OHM Design Report

2013 Intelligent Ground Vehicle Competition

University of Michigan – Dearborn

Dearborn, Michigan 48128, USA

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I hereby certify that the design and engineering of OHM for the 2013 Intelligent Ground Vehicle Competition are significant and equivalent to what might be awarded credit in senior design course and include the development of GPS navigation, vision lane following capabilities and object detection and avoidance using a scanning laser range finder.

Dr. Nattu Natarajan

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1. Introduction

The OHM design project brings together 4 senior Electrical and Computer Engineers from the Intelligent Systems Club of the University of Michigan – Dearborn with the goal of competing and winning the 2013 Intelligent Ground Vehicle Competition. While the University of Michigan – Dearborn has past experiences with the IGVC competition none of the current members have ever participated in this specific competition. The team will rely on their previous experiences building and developing robots for the Institute of Navigation autonomous robotics competitions, although this competition will provide both new and more complex problems that must be approached and tackled using the experiences and knowledge of computer and electrical engineering gained both in and out of the classroom.

1.1 Team Composition

The OHM team is comprised of 4 undergraduate seniors, with backgrounds in either computer or electrical engineering. The members include:

Name	**Year**	**Major**	**Hours**
Zachary DeGeorge (lead)	Senior	Computer and Electrical Engineering	300
Angelo Bertani	Senior	Computer and Electrical Engineering	150
Yanchen Shang	Senior	Electrical Engineering	300
Qijie Xu	Senior	Electrical Engineering	300
Tong He	Senior	Electrical Engineering	300
Tianyu Wang	Senior	Electrical Engineering	300

All team members are part of the Intelligent Systems Club at the University of Michigan – Dearborn. Angelo and Zach are leading members of the ISC and have been active in the club for nearly two years, with this year's IGVC being their 4^{th} autonomous robotics competition. They have had much success in the past, and look to use the experiences from their previous competition to continue this success in the current competition. Yanchen and Qijie are foreign exchange students from China, and this will be their first experience in a robotics competition.

2. Design Overview

OHM is a first iteration project, but many of its required subsystems have been previously developed in some form for other ISC projects. The design philosophy of OHM is modularity and simplicity with a focus on the integration of the necessary navigational sensors needed to navigate autonomously in the course requirements of the competition. The three main navigational subsystems that OHM will rely on and their respective significance are:

1. Computer Vision   Lane Following
2. GPS   Waypoint Navigation
3. Lidar   Object Detection

The information from these systems will be integrated to create a map that will be used for navigation. Additional systems will be included, such as speed control using wheel encoders, but they will not be relied on for navigational purposes.

Note: As this is a first iteration project the "Improvement" sections will be omitted

2.1 Cost Analysis

All of the components used on OHM for the 2013 IGVC were provided by the ISC with help from the Electrical and Computer Engineering department and the College of Engineering and Computer Science at the University of Michigan – Dearborn. The most recent significant contribution was a new SICK laser range finder that was used for the 2013 ION Autonomous Snowplow Competition, and will be retrofitted for use as OHM's object detector and local navigational sensor. The team had multiple prepared robots to choose from for use in this competition. While no money was needed to be spent for the components for this competition here is a list of how much the parts would cost if the project was started with no previous resources.

#	Description	Actual Cost
Chassis Construction/Mechanical Design		
1	Square Metal Tubing and Wood Panels	$100.00
2	Electric Wheelchair Wheels 12.5 Wheel	$280.00

3	Wheelchair Electric Motors	$1864.00
Motor Control Circuitry		
1	Roboteq Motor Controller Ax2850	$620.00
Robot Computer		
1	Dell Laptop Computer	$999.00
Sensors		
1	Wheel Encoders: Quad Optical Encoders	$338.00
2	Sick Laser Sensor	$5273.00
3	VECTORNAV VN-100 IMU	$500.00
Camera		
1	Microsoft Lifecam HD	$50.00
2	Camera Enclosure	$54.95
Controller Transmitter and Receiver		
1	Bulldog Wireless Car Starter	$60.00
GPS		
1	Hemisphere VS100 Series DGPS	$4195.00
Accessories		
2	2 Optima Yellowtop Batteries	$450.00
2	Multi-Bank Battery Charger:5/5amp 2 Bank Charger	$189.00
5	Exterior lights	$100.00
6	Switches, Wires, Connectors, Electronic Parts, Enclosure, Etc	$500.00
Tax(6%)		$934.38
Total		$16507.33

2.2 Design Planning

The design planning of OHM is the philosophy that simple is better. Much time is spent brainstorming ideas and then figuring out how to represent those ideas in the simplest means necessary..

2.3 Design Innovations

The strength of OHM's design comes from the software integration techniques that were used to combine and manage all of the sensors and electrical components of the project. While the software will be developed in C it will use an object oriented and singleton design pattern to produce code that is very portable, modular and robust allowing the robot to continue to function if there are sensor failures or inaccuracies.

3 Mechanical Design

OHM will be implemented on a previously built robot that was designed and fabricated before any of the current members were active in the club. There were many options available to the team for choosing a chassis, as the ISC currently has 3 functional robots: a 2-wheel-drive lawn mower robot, a 2-wheel-drive general purpose robot, and a recently built 4-wheel-drive snowplow. The team decided to use the lawn mower robot, and retrofit it for the competition and payload based on its lightweight design and the lack of modifications that would need to be made for the multiple sensors. This decision was highly influenced by the fact that there are no current mechanical engineer team members, and any mechanical knowledge received is purely through consultation.

3.1 Chassis

The robot was originally designed to be a four wheeled vehicle with two drive motors in the rear. It is from this design that the chassis was built. The primary concerns when designing the robot was its simplicity and low cost, which affected what types of materials were considered from the chassis. Aluminum tubing proved too expensive at the time and so less expensive tubular steel was used. When the chassis was built it was taken into consideration that future students might also utilize their work, and because of this the mower deck has the ability to be removed to allow for other applications of the robot, such as in the case of OHM. Figure 1 shows a computer drawing of the chassis.

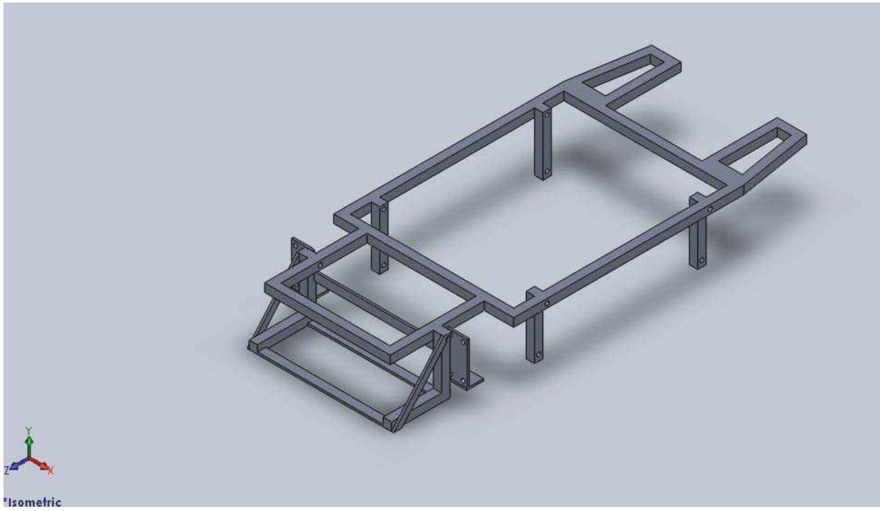


Figure 1- OHM Chassis

3.2 Dimensions

Feature	Dimensions/Mass
Chassis Width	0.763m
Chassis Length	1.17m
Chassis Height	1.01m
Motor Controller Platform	0.387m x 0.248m
GPS Platform	0.284m x 0.64m
Wheelbase	0.66m
Mower Deck Width	0.5m
Battery Weight	19.7kg
Overall Weight	98kg (215lbs)

3.3 Drive Chain

The robot is powered by two Invacare wheelchair motors. These motors are incredibly diverse and provide a lot of torque, which will be necessary to move the weight of the robot over the off-road terrain. Because of the conditions that OHM will be operating in the standard wheelchair wheels are not sufficient for the design and wider off-road wheels will be used which will provide more traction. The chassis for OHM has been tested to be able to go up a 10% slope, while cutting grass, at a 25% duty cycle.

3.4 Power

Two Optima yellow top batteries are wired in series to provide 24V DC power supply capable of providing 55Ah of power. These deep cycle batteries have a long life, are spill proof and recharge faster than a standard battery. Continuously running the motors at high speeds these batteries will provide 1.5 hours of run time, which will be necessary for testing and the competition.

3.5 Motor Control

The robot interfaces with a dual channel Roboteq motor controller to send speed commands to the motors through a serial connection. The robot utilizes differential steering to turn with 2 wheel drive with the motor on each side of the robot is connected to a separate channel output from the Roboteq. To produce values to send to the motors the x and y axis values of the desired control vector converted to Speed and Turn values. Equations (1) and (2) are used to calculate the left and right speed values to send to the motor controller. A gain is also applied to the resulting wheel speeds before they are sent to the motor controller.

$$\text{Left Speed} = (\text{Speed} + \text{Turn}) * \text{Desired Speed} \qquad (1)$$

$$\text{Right Speed} = (\text{Speed} - \text{Turn}) * \text{Desired Speed} \qquad (2)$$

4 Electrical Design

The electrical systems of OHM are designed to integrate the electrical sensors with the mechanical robot in a safe and efficient manner. The sensors run off of either 12 volts or 24 volts so that they can easily be powered from the robots batteries, such as the GPS and SICK Lidar. 5 volt sensors, such as the wheel encoders and camera, are powered from the computer via USB. The required laptop can also easily be powered off of the batteries by using a simple 12 volt car inverter. Anderson Powerpulls are used to easily make power connectors for all of the different devices.

4.1 Safety System

Safety is primary concern when designing these large, autonomous robots. Two emergency stops have been integrated into the electrical system using solenoids and relays so that the power to the motors of OHM can immediately be shut off in the case of an emergency. One emergency stop is located on the rear of the robot, while another is a remote stop that is effective at ranges greater than 50 meter. Below is a schematic of the power and safety systems.

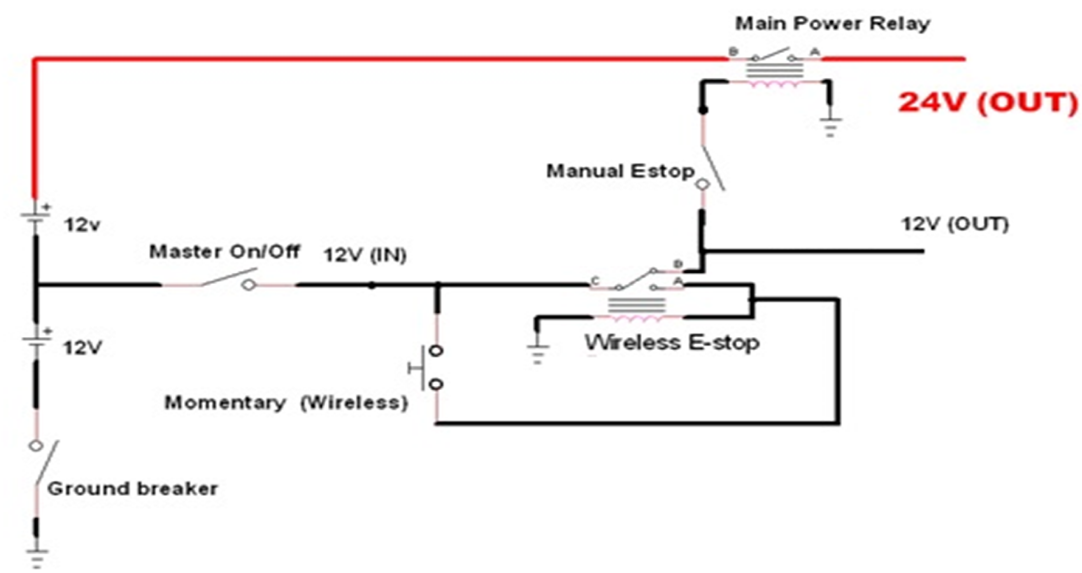


Figure 2 - OHM Power and Safety Circuit

4.2 Sensors and Communication

OHM will utilize multiple sensors in its design, each having their own purpose and communication specifications. Below is a list of all the sensors, their purpose, and the communication protocol that they require.

Device	**Purpose**	**Protocol**
GPS	Absolute Localization	Serial
Lidar	Object Avoidance, Relative Localization	TCP
Wheel Encoders	Speed Control	Serial
IMU	Heading	Serial
Camera	Lane Detection	Video Stream

4.3 Computer

OHM is operated using any laptop computer so that in the case of any emergency any computer can be used during the competition. This also allows for multiple parties to be independently developing software for OHM and avoids problems that can result when an on-board computer fails.

5 Intelligent Systems

Once the required electrical and mechanical systems are integrated and interfaced they must be used in coordination to create an intelligent system that is capable of autonomous navigation. The design requires that the robot must be able to navigate to specified latitude and longitude coordinates while staying between solid or dashed lanes and avoiding obstacles. Each of these design points must be tackled individually before they can integrate together.

5.1 Lane Following

For the lane following, a camera mounted above the vehicle will be used to capture images with the OpenCV library used to perform the image processing. After having attained the camera's point of view and calibrating the image to obtain relative positioning of objects in the image the lines representing the path's edges can be obtained. The canny algorithm functions as the edge detector. Then the Hough transform algorithm finds all the detected lines, which will further be utilized for the curve fitting to figure out the equations of the left line and right line of the lane. The target path line is in the middle of the side lines where a target point lies to guide the vehicle. In addition, a TSE (Total System Error) is introduced to judge if there exists an obvious lane and improve the vehicle’s performance.

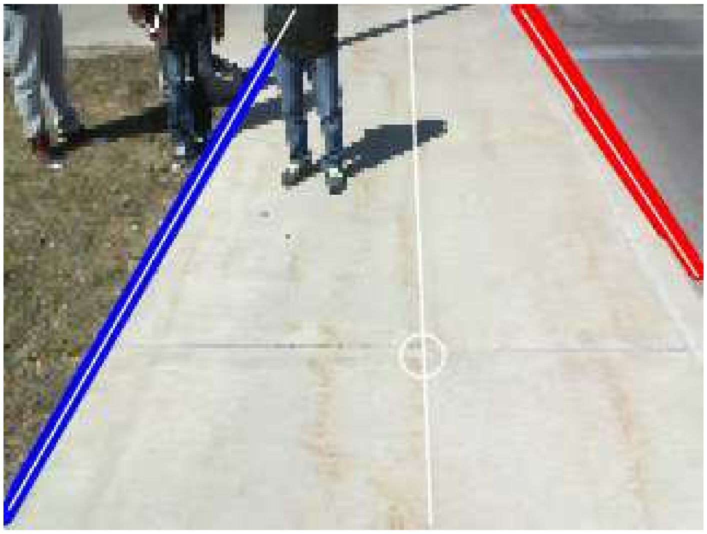


Figure 3 - OHM Lane Detection

5.2 Waypoints Navigation

The first step for waypoint navigation is to obtain the latitude and longitude data from the GPS using C programming language. The absolute location of the robot is obtained from the device in a standardized string format, and a library for parsing the nmeap sentence, which can be referred to in the convention of GPS (NMEA0183), is integrated so that data such as latitude and longitude can be obtained to locate the robot. Ultimately, with several waypoints to reach, the robot must also have the capability automatically update the waypoints after it passes each one. To travel to the specified waypoints, a least cost path planning algorithm is used to calculate optimum changes in heading. Position and heading will be calculated by combing successive GPS readings and Inertial Measurement Unit (IMU) readings, and then applying a Kalman Filter to reduce errors.

5.3 Obstacle Avoidance

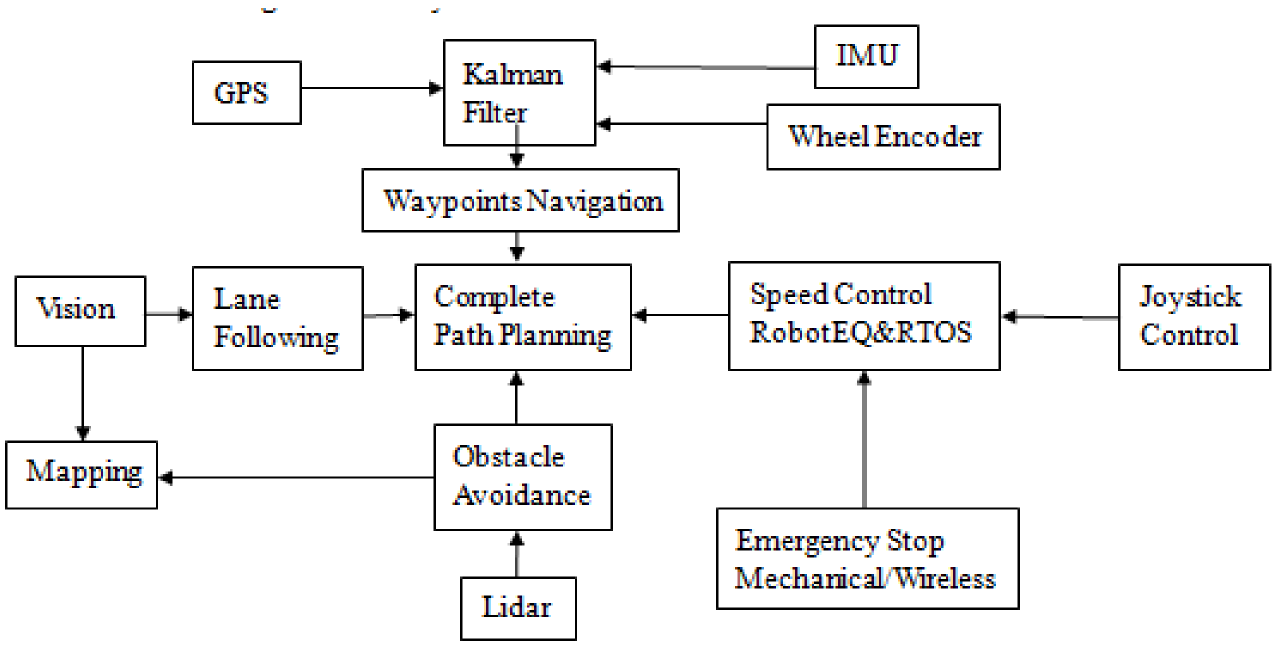
Obstacle avoidance is implemented using the SICK LMS Lidar, which is an electro-optical laser measurement system that electro-sensitively scans the perimeter of its surroundings in a plane with the aid of laser beams. The LMS measures its surroundings in two-dimensional polar coordinates. If a laser beam is incident on an object, the position is determined in the form of distance and direction. However, one object can give the LMS myriad data points. Therefore an object detection algorithm is necessary and consists of a state machine the scans the range data looking for groups of similar values and create a field to represent the object. Once an object is detected is placed on the map so that it can be avoided. As an added bonus once an object is placed on the map it can also be used to navigate the vehicle, as long OHM can see three known object. Navigation using the lidar is much more accurate than using the GPS, and may be relied on for precision maneuvers.

5.4 Mapping and Path Planning

OHM will take all of the information from the separate sensors and combine them into a single global map that will then be used to plan the desired path. This map will be implemented using image files and the OpenCV library. Each color channel will represent data from a different device, such as red being the lane obstacles from the camera, and green being the objects from the lidar. In doing this it will allow OHM to prioritize different obstacles, such as to say the the red lane obstacles are a higher priority than the barrels detected by the lidar. In order to keep OHM from travelling backwards an "Invisible Wall" will also be implemented. In this method a phantom obstacle is constantly placed behind the robot, so as to keep it from thinking that the best path is behind it, and keeping it constantly moving forward.

5.5 Integration

All of the information from the sensors are combined and then passed through a Kalman filter to reduce errors. A summary of the current block diagram is provided below.



6. Conclusion

The IGVC is a great learning opportunity, especially for undergraduates, and the team OHM is very excited to participate in this year's competition. While no members of the team have previous experience in this competition, the University of Michigan – Dearborn has had previous success and OHM looks to continue that tradition.

OHM will be implemented on a retrofitted lawn mower robot that should provide the traction and control needed for this competition. OHM will rely on three primary navigational sensors: GPS, Lidar, and Vision. The design philosophy of the team is simplicity.

Thank you for this opportunity.

7. Acknowledgments

All of the team members from OHM would like to thank our advisor, Dr. Nattu Natarajan, for all of the time and commitment that he has shown to club, and to the principle of teaching and sharing knowledge. Without his commitment, enthusiasm, knowledge, and experience the Intelligent Systems Club at the University of Michigan – Dearborn would not be able to participate in advanced competitions, such as the IGVC.