

UNIVERSITY OF CINCINNATI DESIGN REPORT.....

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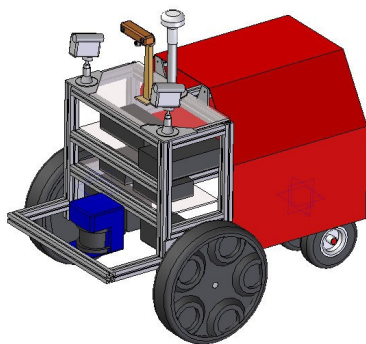
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1. Introduction

This year marks the 15th year that the University of Cincinnati Robotics Team has participated in IGVC. While the frame and design has remained relatively static over the past few years, the control algorithms continue to evolve and improve. The vehicle is an educational testbed to explore and experiment with different robotic control methods and algorithms with the hope of someday being able to unlock the secret behind autonomous vehicle intelligence.

The design process we used is called continual improvement. The team applied for and received \$9,000 in funding from the UC Student Activities and Leadership Development Council. Also, a brochure was designed and mailed to about 100 potential industry sponsors. Regular meetings were held each Friday at 1 PM. A public web page at www.robotics.uc.edu and a private web Blackboard page were used for communications. A public Wiki at <http://bearcatrobot.wik.is> and a private development site at: <http://robotresearch.mie.uc.edu> were also utilized.

This year we have improved the software system by implementing a distributed multi-agent system. Source Safe was established for keeping track of the versions of software developed by various team members. Using this approach permitted more experimentation with the sensor systems such as web cams, GPS and laser scanners and different control structures. However, as the time to the contest approached, most of the development was concentrated by the two main developers.

The paper is structured by first outlining in Section 2, the innovations that have arisen this year. This is followed by a description in Section 3 of the mechanical system. The electrical and electronics systems are described in Section 4. The software architecture is described in Section 5. The description of the vision systems is given in Section 6. The GPS waypoint system is described in Section 7. The obstacle avoidance system is described in Section 8. The predicted performance is described in Section 9 and vehicle

components and cost are described in Section 10. A brief conclusion is given in Section 11.

2. Innovations

The innovations on the Bearcat Cub this year mainly focused on the new software design and implementation testing.

- a. Distributed multi-agent system architecture
- b. New vector field based obstacle avoidance
- c. Lane following using single camera and a new vision algorithm
- d. Agent negotiation

3. Mechanical System

The mechanical system of the Bearcat Cub, 2007 consists of the following main parts:

1. External frame
2. Wheels
3. Brakes
4. Motor and motion control system
5. Power system

3.1 Frame

The frame forms the base structure on which the IGVC robot is built. The frame is built of light weight 80/20 aluminum extrusions which reduces the weight of the robot without compromising the strength of the frame structure. The junctions are made using small joining strips at the ends or by utilizing corner brackets which sit inside the joints. The main advantage of using a frame as the base structure is its ease of reshaping and also the ease of addition of new components as there are developments in the design of the robot. CAD design was done in Solid edge. A factor of safety of 1.25 is used while calculating the stress and weight of the joints.

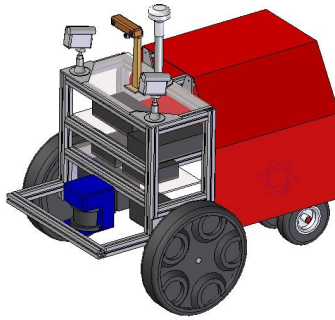


Figure 1 CAD of the Bearcat Cub

3.2 Wheels, Brakes and the Motor System

The Cub's mechanical system utilizes two types of wheels – two main drive wheels and a dual rear castor wheel. The main drive wheels are 19" diameter enhanced traction wheels designed by Michelin for the Segway Human Transporter. The rear castor wheel helps improve the stability of the robot during turns such as those with a zero turning radius. This 8", 90 series, dual castor wheel, is from Borne & Co. Since the drive wheel size is 19" and the maximum speed of the robot is 5 miles/hour, a frictional coefficient of 0.125 and a gearbox efficiency of 70% have been used to calculate the required gear ratio. A gearbox with a gear ratio of 25:1 was selected and obtained from Segway. The required motor power has been found to be 1.75 hp per motor. Two Pacific Scientific PMA43R-00112-00 2 hp brushless servo motors have been selected for providing power. The gearbox and motors have been selected based on the calculated values. The robot's power system can utilize a maximum of 2 Honda EU-2000i, super quiet generator sets, however a single generator set has proven to provide 4 ½ hours of continuous power. The advantage of having a generator set in place of batteries is that there is less down-time after losing power, since refueling the generator set is much quicker than recharging a battery.

4. Electrical and Electronic Systems

The electrical and electronic system consists of the following:

- a. Honda generator
- b. Galil web based motion controller

- c. Copley amplifiers
- d. Pacific Scientific motors
- e. SICK laser scanner
- f. Garmin and Novatel GPS and Honeywell electronic compass
- g. Dell laptop with Windows XP operating system
- h. Network devices
- i. Futuba E-stop

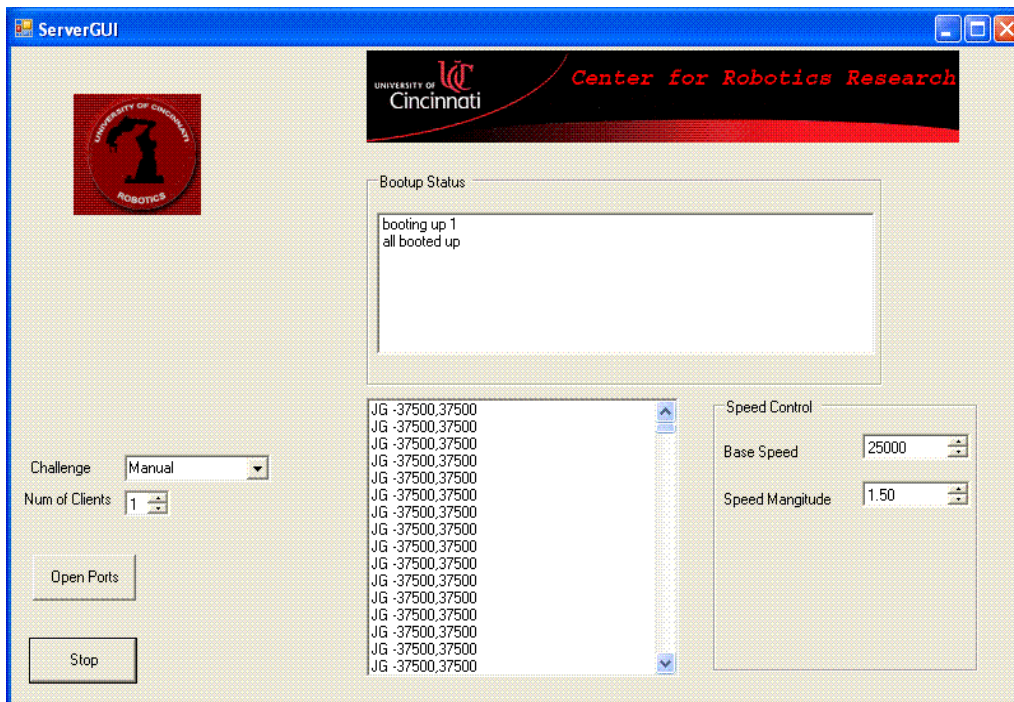
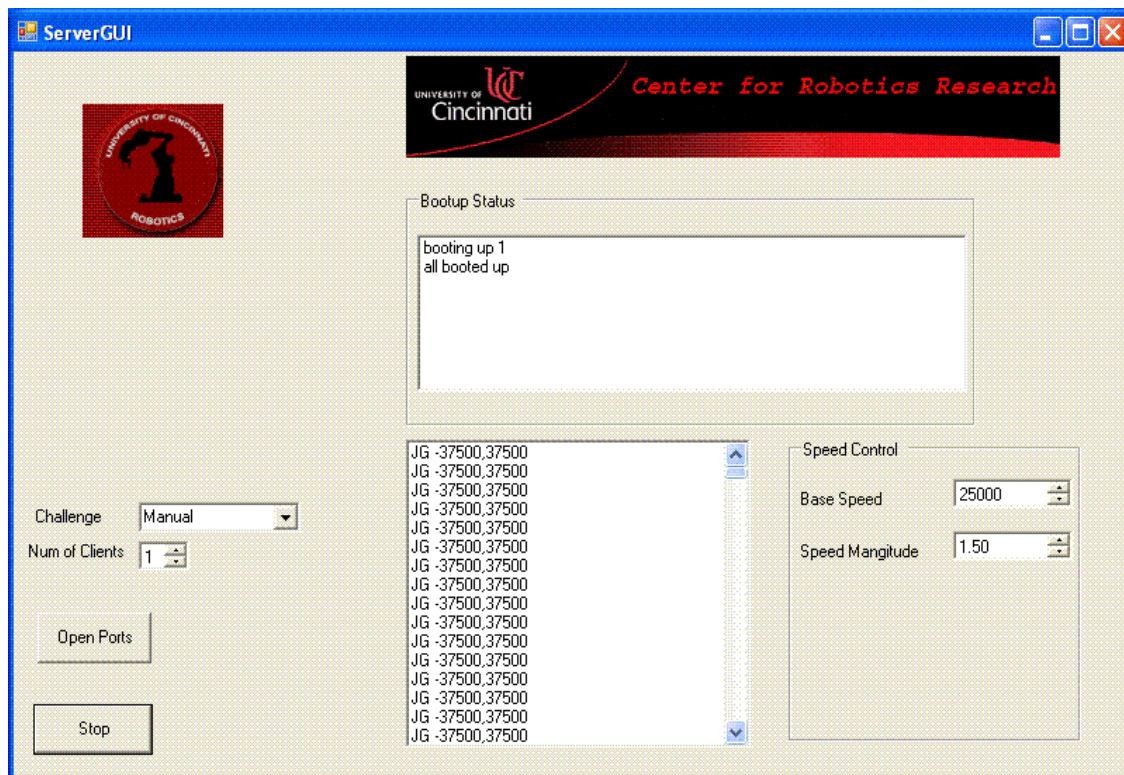


Figure 2 Software control page

4.1 E-stop

Both mechanical and electrical brakes can be applied. A manual red button E-stop is located on the rear of the vehicle more than 2 feet above the ground activates the brakes. A Futaba remote control E-stop can also activate the brakes from a distance of 65 feet. Both E-stop systems have been repeatedly tested. The use of these systems around humans can be seen on several YouTube videos such as <http://www.youtube.com/watch?v=eCoWquWrSR0> .



5. Software Architecture and System Integration

The Bearcat Cub is equipped with a Dell laptop Latitude D820. This laptop is used for making the control decisions and reading in information from the various sensors. There are two types of agents that run on the laptop; the summation server and the sensor clients. The summation server takes all the data sent to it from all the sensor clients and synthesizes them into one decision. Each sensor client is dedicated to one sensor and it reads in the inputs from them and processes them into suggestions on a different path for the robot.

The sensor clients communicate with the summation server through TCP/IP sockets and each sensor client each exchange wheel speed commands. This allows the summation server to treat each sensor in the same way and this in turn allows sensors to be added and removed from the system and the system at will and the robot will still function in the proper way. The summation server is able to fuse the sensors together to create a unified decision on direction and speed.

The summation server will query each sensor and ask for its suggested path correction. It will then combine those decisions into one command and send it down to the Galil motion controller. Each sensor can be located on different machines all together allowing for multiple computers to work together to achieve the goal.

Each sensor client is itself a separate process and each one creates a listener thread for the server. This allows for a very fast system. Each second the motion controller receives 20 to 30 commands even though, for instance, the GPS system takes a second to retrieve the data. This system set up allows the robot to be very fast and robust and it will not slow down because one component isn't fast enough.

5.1 Conflict Resolution

To resolve conflicts where sensors give opposite results few rules have been set. For lane following challenge the sensors used are the vision based lane tracker and laser obstacle avoidance. In case of conflict the lane following agent is given preference over the laser sensor. In case of navigational challenge the laser is given the preference.

6. Vision Based Lane Following

6.1 Introduction

6.2 Algorithm

- a. The on-board wide angle camera generates a stream of images in RGB format.
- b. The images are then searched for white colors.
- c. The white points are calculated using the vector field algorithm and an optimal path is found .

6.3 Color detection Algorithm

6.3.1 Purpose

The lanes and some of the obstacles are painted in white, so it would be best to look at the white things on the image only. The system has to be able to detect the white color in various lighting conditions. The lanes can also be yellow and green, solid and dashed. Different ratios can be set for the various colors. A continuity condition is used when the lines are dashed.

6.3.2 Approach

The image that is received from the camera is broken into three primary colors: Red, Green and Blue. An easy way to look for some color is to look for pixels with the right color components. This works perfectly in an ideal world. In the real world the color of a body or a white line varies from place to place because of the angle variation between the light source and surface normal vector and with the intensity of the light source.

To resolve this dilemma, the problem was divided into two parts:

- a. The change of color under various lighting conditions
- b. Non-uniformity of color in an object

The first problem is solved by taking the ratio of the color components instead of the exact color component values. An example is shown in Figure 3. The problem is to detect the road based on its color. If we use exact values of the color components we get a result shown in Figure 4.



Figure 3 Image of a road with markings.

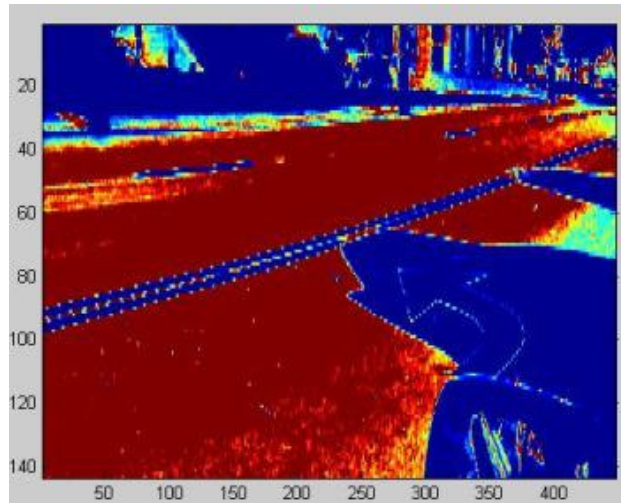


Figure 4 The detected road is shown in red.

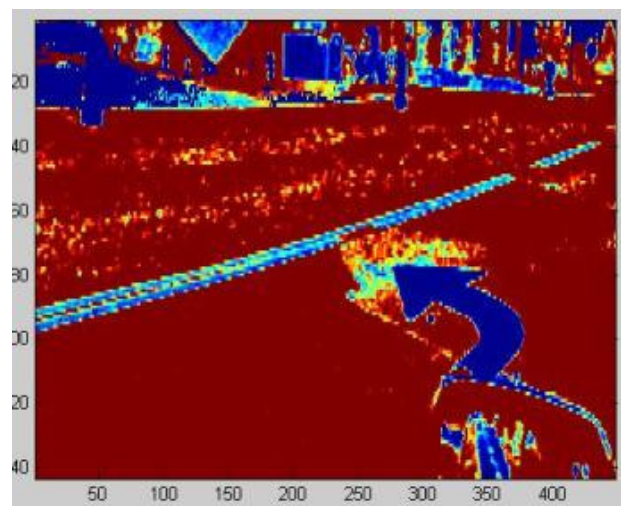


Figure 5 The output image using ratios of color components.

From Figure 4, it is clear that the zone in the shade could not be detected by using values of color components. In Figure 5, the ratio of color components was used to obtain a much better though not perfect solution.

In the second part of the problem we use a probabilistic approach to locate a color. A joint probability distribution is used to find the probability index.

The Gaussian distribution is given in Equation [1]

$$p(x_b, x_g) = e^{-\frac{(x_b - \mu_b)^2}{2\sigma_b^2}} \times e^{-\frac{(x_g - \mu_g)^2}{2\sigma_g^2}} \quad (1)$$

where

$$x_b = \frac{b}{r}$$

$$x_g = \frac{g}{r}$$

μ_b = mean of x_b

μ_g = mean of x_g

σ_b = standard deviation of x_b

σ_g = standard deviation of x_g

Where r , b , g represents the color vector values. The mean and variance have been determined experimentally. One then selects the pixels having a probability value higher than a certain fixed threshold. The threshold value of the object region is also determined through experimentation.

6.4 Path Planning and Lane Compliance

6.4.1 Purpose

The IGVC Autonomous Challenge contest rules indicate that the vehicle must stay between two lane marking lines while avoiding the obstacles. This algorithm finds a suitable heading and keeps the robot within the two lines and also avoids any obstacle including those that have white rings on them.

6.4.2 Approach

A modified vector field approach is used in this problem. First, the distance is calculated to each of the white pixels from the bottom center of the image. These distances and the angle becomes the input for the vector field approach which is usually used for sonar and laser sensors.

6.4.2.1 Vector field general theory

In the vector field concept (VFC) the robot is considered to be in a force field where all the obstacles push the robot away and the target pulls the robot towards itself.

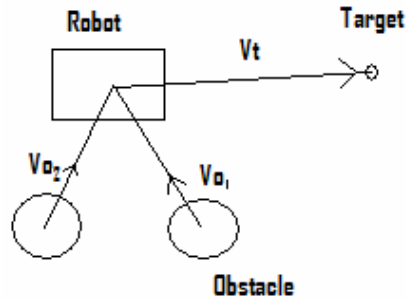


Figure 6 Robot with two obstacles and a target location.

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 (2)

$$\vec{V}_p = \vec{V}_t + \frac{1}{n} \sum_{i=1}^n \vec{V}_{oi} \quad (2)$$

where n is the number of obstacles in range and V_{oi} is the force exerted by them on the robot. V_t 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.

6.4.2.2 Modified Vector field Concept

The VFC uses just one vector to represent the obstacle. It is possible that obstacle might have a part sticking out of the main body. This may become a potential hazard for the robot. If multiple vectors were considered originating from the visible surface of the obstacle the robot would know about the protruding part.

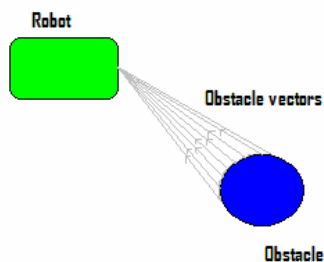


Figure 7 Multiple obstacle vectors covering the entire visible area.

This enables the robot to pass very close to the obstacle and through narrow passage ways.

The magnitude of the obstacle vectors is determined by Gaussian distribution shown in Equation (3)

$$\left| \vec{V}_o \right| = ke^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (3)$$

The resultant of all obstacle vectors forms the final obstacle vector.

Even when the actual white line and obstacles may not be at the exact same angle with the robot body as the corresponding pixel in the image, the robot corrects this error as it moves forward. It does this correction automatically as the image from the cameras is processed and new headings are generated continuously.



Figure 8 View from the camera.

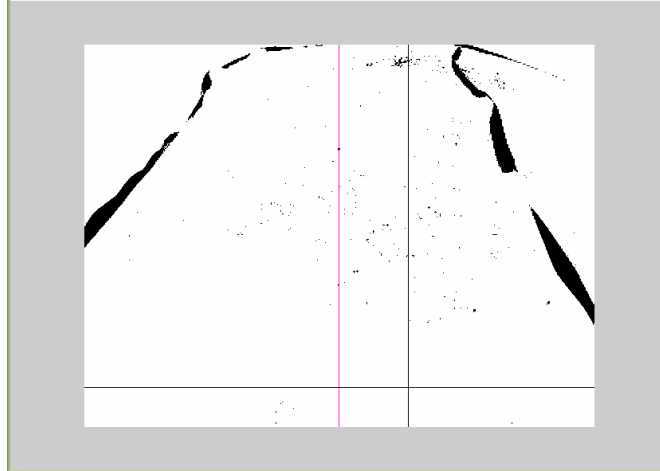


Figure 9 Processed image with heading direction.

7. Waypoint Navigation

The system uses the Garmin GPS and a Honeywell electronic compass to compute the heading for the navigation challenge.

The system knows about its current latitude and longitude position from the GPS unit and its current orientation to the earth's magnetic north using the electronic compass. The heading vector toward the next waypoint is calculated from these two systems. The algorithm also tries to optimize the heading so that it has to turn less.

The GPS waypoints are read in from a file and sent as input into Dijkstra's algorithm. This then hands the waypoints off to the GPS sensor client to orient itself towards the closet waypoint in the proper order.

8. Laser Obstacle Avoidance

We are using a SICK LMS 200 laser system to locate the obstacle in front of the robot. A vector field concept is again used to compute the path of least distance.

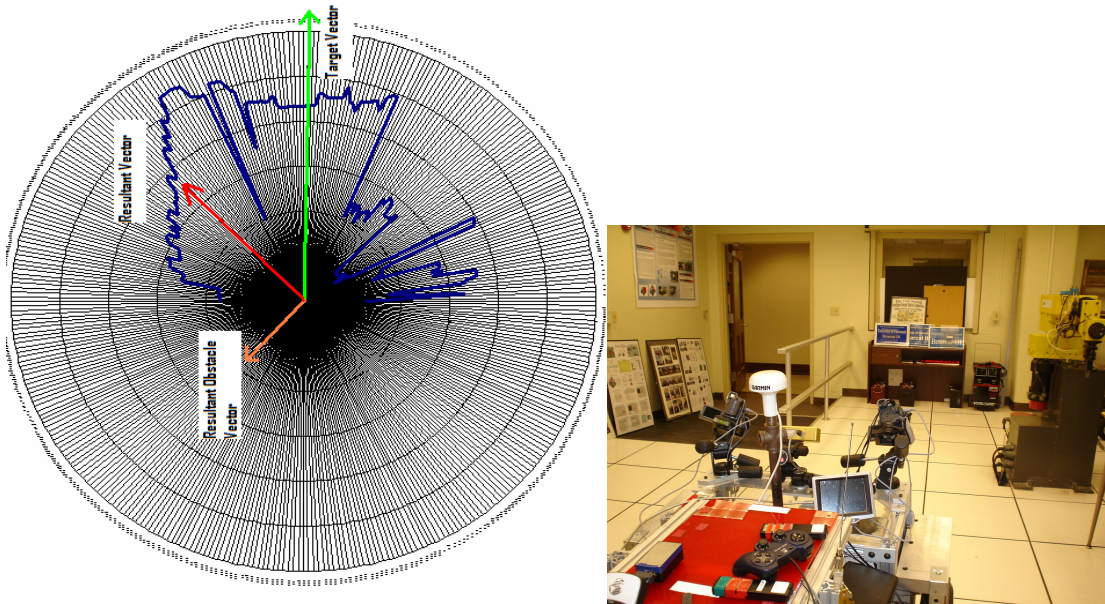


Figure 10 Target, obstacle and resultant vectors superimposed on the laser scan on the left and an actual view of the robot and room on the right.

The benefit of using the vector field concept is dynamic obstacle avoidance. It is a dynamic fast and robust process[1][3][4][5][6]

9. Predicted Performance

9.1 Speed and Ramp Climbing Ability

During the dry runs we found out that the robots can run more than 5 miles per hour but it has been constrained to move less than 5 miles per hour using the on-board software to keep the speed below the maximum.

The robot successfully climbed the 8.5 degree. Ramps up to 30 degrees have been successfully climbed.

9.3 GPS accuracy

We are using a Garmin GPS system which has an average accuracy of 3 meters but while moving the accuracy goes up to 2 meters or less. We have purchased a new Novatel GPS system which has an accuracy of 0.15 meters.

10. Vehicle Components and Cost

Part	Manufacturer	Model No.	Price
Frame	80/20 Inc	Custom Design	\$1,100
Generator	Honda	EU 2000i	\$1556
Motors	Pacific scientific	PMA43R-00112-00	\$970.00*2=\$1940
Amplifiers	Copley Controls Corp.	Xenus Servo Drives XSL-230-36	\$768.00*2=\$1536
Drive Wheels	Segway	Enhanced Traction	\$188*2=\$376
Gearboxes	Segway gearbox	HT design, 25:1 gear ratio	\$688*2=\$1376
Castor wheel	Borne	8 inch, 90 series, castor wheels	\$100
Laptop & accessories	Dell	Core2 1 GB Ram	\$1200
E-stop	Futaba	FRF-0302U	\$321
Motion controller	Galil Inc.	DMC-2130 web based	\$3,900
Camera mounts	Pelco	PS7-24,PT270P	\$300
GPS	Garmin	Garmin 76	\$251
Cover	Sheet Metal	Square D	\$300
Digital Compass	Honeywell	HMR3300 demo-232	\$400
Wide angle webcam	Creative	Creative live motion	\$150*2=\$300
Router	Netgear		\$60
		Total	\$15,016

11. Conclusion

The Bearcat Cub continues to evolve and each year presents many new challenges. This year the team decided to embark on the vector field concept as a simple fast robust way

to control the robot. The Bearcat Cub continues to be a source of research innovations and are looking forward to competing again this year.

ACKNOWLEDGMENTS

We gratefully acknowledge all the team members and sponsors.

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] E. W. Dijkstra. "A note on two problems in connecton with graphs, ". *Numerische Mathematik*. 1 (1959), S. 269–271
- [3] J. Borenstein, and Y. Koren, "Histogramic In-Motion Mapping for Mobile Robot Obstacle Avoidance," IEEE Transactions on Robotics and Automation, August 1991, pp. 535-539.
- [4] I. Ulrich, and J. Borenstein, "VFH+: Reliable Obstacle Avoidance for Fast Mobile Robots," IEEE Int. Conf. on Robotics and Automation, May 1998, pp. 1572-1577.
- [5] I. Ulrich, and J. Borenstein, " VFH*: Local Obstacle Avoidance with Look-Ahead Verification." IEEE Int. Conf. on Robotics and Automation, April 2000, pp. 2505-2511.
- [6] R. Siegward, I.R. Nourbakhsh "Introduction to Autonomous Mobile Robots," MIT Press, Cambridge, Massachusetts, London, England, 2004, pp. 267-272.

CERTIFICATION

I certify that the engineering design in the vehicle Bearcat Cub (original and changes) by the current student team identified in this Design Report has been significant and equivalent to what might be awarded credit in a senior design course.

Ernest L. Hall, Paul E. Geier Professor _____

Faculty Advisor to the UC Robot Team

J AUS Appendix

For this year's JAUS requirements, we modified the C++ socket implementation we used to qualify for the level 1 JAUS requirements in 2006. This code uses a thread to continuously monitor port 3794 on the host system. When a packet commanding a motion response is received, the main code is signaled and responds appropriately, however packets requiring a response to the controller are handled internally by the thread. In addition to responding to the 03, 04, and 0406 commands, the thread now also responds to the 240C waypoint query with a 440C waypoint response.

We did initial development of this code with our own JAUS controller, and then migrated to using the JCTS system. Our own controller has the advantage of binding to port 3795 and only transmitting to port 3794 which allows development and debug work to take place on one machine.

After getting access to the JCTS, we modified the code to further parse the messages and check for improperly formed packets. Most of the work for this challenge was in making sure the details of the protocol were handled correctly since the basic framework was already written.