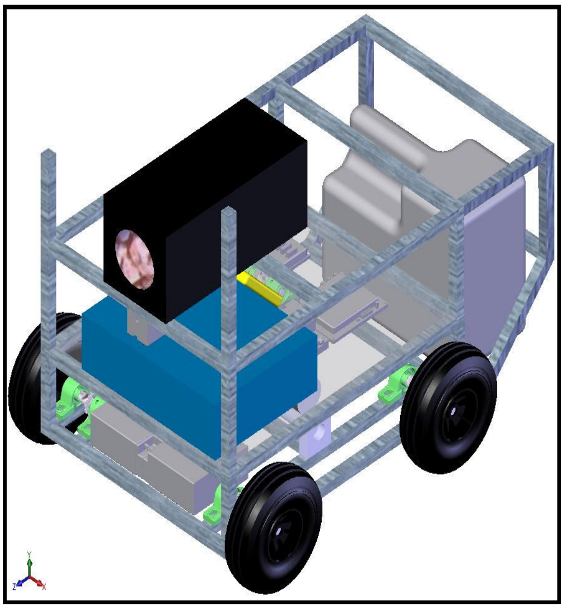
BullDog II



Presented By: Kettering University

IGVC 2006

I, Dr. Weihua Sheng, hereby certify that the engineering in this vehicle is significant and that the students involved earned 4 credits for their work.

Weihua Sheng

Dr. Weihua Sheng
Associate Professor of Computer Engineering
Kettering University

I. Introduction

The Kettering University Robotics Team is excited to announce our 2nd year entry to the Intelligent Ground Vehicle Competition (IGVC). This year's intelligent vehicle, BullDog II, is the modified version of our first autonomous vehicle design the BullDog I. Our design reflects the rules and the three competitions encompassed in IGVC as well as a modular approach allowing for testing and future enhancements. BullDog II is based around a platform that is easily modified, controlled, transported, and serviced while maintaining robustness and meeting low cost targets.

After making several changes to there robots design. The BullDog II, is the result of improving the original design of the BullDog I. Improvements on last years design focus on the sonar, digital compass, motor control, programming and adding a SICK PLS laser for obstacle detection. Design changes for the wheel base are also considered.

II. Club Layout

Kettering University is a unique school consisting of a mandatory CO-OP program and 11-week semesters. Students alternate work and school sessions split into 2 alternating sections, A and B. A-section attends school in the summer and winter, and B-section attends in the fall and spring. Due to the nature of the school, the robotics club has an additional challenge of intersection communications throughout the year. This alternation is challenging to deal with but it also provides the club with a great deal of members of different temperaments. Each section consists of a group of officers and leaders, similar to that of a small company. *Tables 1 and 2* show the breakdown of club members and committees between A and B sections.

Name	Section	Class	Group
Alex Linebrink	A	JU	Sensors
Munaf Assaf	A	JU	Sensors
Seth Billings	A	JU	Sensors
Trevor Cook	A	JU	Sensors
Chris Lam	A	JU	Chassis
Nate Lowrie	A	JU	Chassis
Luke Berry	A	SE	Drivetrain

Table 1- A-Section Team

Name	Section	Class	Group
Justin Griffiths	B	JR	Software
Scott McCleary	B	SO	Chassis
Joseph Carah	B	JR	Sensors
Benson Malonzo	B	SO	Sensors
Tony McKahan	B	SO	Drivetrain
Kevin Helpingstine	B	SE	Software
Nathan Heijmaus	B	SE	Sensors

Table 2 – B-Section Team

III. Design Process and Considerations

Customer Identification

The first task in our design process was identifying the customer(s). In this case, there were several customers to be identified. The first customers were the current students in the club as well as future students. This is because, ultimately, we are here to learn and advance ourselves in attempt to become more professional and successful in the post-college world.

We also put consideration into having the current and future competition being customers as well. We want to make our current parts to last for years to come. Identifying the future competitions allowed us to consider and incorporate modularity and document all aspects of our current design.

The last considerations we included were the ease of use and transportability factors. We wanted to make the robot robust and effective, without sacrificing the ability to change or manage the robot easily. This consideration applies mainly to interfacing and producing an easily constructible and reconfigurable robot.

Design Planning

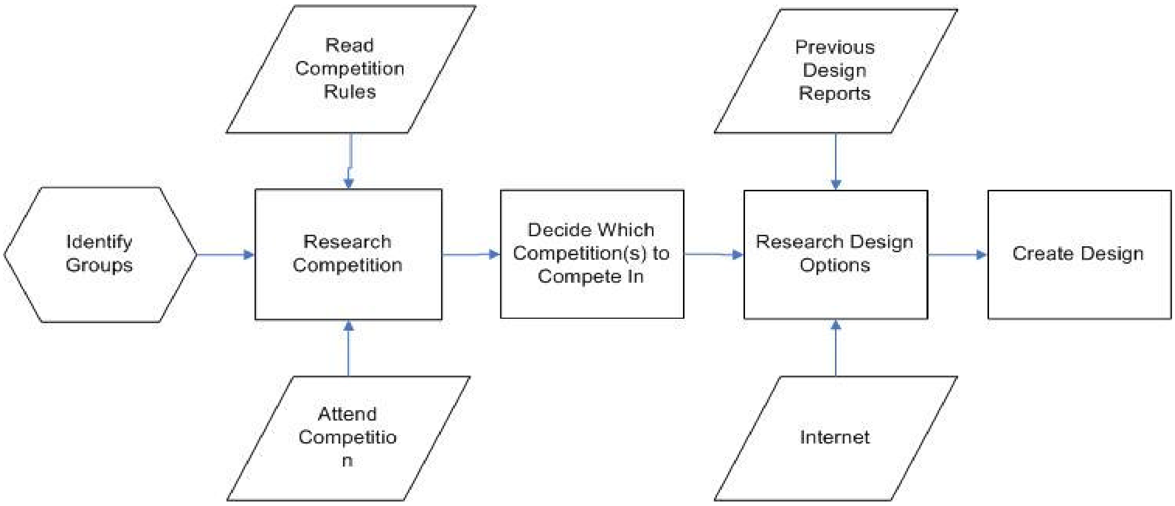


Figure 1 – Design Process

Figure 1 shows the design process we decided to use as a group to accomplish the rough design of BullDog II. After establishing the Kettering Robotics Club, we then organized the club by splitting into the current formation of 4 groups. These groups include chassis, motor control, sensors, and software integration.

After the first competition experience the team knew that several serious issues would have to be resolved. Motor control board was not functioning properly and the line detection program was running very slowly. A new motor control was needed and a program that could run more quickly and use less memory was also among are top priorities.

Progress Tracking

Each group was to organize what devices and methods were to be used to complete their respectable module. Having 3-month semesters and 2 different groups alternating each semester completing the same tasks made unique challenges for our team that most other teams do not face. We created a Blackboard group off of the Kettering network to stay organized between sections. Students who were away at work could communicate with students who were working on the robot at school. This way there was less of a learning curve required to figure out what exactly the opposite section did while the either was on their co-op term.

The progress was to be determined on a weekly basis during a common team meeting. This meeting also provided for setting goals that were to be done in weeks to come. Every group was required to have a weekly group meeting, a group-advisor review, and attend the weekly team meeting.

The following are the main considerations, in order of importance, we adopted while designing BullDog II:

Modularity and Reconfigurability

The main consideration in the design of BullDog II is modularity and reconfigurabiltiy. We wanted to design a very modular robot so that the platform can be used in the future designs and competitions. The club has also not yet acquired a trailer and will frequently be required to transport BullDog II from lab to testing and eventually to competition. Modularity and reconfigurability make the robot much easier to teardown and setup in a fraction of the time of a permanently fastened robot.

Safety and Reliability

Our second important considerations are safety and reliability. BullDog II needs to be safe both for the students working on and testing it and the judges who watch it while it competes. Detailed precautions related to reliability of components are also important. BullDog II needs to be weather and vibration resistant as well as robust enough to last through rigorous testing and competition.

Maneuverability

BullDog II needs to be able to maneuver around obstacles without hitting anything in its blind spots. This involves a minimum turning radius as well as very careful data processing for assurance that BullDog II will not hit anything while completing maneuvers. To decrease the amount of friction on the wheels during a turn, the team has decided to use caster wheels that will be located in the front of the robot. This will be a future modification of the current design. Caster wheel design modification may appear on the robot for the 2006 competition

Cost

In order to meet our budget and still have efficient parts, we made several strides. One of the most successful was to receive donations of parts from several companies. We also built our own PC, and researched the best cost options for various comparable parts before buying them.

IV. Hardware Design

Chassis

As stated above the design goal for this year's robot was the implementation of modularity and reconfigurability. The chassis was constructed out of 1.0"x .125" wall square aluminum stock. The frame consists of a 30"x 32"x 2" thick base and three sub-frames to hold the various components. Each sub-frame is secured using ¼" quick pins (Figure 2). The generator, and processing hardware each have their own dedicated frame. This allows for separation and easy serviceability if needed. Furthermore the generator can be used separately as a power source when needed. Each sub-frame and the base frame weigh less than 40lb's which aid in the transport of the robot. This modular approach also allows for easy adaptation in the future.

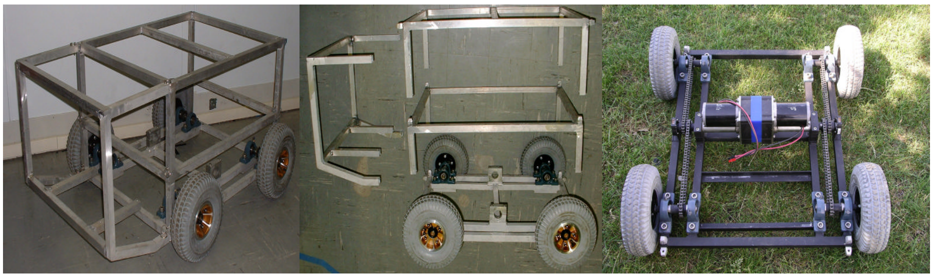


Figure 2 – Showing the frame assembled and split into sub-frames

The drive motors consists of two 24V CIM motors and gear housings from a donated Amigo Wheelchair. The motor and gearbox assemblies (Figure 3) are mounted in the middle of the base frame to lower the center of gravity. Through the use of readily available #35 chain and sprockets the power is transferred to each of the four wheels. Each wheel is cantilevered beyond the bounds of the frame using two bearing blocks. This enhances stability, maneuverability, and the ability to tackle rough terrain. All of the sprockets and wheels are held in place with quick pins, which allows for easy disassembly and serviceability; moreover, this modularity allows easier and safer transport of the robot by one person without the aid of tools. With the use of only socket head cap screws throughout the chassis and drivetrain changes can be made easily. From the original design the wheels can be mounted either on top of the base frame or underneath the base. The ability to change wheel location allows for both a stable robot with a low center of gravity and a robot with high ground clearance if those obstacles arise. In the unforeseen case of a failure the robot driveline can be serviced using one set of allen wrenches.

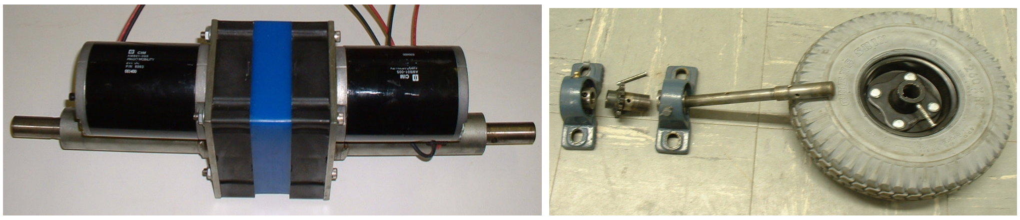


Figure 3 – Motors with Gearbox's and wheel with shaft, sprocket and bearing blocks

Electrical System

The overall electrical system of the BullDog II is shown in Figure 4. BullDog II's means of data processing is by PC. The sonar/ digital compass control board is connected to the PC via RS-232. The web cam is connected to the CPU via fire wire and all of the processing is done via the CPU. After the information is processed, output motor commands are sent to the motor control board via RS-232. The motors run and create feedback signals on the encoders. Feedback is then sent back to the CPU via RS-232.

Main Controller—PC

All decision-making is done via Personal Computer. The PC is composed of an AMD Athlon processor, 256MB of RAM, a 80GB hard drive, 2 fire wires ports, and 3 RS-232 Ports. The PC is mounted to the robot by a custom case designed to hold the motherboard, hard drive, and power supply. The PC is powered straight from the generator's 120VAC output. The PC's power supply is also used to power the sonar/ digital compass control board.

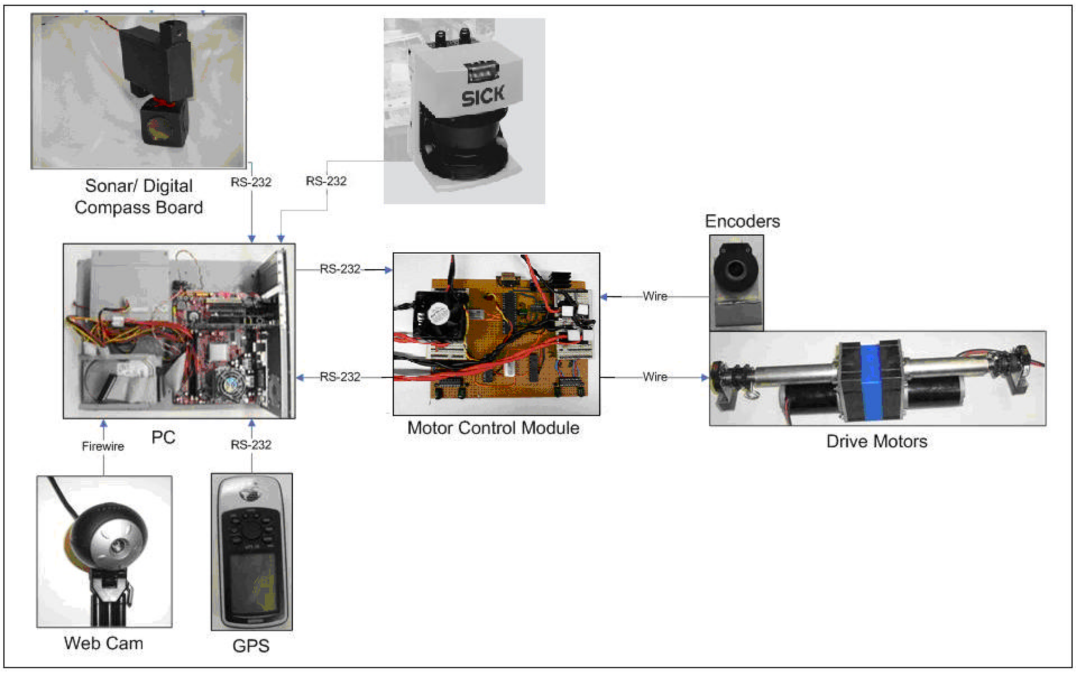


Figure 4 – Overall design of the control system

Power Systems

When we first assessed (Table 3) the power needs of a robot this size, we quickly realized that a purely battery based energy storage system did not possess enough power capacity to sustain the robot for time periods longer than an hour. Being that the energy density of gasoline is far greater than today's current battery technology we decided to implement a hybrid gas/electric system. With the use of the generator BullDog II is able to run up to 10 hours without stopping. This is achieved by running the generator at 54% of the rated output, which is near the generators highest efficiency. Furthermore, we have reduced down time in comparison to an all-electric vehicle; all that needs to be done is to refill the generator.

Several safety factors were built into the system. First, the system has both an on board and wireless emergency stop, which will automatically disconnect power to the motors in the event of a mishap. Next, the generator also isolates the PC power supply from the motor power supply that eliminates the possibility of computer shut down due to low voltage. A set of two parallel sets of two batteries connected in series is connected to the motor to provide a source of power able to sustain rigorous current draws for a short period of time. A 24V 8A Soniel battery charger serves to maintain the batteries while the generator is running. Furthermore, the batteries are non-spillable Exide batteries to prevent corrosion and acid leakage. Moreover, all cables and connectors are properly shielded to prevent injury.

The system is highly adaptable and modular. The generator is housed in it's own side frame compartment. If need be, it can be replaced with batteries or another power source such as a fuel cell. While on or off of the robot the generator can act as an independent power supply for electric tools, lights, etc. The batteries and charger have the same modularity, with the ability to add or subtract batteries to suite the current application. All of the interconnects between sections are industrial off-the-shelf components which are readily available. These interconnects are quick disconnects that allow modules to be connected and disconnected quickly and easily. By building a modularized power system into the design, we have created an easily upgradeable system that can handle a broad range of power needs while maintaining safety.

Component	Power (watts)
Soneil Battery charger (Includes motor controller)	192
Computer Power Supply (Includes CPU and all sensors)	290
Generator output	900
Average used power	~482

Table 3 – Average Power Consumption

Motor Control

The PIC receives 2 separate inputs in the form of desired distance and direction from the main PC of the robot. The PIC breaks down the data from character commands to numeric values. The numeric values are then sent to the 8-bit digital to analog converters (DAC), which in return sends them to the control board which uses them as a control signal to drive the motors. The DAC produces a 0 to 5 Volt signal; 0 to 2.3 V is used to go in the reverse direction, 2.5 V is used to stop the robot and 2.7V to 5 V is used to go in forward direction. Error correction is performed by a PID loop on the PIC, which receives it data from shaft encoders mounted on the motors producing 512 ticks per shaft rotation. These ticks are counted with interrupt handlers onboard the PIC, and translated into the appropriate unit for comparison to the ideal data given in the command from the PC. The PID loop then calculates and corrects for error.

We have also thought of several improvements that can be made to our motor control system. Converting to an H-bridge based drive system will eliminate the risk of control level failure. We also would like to send the shaft encoder data directly to counters that can be referenced by the processor. The current interrupt system we use inside of the processor requires a large amount of processor time. Time pending, these improvements are planned to be done by the time of the competition.

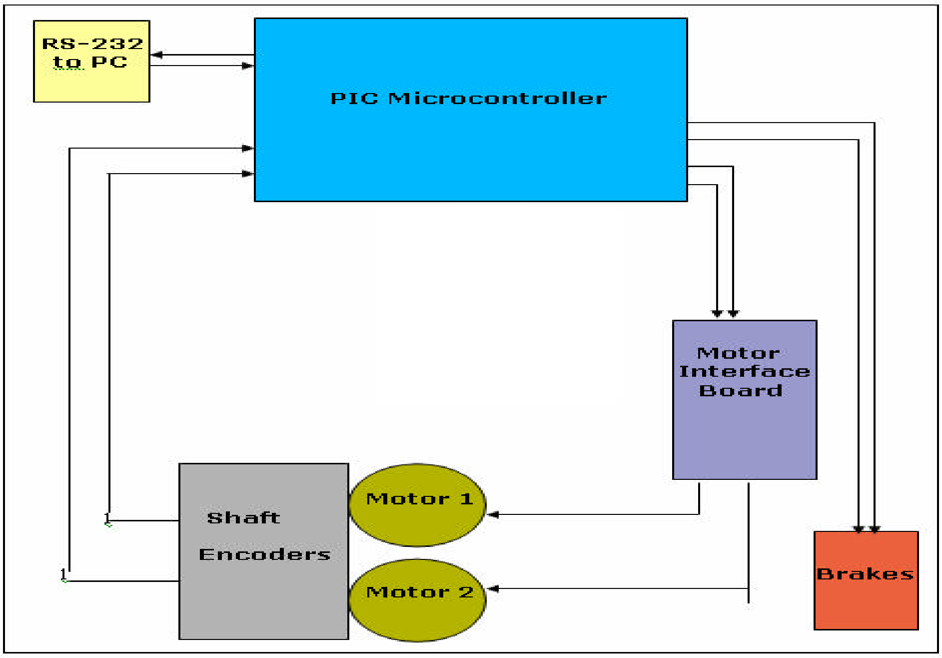


Figure 5 – The Diagram of the Motor Control Module

Sonar and Digital Compass

BullDog II utilizes two commercial sonar units and a SensComp 6500 Ranging Module. Each unit's pinout includes Vdd (power), Vss(ground), INIT(input),and ECHO. Initially the INIT and ECHO lines are pulled low. Operation of the module starts when the INIT is taken high by a controller microchip. Sixteen pulses at 49.4 kilohertz with 400-volt amplitude will excite the corresponding transducer as transmission occurs. At the end of the 16 transmit pulses, a DC bias of 200 volts will remain on the transducer as recommended for optimum operation. Because the same transducer is used to receive the pulse waves, it is possible that the resonance caused by the transmission could be heard as the response wave. To solve this, the Receive (REC) input of the ranging control IC Is inhibited by internal blanking for 2.38 milliseconds after the initiate signal.

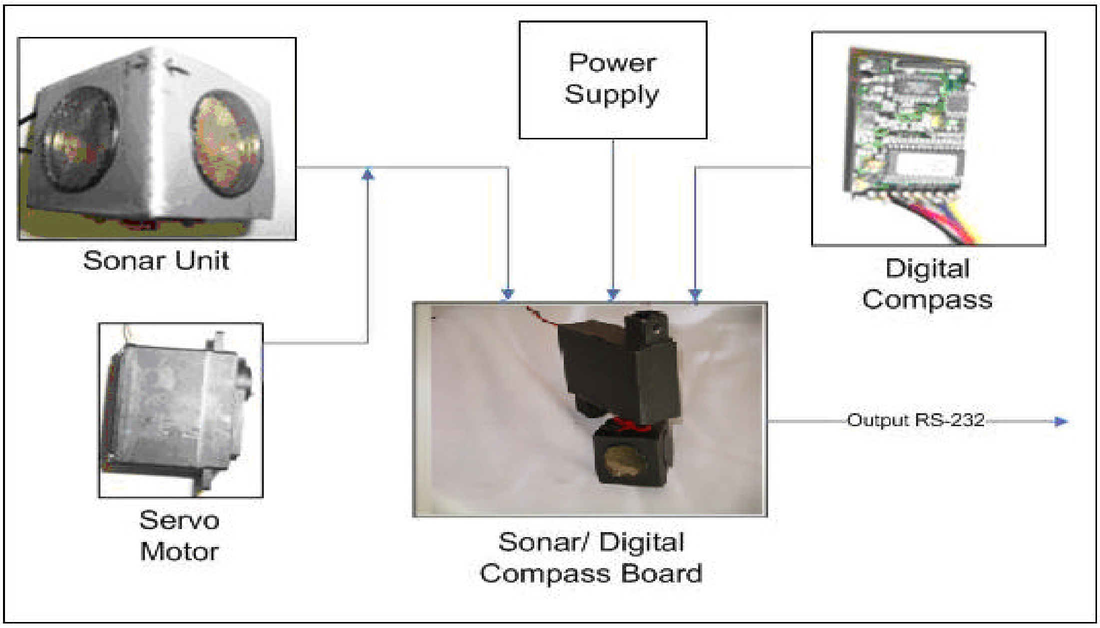


Figure 6 – Sonar/ Digital Compass System

When the echo of the transmission pulses is received the module takes the ECHO line high. The time difference between the controller microchip pulling INIT high and the module pulling ECHO high is proportional to the distance to the obstacle that reflected the pulse waves. Because the module's internal blanking lasts 2.38 milliseconds, the minimum range that the processor can accurately calculate is approximately sixteen inches. The distance calculations themselves are done within the controller microchip.

PWM Servo Motor

In order to fit the budget, we decided to use a servo motor to view different angles, as opposed to several sonar units. Each of the two sonar modules have a corresponding transducer. The transducers are perpendicularly mounted on a PWM servo motor. The controller microchip emulates a PWM signal through a digital output pin in order to control the positioning of the servo. A numerical PWM values corresponds to a specific angular position. The corresponding values for our targeted range of motion of 90 degrees was found experimentally. Since the transducers are perpendicular the processor can calculate distance at a heading within the 180 degrees.

Digital Compass

The three axis digital compass we chose was Honeywell's HMR3300. Its communication consists of a TTL level UART and utilizes an ASCII based protocol. The parameters of the UART are 19200 bps, at eight data bits, no parity bits, one stop bit, and no flow control. The ASCII commands that are available include receiving updated heading and magnetometer values, and initiating calibration. The same processor that oversees the sonar units also communicates with the digital compass to acquire updated heading values.

Sonar/ Digital Compass Control Board

The circuit board that interfaces sonar and the digital compass to the host PC contains an 18F8520 Microchip. This processor was chosen because it has two hardware UART registers. This allows two different channels of serial communication, one for the digital compass and one for the host PC. The host PC uses RS-232 as a means of communication, so a MAX233A is used to convert the microchip's TTL level communication to a format that the PC can understand. The circuit board also has pin headers for the sonar units' PWM servo and for the digital compass. JST connectors for the sonar units are also on board.

As the servo rotates 90 degrees, the processor calculates a linear distance from each sonar module at a 10-degree interval. The time at which the sonar pulse is transmitted and when and echo wave is received is recorded by the controller microchip. The time interval is then divided by two and multiplied by the speed of sound to acquire a linear distance. Experimentally we've concluded that our accuracy is within a half inch of the obstacle.

All communication on the RS-232 bus is initiated by the host PC. If the host PC requires update range values, it sends an ASCII 's'. The controller microchip's hardware UART interrupt handler then sends all range data to the host PC. Similarly if the host PC requires heading, it sends an ASCII 'h' and the controller microchip response by sending the heading.

SICK PLS Laser Range Finder

The laser range finder used on the Bulldog-II Robot is a SICK PLS (Proximity Laser Scanner). This is an Optoelectronic Protective Device for Industrial Safety Systems. The PLS takes measurements over a 180-degree radius; one measurement per degree from 0 to 179.

The PLS uses an RS-232 serial interface to communicate with a PC. SICK provides the packet structure necessary for data transfers between the PLS and another device. When turned on, the PLS automatically sends an identification packet and measurements over the serial connection. The computer controlling the robot retrieves these measurements, and passes them on to the robot control system as polar coordinates. These coordinates can then be used to assist in vision and path planning.

GPS

The GPS unit we decided to use is a Garmin GPS 76 marine GPS module. It was selected solely for use in the Navigation Competition. It communicates to the PC via RS-232. A coordinate is sent to the PC in the form of a string, which is then processed into a numeric value.

Vision System

The vision system for the autonomous challenge is used to detect lines on the field. By being able to find the lines, the robot will be able to stay within the painted white lines that are on the field. Figures 7A-C show the various processes an image goes through in order to process line avoidance data.

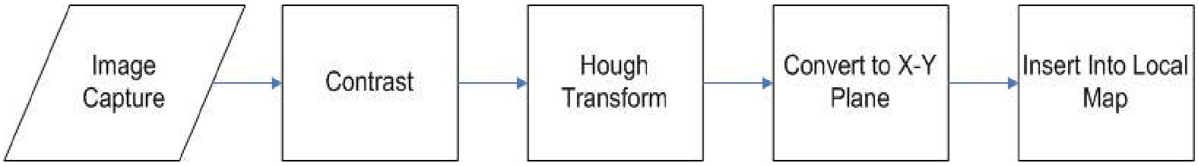


Figure 7A – Image Capture *Figure 7B – Hough Transform* *Figure 7C – Local Map*

The image is found with a fire-wire web cam and is inserted into a C program to be processed (Figure 7A). The first step in the program is to apply a contrast threshold to the image. This image allows us to see the boundaries of the areas of high contrast. This data is based on a pixel output of the camera. These points need to be transformed into real distance from the robot. By converting it to real data, the robot can see in two dimensions from a single camera. The lines are detected using an algorithm known as the Hough Transform. The Hough Transform is able to find the dominant lines by finding the largest number of collinear points. The result of the Hough Transform gives a point. This point is the point that the found line (Figure 7B) and a line to the origin cross at 90 degrees. Using this information, a plot of where the lines that need to be avoided can be found (Figure 7C). The lines that are found are then placed into the overall local map to be use for path planning.

V. Software Design

The intelligent navigation capability of the BullDog II is implemented in C, as well as in the low level motor control, sensing modules discussed above.

Programming language

LabView was the original language for the BullDog I. However, for the BullDog II the team was very grateful to have a team of programmers with the needed skills to implement a much faster means of handling the information. Due to the large amount of information generated by the various components, LabView ran much slower than the new C application.

Robot Navigation Algorithms

Establishment of a central decision making program is a very complex and difficult task. The most important part of BullDog II's development was unanimously agreed to be a solid, effective architecture.

The main routine, seen in Figure 8, starts with retrieving data from the camera vision system (white line detection) in the form of points on and x-y plane. The main routine takes these points and incorporates them with points acquired from the SONAR module, also in the x-y plane. The combination of these points is known as the 'local map,' which is later used for path planning. The local map is also dumped into what is known as the 'world map,' that is temporary storage of points for reference in case of taking a wrong turn undetectable by the local map.

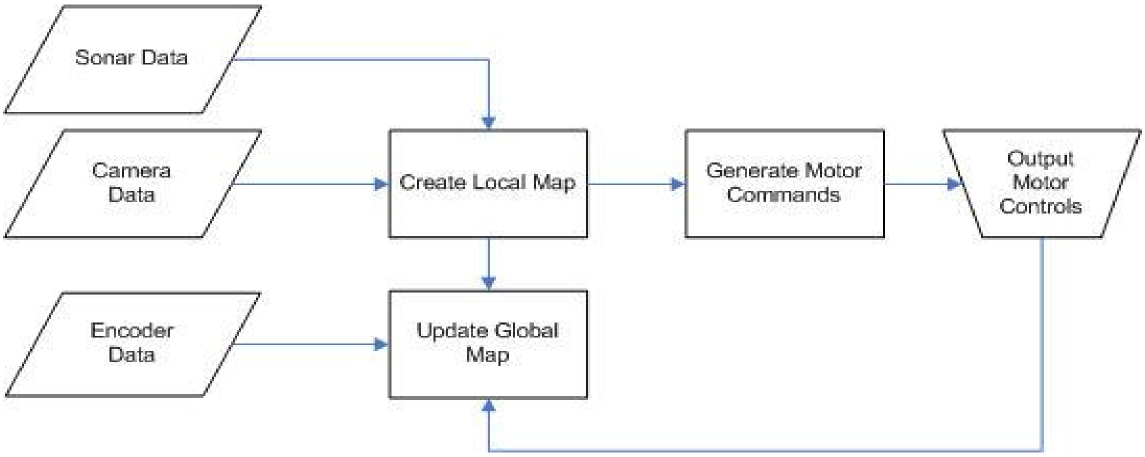


Figure 8 – Autonomous Navigation Algorithm

Path planning is done by viewing the local map to see if a path can first be made directly in front of where BullDog II is currently located. If a straight path cannot be made, it looks 10 degrees left, then 10 degrees right. If, again, BullDog II cannot find a path to travel, it increases it's site another 10 degrees each direction. This continues until BullDog II is looking 50 degrees in each direction and still cannot find a valid safe path. After 50 degrees, BullDog II references the world map and reverts back to its previous position and seeks an alternate route of travel. The path planning algorithm is shown in Figure 9.

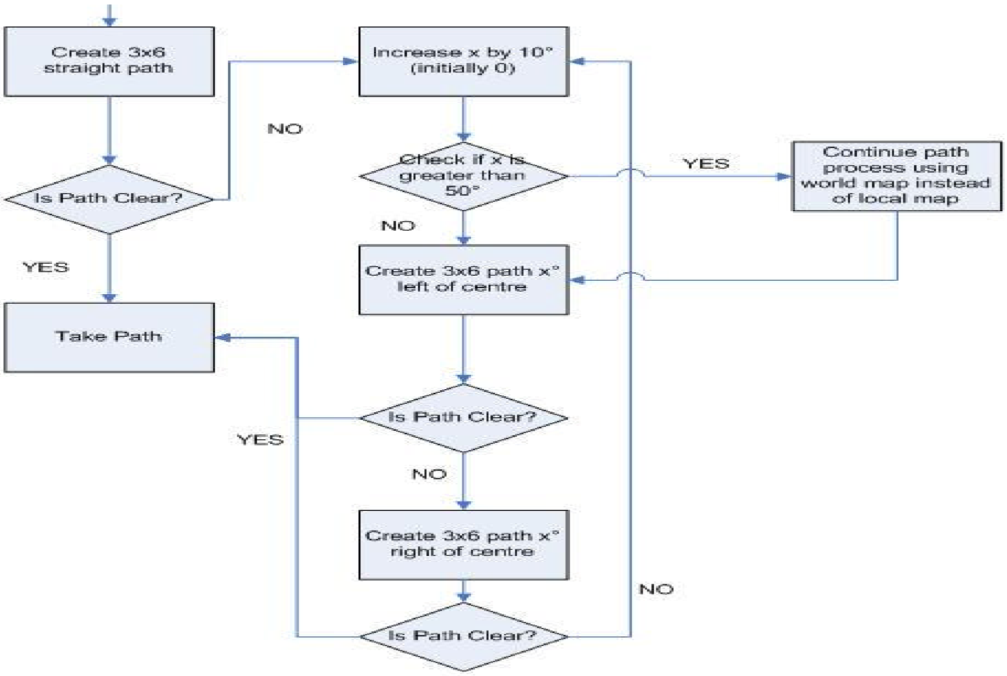


Figure 9 – Path Planning Algorithm

VI. Testing

Upon completion of BullDog II, major modifications and improvements had to be made to all of the systems and components. Agreed upon the members of the team, the best way of testing is to create a mock course comparable to the real IGVC course. Several scenarios we created to simulate what could happen to BullDog II while in competition. Failures to complete given courses and tasks resulted in program or system changes.

VII. Conclusions

At the time of the writing of this report, the robot is capable of competing in both the design competition and the Autonomous Challenge. The parts are purchased and available for the Navigation Challenge, but have not yet been utilized. The overall cost of the robot, in its current state, can be seen in Table 4.

Component	Retail Cost	Actual Cost
Aluminum frame materials	$122	$122
(18) 1/4 quick pins	$32	$32
Sprockets and chain	$51	$51
Bearing blocks	$72	$72
(4) Aluminum wheels w/pneumatic tires	~$240	$0
(2) 24V Cim drive motors w/gearbox	~$400	$0
Yamaha EF1000iS Generator	$700	$700
Soneil Battery charger	$65	$65
(2) 18Ah Exide non-spilllable betteries	~$70	~$70
LabVIEW 7.0 Student Edition	$50	$50
Custom Built PC	~$508	$508
Web Cam	$78	$78
(2)Senscomp 6500 Ranging Module	$72	$72
1818520 MicroChip Processor	$12	$0
PCB Control Board	$80	$0
3-Axis Digital Compass	$385	$385
Motor controller	~$170	$80
Garmin GPS 76	$200	$200
Misc. parts	$171	$27
TOTAL	~$3478	$2511

Table 4 - Cost Break Down

VIII. Acknowledgments

The Kettering University Robotics Team would like to pay special tribute to our support and sponsors. First and foremost, we would like to extend our appreciation to the Kettering University ECE department for monetary, space, and logistical support. We would also like to thank Amigo International Inc. for their donation of our drivetrain components, Prof. Doug Melton for his donation of the Laser Range Finder, and our ECE department technician Jerrey Kozlowski for his support in providing the necessary components needed in this project.