4] R. Siegward, I.R. Nourbakhsh “Introduction to Autonomous Mobile Robots,” MIT Press, Cambridge, Massachusetts, London, England, 2004, pp. 267272.

Team Bearcat Cub for Intelligent Ground Vehicle Competition 2010 (Appendix A)

1	Mark Aull	Aerospace Engineering
2	William Hilton	Mechanical Engineering
3	Jim Chen	Electrical Engineering
4	Naomi Fitter	Mechanical Engineering
5	Amanda LaCombe	Mechanical Engineering
6	Timothy Wagner	Mechanical Engineering
7	Bryan Hallez	Mechanical Engineering

Bill of Materials (Appendix B)

Part	Manufacturer	Model No	Quantity	Unit Price	Total
Frame	80/20 Inc.	Custom design	1	950	950
Batteries	Rocket	DC31DT	2	85	190
Motors	Pacific scientific	PMA43R-0011200	2	970	1,940
Amplifiers	Copley Controls Corp.	Xenus Servo Drives XSL-23036	2	540	1,080
Drive Wheels	Segway	Enhanced Traction	2	188	376
Gearboxes	Segway	HT design, 25:1 gear ratio	2	488	976
Laptop	Dell	D830	1	1,181	1,181
Cameras	Sony	PVDV51	2	290	540
Estop	Futaba	FRF0302U	1	321	321
Motion controller	Galil Inc.	DMC2130 Ethernet	1	2,800	2,800
Inverter	Whistler	800 W	1	52	52
GPS	Novatel	ProPakV3HP	1	3,252	3,252
Laser Scanner	Sick	LMS-100	1	6000	6000
Stereo Camera	PointGrey	Bumblebee	1	2000	2000
Compass	Honeywell	HMR3200	1	300	300
Miscellaneous				300	300
			Total		$22,268