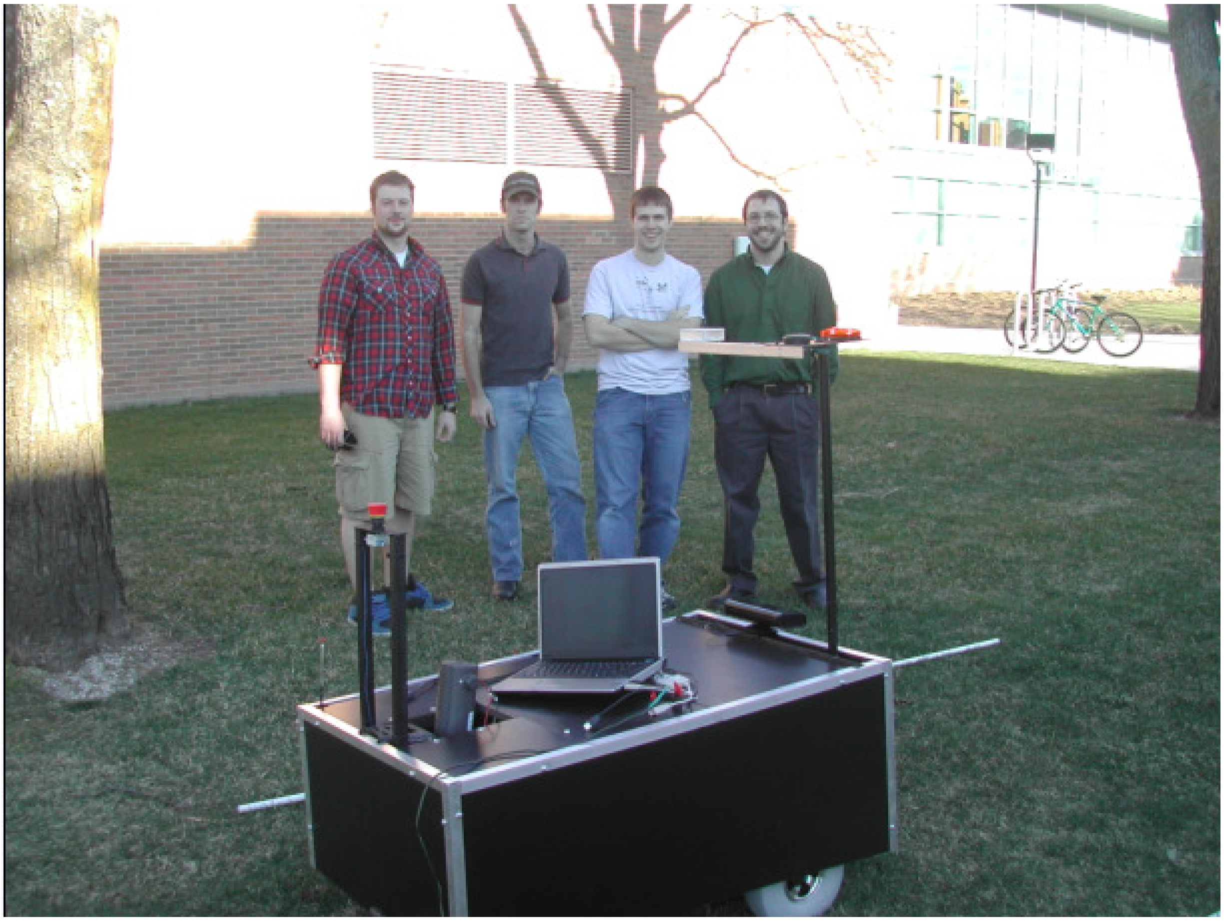
4/4/2011

SVSU

K.I.T.T.
Kinematic Intelligent Tactical Technology



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Faculty Advisor Statement
I certify that the engineering design of the vehicle described in this report, KITT, has been significant, and that the student effort was a senior design capstone project.

SVSU Saginaw Valley State University

1. Abstract

The Intelligent Ground Vehicle Competition is held at Oakland University each year. The group designed a vehicle that could navigate autonomously through various courses in the allocated amount of time. The vehicle had to meet competition specified requirements which include: overall size, safety requirements, and speed requirements. This project is the pinnacle of a compilation of four years of electrical engineering design theory applied to a real life application.

2. Introduction

The development of vehicles capable of navigating autonomously has been an area of increasing focus over the past few years. Autonomous functions have long ago been incorporated into aircraft technology, while incorporation into the automotive industry has been much slower. This disparity is due in large part to the complexity of ground navigation as it relates to determining the proper destinations and paths. When driving a car most decisions are based on interpretation of visual data. These decisions are relatively simple to teach a human being, but are more complex when implemented by a computer. The difference between a driveway and a boat launch may be fairly obvious to a person, but communicating such differences to a computer control system is much more difficult. The ability to navigate in any form involves the ability to sense the environment and knowledge of position in respect to the destination. For aerial vehicles this involves the knowing the position and heading of the vehicle, knowing the location of the destination, and the ability to detect and avoid obstacles. With ground vehicles the added visual component is necessary in order to navigate effectively. Interpretation of visual data through computer logic often involves the development of algorithms that perform advanced pattern recognition techniques in order to identify objects that the average human-being could easily identify. The designs developed as part of project KITT utilize rudimentary vision techniques in addition to other necessary sensors in order to create an autonomously navigating ground vehicle.

The goal of the KITT project was to consider a simple case where the vehicle need only to avoid obstacles while staying within boundaries outlined by lines of different color than the course. A key motivation for this project was to prepare a vehicle that abides by the rules and specifications of the Intelligent Ground Vehicle Competition (IGVC) held annually at Oakland University in Rochester, Michigan. This competition provides a venue for teams from universities across the United States and abroad to test the design and processing of small-scale autonomous vehicles. The demands of this competition were used as a guideline for construction and operation of the KITT project. The IGVC has detailed descriptions of the challenges available at the competition. From these descriptions basic requirements were developed that the vehicle must be able to navigate using GPS coordinates while avoiding obstacles and staying within boundaries. Sensors were chosen that would provide the necessary data to the vehicle for completion of the IGVC challenges. Much of the design involved in this project entailed communication with and interfacing of the various sensors, controllers, and components. Another major aspect of the project was developing the search algorithm to navigate the vehicle. The operation of KITT's major components as well as details of the hardware and software designs used for this project are provided in this report.

3. Design

Below is a block diagram of the entire system used for the vehicle. On the left hand of the diagram are the inputs of the system, which include a digital compass, a GPS, and an Xbox Kinect. The output is heading to the motor controller as two commands, one for speed and one for direction.

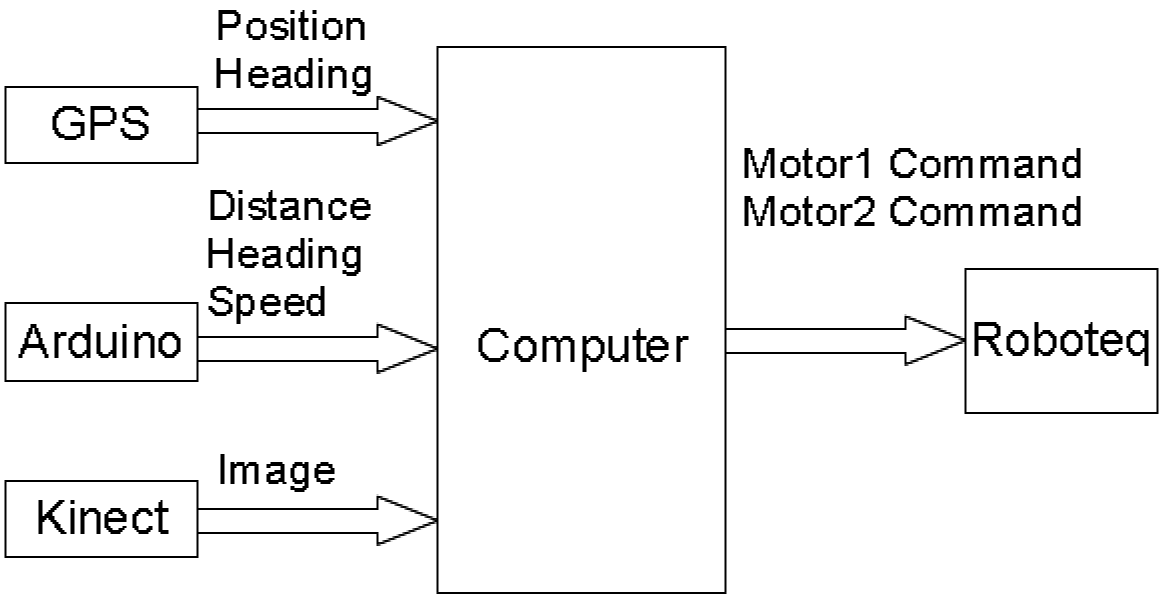


Figure 1: System Block Diagram

3.1 Drive System

The drive system uses a compact drive assembly 24 volt DC motor. The motor was purchased from Amigo Mobility. The motor was chosen because of its compatibility to the frame which was donated to the team. Braking is a key requirement by the IGVC guidelines and the motor automatically provided braking when voltage is removed.

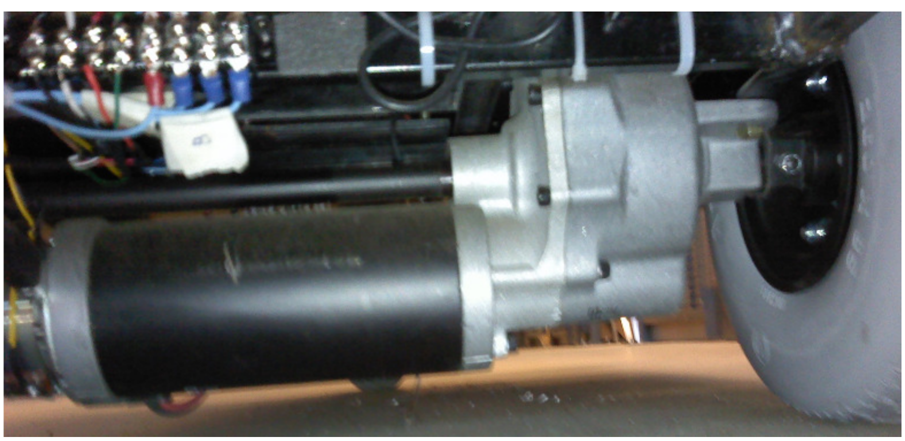


Figure 2: Differential Drive Motor.

3.2 Steering System

The steering system uses a Dayton 12 volt DC motor. The motor was used because it was configured with an encoder and was free because it was taken from an old project. The steering system is connected to a DC motor controller which is controlled through software in order to adjust the heading of the vehicle.

Figure 3: Steering Motor

Voltage: 12V

Horsepower: 1/5

Amps: 18.5

RPM: 80

Torque: 135 in*lb

Ratio: 20 to 1

3.3 Batteries

Absorbed Glass Mat (AGM) batteries were chosen. An AGM battery is spill proof and considered the most vibration and impact resistant batteries available. These batteries also have the advantage of needing no maintenance. This means two things: first, battery acid never has to be added; and second, if the charging is not controlled the battery would be destroyed.

Since there are both 12-volt systems and 24-volt systems, it was necessary to have two battery banks. The 24-volt system that powers the motor controller as well as the motors consisted of two 33Ah AGM-lead acid batteries. The 12-volt system powers everything else aside from the computer and consists of a single 33Ah AGM-lead acid battery.

3.4 Motor Controller

The motor controller is responsible for controlling the responses of both the drive motor and the steering motor that allow the vehicle to move and turn. The controller used for this project is the Roboteq AX2550. This controller has many useful features including the ability to operate both the steering motor and drive motor. One key trait of the Roboteq controller is the ability to communicate directly to the computer through RS232 serial protocol. The controller is able to both receive commands and send data about the current operation back to the computer. The commands used to control the motors are simple one-line commands. A program was written that uses these motor commands in order to execute turns and linear motion. Two different methods of turning were considered: one in which the next position was given in coordinate form and the necessary turning radius and turn distance were calculated. The second method utilizes the digital compass and involves commanding a heading and distance. It was determined that this second method was simpler to implement given the availability of the digital compass and it also follows the path method used in the algorithm used for path-finding. To accomplish this turning motor is set to an angle near 90 degrees so that it will turn with nearly a zero-turn radius. The drive motor is activated until the proper heading is reached. The steering motor is then set to 0 degrees and the vehicle moves until the designated distance is reached. A function for forward motion was also designed. This function uses the distance data from the hall effect sensor to determine how far the vehicle has traveled and when the vehicle has reached the desired position.

Max Current: 60A
Surge Current: 250A
Communication: RS-232 (9600 Baud)
Voltage Protection: below 12 volts and above 43 volts

Figure 4 Motor Controller

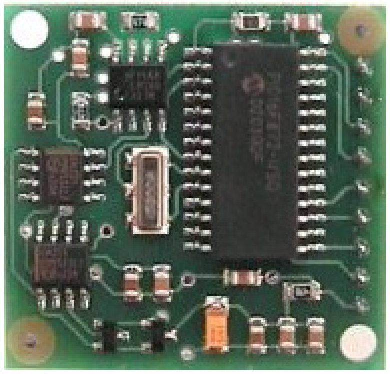
3.5 GPS

The GPS used was a Garmin unit designed to communicate via RS232 serial communication. This constantly transmits data to a serial port on the laptop. The software polls this serial port at regular intervals stores it as a string. Since the GPS constantly sends data, the string must be searched for the necessary data then be parsed out by the software. As long as serial port is read for a long enough period of time, the entire word will be received at some point in the data stream. The sentence being sent by the GPS always begins with the same identifying word and the data that follows is separated by commas. All that is necessary is to search for the starting word and separate the sentence by the comma. These functions are included in the string library and therefore getting data from the GPS was relatively straightforward.

Figure 5: Garmin 18-5 GPS.

3.6 Digital Compass

GPS will give a heading of movement if the vehicle that it is attached to is moving. This means that if the vehicle stops and turns, the vehicle will not know which direction it is pointing until forward motion is again achieved. Therefore, the need for a digital compass was needed so that the vehicles computer would know the direction of the vehicle at all times. The compass that was used was a CMPS03; this digital compass uses two magnetic field sensors that are perpendicular to each other which allow the compass to measure the earth’s magnetic field in all orientations. By wiring the digital compass to an Arduino microcontroller using I2C specifications only two wires were required to transmit data to the microcontroller. The heading that was returned to the main computer from the microcontroller was in degrees using North as a reference as zero.



Voltage - 5v only required
Current - 20mA Typical
Resolution - 0.1 Degree
Accuracy - 3-4 degrees approx. after calibration

Figure 6: CMPS03 Digital Compass.

3.7 *Speed/Distance Sensor*

In order to accurately return to a previous waypoint, the most accurate way would be to use data from GPS and compare that to distance traveled from last waypoint. To accomplish this, an accurate way of measuring distance had to be designed. The solution that this vehicle uses is a Hall Effect sensor that reads the number of times that the drive shaft turns. The calculation to find distance is then straightforward as the distance traveled is just the number of rotations multiplied by the circumference of the wheel. This calculation was accomplished by an Arduino microcontroller which communicated with the main computer through serial communications.

One of the specifications for the competition is that the vehicle must maintain a minimum of one mile per hour. To maintain the one mile per hour minimum speed that is required while on the course, a way of measuring speed had also be included in the design. The speed was calculated by utilizing the number of rotations that the drive shaft turns, multiplying by the circumference of the wheel and then dividing by the time that was required for the shaft to turn. These calculations were also computed by the Arduino microcontroller

3.8 Camera

For KITT's main source of vision the Microsoft Kinect was uses as both a camera and an infrared depth sensor. The Kinect camera generates a 640x480 color image from its standard RGB camera, as well as a 640x480 image that contains depth data of the objects in its field of view. These images were obtained through the use of the OpenKinect Library, and they are used in the software to obtain data about obstacles on KITT's pathway.

Field of View
Horizontal field of view: 57 degrees
Vertical field of view: 43 degrees
Physical tilt range: ± 27 degrees
Depth sensor range: 1.2m - 3.5m

Data Streams
320x240 16-bit depth
640x480 32-bit colour

Figure 7: Xbox Connect.

A depth image is created from the Kinect using a process known grid distortion. Grid distortion works essentially in three steps. First a grid of infrared light is emitted works essentially in three steps. First a grid of infrared light is emitted from the Kinect. This grid is then reflected back towards the sensor, with lines either being elongated or condensed based on the distance away from the Kinect. The Kinect then processes this grid to calculate the forward distance from the Kinect to the object.

For the actual processing of the image the first process is obtaining a edge map of the obstacles. Using OpenCV, a digital image processing library, the color image is first converted to a grayscale image. This image is then sent through a canny edge filter to obtain edges of all the obstacles in the field of view. The canny edge filter works by essentially comparing pixel values to nearest neighbor pixel values. If the two values are shown to have difference of greater than a pre-selected threshold, that pixel is selected as an edge.

Once a new image is obtained containing all obstacle values, it is cross referenced with the depth image. From this, depth values for every obstacle can be obtained and a map of both obstacles and distance from KITT can be obtained. Using these values, a 2D map is created that contains all obstacles found from the Kinect, in reference to KITT. This 2D map is then combined with data from other sensors to form essentially a top-down view of around KITT, containing both past data and new data from the Kinect.

3.9 Safety Light

New requirements for the competition this year specified that each vehicle must have a safety light. This light must remain illuminated when power is applied to the vehicle and flash when the vehicle goes autonomous. This requirement was met through the use of relays. By wiring the light to the common side of the relay, applying 12 volts to the normally closed side of the relay, and an automotive flashing relay to the normally open side of the relay the light would remain illuminated as soon as the 12 volts supply was turned on. The ground of the coil side of the relay was wired to the Dayton power relay. Therefore when the emergency stop circuit was closed, the coil for the safety light relay was energized and the normally open contact of the relay was closed making a continuous circuit making the light flash.

3.10 Algorithm

KITT utilizes a very common algorithm for path finding and obstacle avoidance, which is known as the Vector Field Histogram (VFH). VFH works exceptionally well for agile robots because its input is a 2D grid map containing object location as well as target points, which is exactly how KITT's sensor integration works. VFH contains 3 major steps in order to produce a final heading for the robot. They are as follows:

1. Generate map of obstacles and goal node
2. Using 2D map, create polar 1D polar histogram
3. Calculate heading and velocity

Most of the 2D map is already created from KITT's sensors. A goal node just needs to be added to the map, this being the next destination that KITT desires to reach, which is entered as a GPS coordinate and translated to coordinates on the map. Once this is added into the map a 1D polar histogram is created.

The polar histogram is created by calculating the sum, M_{Θ}, of all the certainty obstacle values that are located along some angle Θ. Θ is between 0 and 180 degrees, and is measured from the current heading of KITT. Once the polar histogram is created, all angles that are found to contain a value of MΘ under some pre-determined value, which was chosen through experimentation, are selected. This is done to essentially find a path that is almost guaranteed to be unobstructed by obstacles. The angle from this set that is nearest to goal angle is selected as KITT's new heading.

4. Emergency Stop

4.1 Purpose

For the vehicle to meet competition specifications and to operate in a safe manner, an emergency stop circuit had to be implemented. The rules for the competition specified that both a wireless and mechanical emergency stop was included in the design. The wireless part of the stop circuit had to be effective for a minimum distance of 100 feet, and the mechanical emergency stop switch had to be at the back of the vehicle located between 2 and 4 feet tall. In the interest of being safe, a decision was made so that if the vehicle were to exceed the maximum distance of the wireless stop circuit, the vehicle would automatically stop. This made the vehicle safe in the three imaginable cases that the vehicle would need to be stopped: The vehicle becomes unstable and needs to be stopped wirelessly, the operator becomes incapacitated and cannot stop the vehicle when needed, and the battery voltage of the transmitter falls below the minimum operating voltage. In all three of these cases, the vehicle would go to its maximum transmittable distance and stop.

4.2 Transmitter/Receiver Circuit

The transmitter that was used was a TWS 434A chip that broadcasts an AM modulated signal at 433.92 Megahertz. Although this transmitter has an operating voltage range of 2 to 12 volts, the HT12E encoder that was used has an operating voltage range of 2 to 5.5 volts. Since the transmitter was to be powered by batteries, the easiest way to stay in the range of both of these voltage ranges was to use three AA batteries rated at 1.5 volts making the operating voltage of the transmitter 4.5 volts.

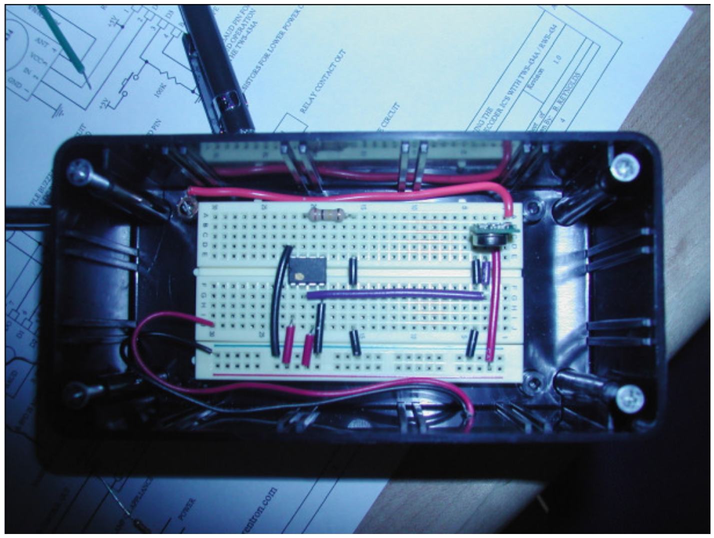


Figure 8: Transmitter Circuit.

The receiver that was used for this vehicle was a RWS 434 which has an operating voltage range of 4.5 to 5.5 volts and receives an AM modulated signal at 433.92 Megahertz and the HT12D decoder was used has an operating range of 4.5 to 5.5 volts. By using a 7805 +5V voltage regulator, voltage was able to be drawn from the vehicle's 12 volt battery and converted to 5 volts for the circuit.

4.3 Relays

Since the wireless receiver is only rated for 4.5 milliamps, and the motor controller could draw up to 80 amps, a circuit was designed to allow for these ratings. When both kill switches are in the closed position, 12 volts is applied to a Dayton 100A power relay. When this relay closes, the ground wires from the Roboteq are connected to chassis ground and therefore allowing the Roboteq to control the steering and drive motors.

5. Finance

5.1 Purchased Items

Date	Items	Company	Cost
1/23/2011	Xbox Kinect	Best Buy	149.99
2/2/2011	Misc. Hardware / Exoskeleton	Lowes	135.49
2/10/2011	IGVC Registration	Oakland University	250.00
2/23/2011	Drive Components	Amigo International	236.84
3/1/2011	Computer Connections	Best Buy	69.96
3/1/2011	Parts for Safety Light	Advanced Auto	41.66
3/1/2011	Misc. Tools / Wire / Connections	Harbor Freight	135.85
3/8/2011	Steering Components	Amigo International	88.48
3/16/11	Material for Covering	Home Depot	222.54
3/18/11	Misc. Hardware	Home Depot	61.57
3/22/2011	Tools for Covering	Harbor Freight	109.86
4/1/2011	Material for Covering	Menards	93.35
		Total	**2044.40**

5.2 Donated Items

Item	From	# of Items	Price	Total Price
Amigo Frame	Chris Rogner	1	50.00	50.00
Arduino Duemilanove	Mike Brady	1	29.95	29.95
Cherry Hall Effect Sensor	SVSU	1	24.64	24.64
CMPS03 Digital Compass	SVSU	1	57.00	57.00
Hardware Enclosures	SVSU	4	3.95	15.80
Dayton 12V Gear Motor (Steering)	SVSU	1	389.07	389.07
MW-10 Potentiometer	SVSU	1	42.31	42.31
Roboteq Motor Controller	SVSU	1	495.00	495.00
TWS 434 Wireless Transmitter	SVSU	1	8.50	8.50
RWS 434A Wireless Receiver	SVSU	1	8.50	8.50
Holtec R-8PE Encoder	SVSU	1	4.00	4.00
Holtec R-8PD Decoder	SVSU	1	4.00	4.00
Dayton 80A Power Relay	SVSU	1	72.95	72.95
PC Relay	SVSU	2	2.80	5.60
Laptop Computer	SVSU	1	1367.21	1367.21
Garmin 18-5 GPS	SVSU	1	222.44	222.44
Werker AGM 33Ah Battery	SVSU	3	75.99	227.97
		Total	**2858.31**	**3024.94**

6. Recommendations for Improvement

The primary avenue for improvement is in the obstacle detection. The Kinect's depth sensor operates at a frequency of infrared light that is disrupted by the infrared rays of natural sunlight. As a result, the vehicle cannot effectively navigate obstacles outside. There are a couple of options for replacing the Kinect system. The first and cheapest is to implement a sonar system. In order to gain knowledge of the entire field of view of the vehicle the sonar system needs to either rotate or consist of many sonar detectors that pulse in such a way as to not interfere with each other. Rotating sonar would likely provide the resolution necessary for true path-finding, and could be designed to provide a full picture of the area surrounding the vehicle on all sides. A laser measurement system is a second, but very costly option. This system scans the entire field of view of the vehicle and provides information on all the visible obstacles. This method is truly the best for autonomous ground vehicles at this time. What neither of these systems address is the visual component of navigation. The camera would still be necessary and new methods for avoiding lines would have to be implemented. Other areas for improvement include adding a more accurate GPS, and researching more complicated search algorithms for more robust path finding.

7. Conclusion

In working on this project many lessons were learned about the development of autonomous vehicles. One major conclusion drawn from this project is that applying search algorithms to a dynamic system such as this vehicle is often a compromise between complexity and effectiveness. The most reliable search algorithms implement complex mathematical equations to determine the best path to follow. Simpler algorithms may lead to poor path choices. No matter what the algorithm is used, however, the complete map is needed for a perfect path to be found. This is not possible with an autonomous vehicle operating in an unknown environment. The other major conclusion from the group's work on this project is about the importance of environmental considerations in selecting sensors. All components of any project should be tested in the environment they will be used in before they are considered for integration into the design.

8. Acknowledgements

The team would like to thank Saginaw Valley State University for the generous grant that enabled us to buy building materials and other equipment. Another thanks to Bob Mackie for instructions on using various machines in the tool shop in Pioneer Hall. Team KITT would also like to thank Chris Rogner and Amigo for the Amigo frame and other support they provided during the construction of this vehicle.

9. Works Cited

"IGVC - Intelligent Ground Vehicle Competition." *IGVC - Intelligent Ground*. Web. 11 Apr. 2011. <http://www.igvc.org/rules.htm>.