Intelligent Ground Vehicle Competition
2017 Design Report
United States Military Academy at West Point

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1. Introduction

1.1 Intro

The United States Military Academy at West Point has formed an interdisciplinary team of 5 cadets from the Electrical Engineering, Computer Science, and Information Technology majors to participate in the 2017 annual Intelligent Ground Vehicle Competition (IGVC). This years IGVC team will be representing the United States Military Academy at West Point with the Iggy. This model uses several pieces of sensory hardware over the modular Robot Operating System (ROS) interface in order to successfully navigate the IGVC obstacle course.

1.2 Design Process

All seniors in the West Point Department of Electrical Engineering and Computer Science Capstone Program use the Agile Development Process based on the Scrum Model. The requirements and constraints for this project are identical to those provided by www.igvc.org for the 2017 competition. Our project is funded by TARDEC, providing funding for our hardware budget, and supervised by the Electrical Engineering and Computer Science (EECS) faculty as USMA.

In August of 2016, our team began with the chassis that the 2013 team designed and built, and was modified significantly by the 2014 through 2016 teams. One of the major design obstacles faced was trying to learn a system that previous year teams designed and modified but did not properly document the changes or create how-to manuals. In addition to the lack of how-to documentation, there was also a lack of clear understanding which components were completely functioning, partly functioning, or were not functioning at all. The majority of the team took a significant amount of time learning how to properly interface with the robot.

Our contributions to the previous year’s project began primarily with implementation and integration of a better navigation and vision system, the team also discovered and worked on other solutions to the previous IGVC robot that would improve performance such as a battery monitor and a Gazebo simulation.

When designing Iggy the USMA team used the Agile Development Process from the Scrum Model[1], making use of Trello to plan out a series of Sprints with specific goals that would allow us to be ready to compete come June. Our team received its funding for this project from TARDEC. The design process was overseen by the Electrical Engineering and Computer Science departments, where instructors Major Larkin and Colonel Lowrance served as team advisors.

We began this process at the start of the 2016-2 academic year, working on the Iggy chassis which was designed and built by the 2013 design team. After determining that the physical design of Iggy was sufficient for success, we continued our work on important subsystems.

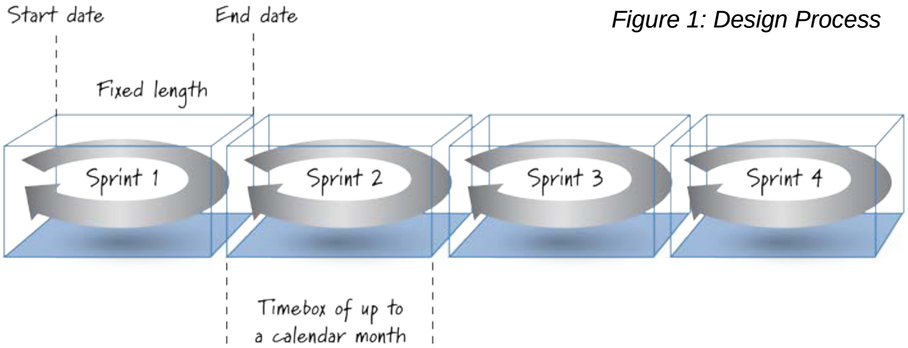

Figure 1: Design Process

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[1] Kenneth S. Rubin, “Essential Scrum: A Practical Guide to the Most Popular Agile Process,” Innolution, LLC., XX, 20XX

1.3 Design Overview

The 2016 West Point competition team vehicle met the mechanical design requirements for the competition (height, width, etc), our team decided to keep the vehicle design and focus on replacing minor internal hardware components and progressing the software components. The design relies on a simple acrylic glass design that supports internal components in a box with sensors mounted on a tower to provide maximum field of view. The entire vehicle is driven by two wheels and is powered by twelve military grade batteries (model: BB-2590) located on the undercarriage of the vehicle.

The auto-navigation concept relies on continuous map building through the ROS navigation stack.To create the majority of the map, the Velodyne H64 LiDAR provides a point-cloud that is passed into software to place obstacles onto a costmap. Additionally, a stereoscopic camera detects white lines that the vehicle cannot cross and flags that the vehicle must pass to the left or right of depending on the color. This creates a 2D map of locations that the robot can and cannot navigate. This costmap is later used for path planning when the robot is given a navigation goal.

To supplement the LiDARs data and provide dead-reckoning capabilities, the IMU (inertial measurement unit) provides linear and rotational acceleration information. Finally, the navigation grade GPS receiver provides an absolute position of the vehicle and a compass to determine heading, and help determine where the waypoints are on the map.

The output of the onboard sensors and their respective software suites are combined through the usage of SLAM (Simultaneous Localization and Mapping) algorithm. Through SLAM, Iggy creates and updates a continuous map of the environment as the vehicle moves in the environment. Maps are created temporarily and not stored after the ROS parent process dies. The navigation algorithm will use the map along with the current location and known GPS waypoints to determine the most appropriate path while avoiding obstacles on the map.

1.4 Team Organization

Our IGVC team is comprised of five undergraduate senior cadets from the Department of Electrical Engineering and Computer Science. We have two electrical engineers, CDT Michael Etnyre and CDT Bryce Grijalva-Hylbert. Additionally, our team has two computer scientists, CDT Zachary Royal and CDT Jacob Weiss. Finally, we have an information technology major, CDT Robert Jenkins. Our team satisfies the multi-disciplinary requirement of the competition.

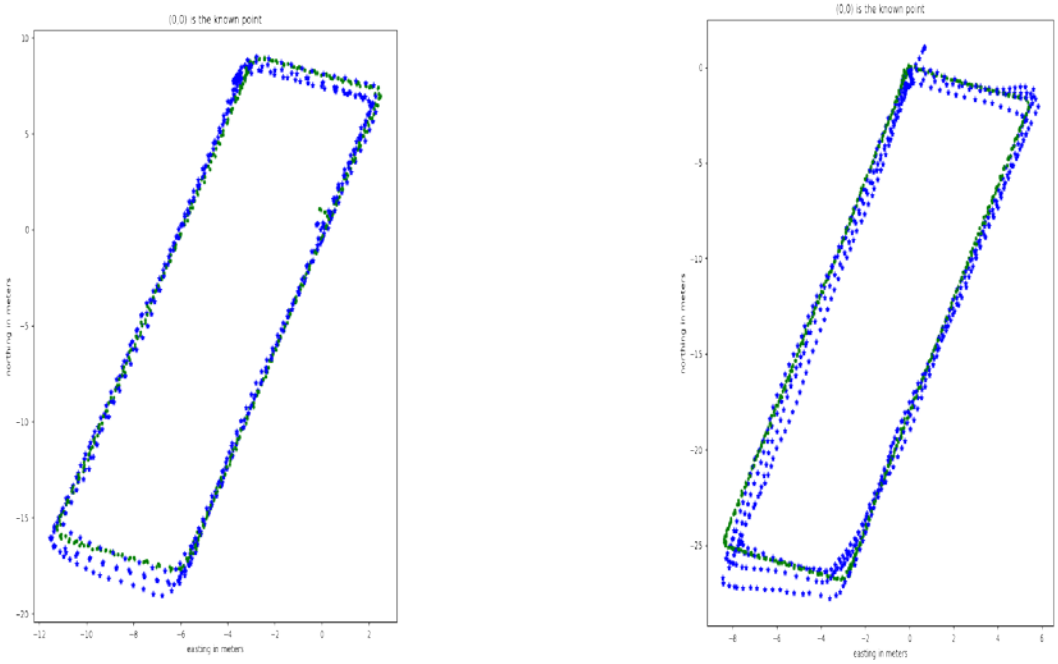
2. Effective innovations in your vehicle design

2.1 Innovative concept(s) from other vehicles designed into your vehicle

In this year’s competition, we have implemented many solutions that were used in previous years to solve issues. Last year the team came up with a solution to power the robot. The team last switched to 12 BB-2590 batteries to power the robot. We found this solution to be effective so we did not make any changes to the concept. The previous year's team also switched to a Velodyne 64 instead of a Velodyne 32. We felt like this solution was also a valid solution to our obstacle detection solution so we used the hardware but improved the code used to integrate the Velodyne 64 into our overall architecture. To navigate to different GPS points previous teams have made use of the CNS5000 GPS system. We felt as if this was an adequate solution and felt that we did not need to deviate from the system so we improved the code to make it more accurate.

2.2 Innovative technology applied to your vehicle

For this year’s competition, we decided to switch from the Bumblebee2 1394a camera to the ZED 2K Stereo Camera to implement our vision solution. The Change was made because of the superior design of the ZED camera. The ZED camera uses a USB 3.0 connection while the Bumblebee uses a firewire connection in order to interface with a computer system. The USB 3.0 is able to transfer data at 625 MB/s compared to the FireWire 1394a which has maximum data transfer rate of 400 MB/s. This additional transfer speed allows us process the point clouds at a faster rate in order to update our cost map making our robot overall faster in its decision making process. The Zed Camera also has a higher resolution at 2560 x 720 with a framerate of 60FPS while the bumblebee’s resolution is 648 x 488 with a frame rate 48 of FPS. This faster frame and higher resolution rate allows us to develop a more detailed point cloud at faster rate to make our cost map more accurate.



Pictured above is one of two GPS tests conducted between the CNS5000 and the xsens sensor. Both sensors were activated and driven on the same square path three times. As indicated by the graphic the CNS5000 (green dots) stayed consistent over a longer period of time than the xsens (blue stars) which is the main reason the CNS5000 was used on the vehicle instead of the xsens.

3. Description of mechanical design

3.1 Overview

The chassis and overall mechanical systems of our robot were left mostly intact following the group’s work in 2016. As an incoming project, we initially discussed the possibility/trade-offs of completely redesigning a new chassis, but we ultimately decided that we would continue with our robot as designed and built.

3.2 Decision on frame structure, housing, structure design

The chassis was constructed in stages to allow for incremental development and testing of other subsystems. Initially a metal plate was set on the wheel chair frame and the motor controllers where attached to allow for preliminary sensor data collection. Once the 80/20 aluminum extrusion was acquired, construction on the actual frame began. This allowed for other members of the team to test sensors and collect data from the actual machine. The final step was installation of remaining 80/20 sections. The chassis was dismantled in stages to install Plexiglas panels. These panels were then sealed with rubber gaskets to make the chassis water resistant. Two panels remain unmounted to enable easier positioning of components inside the chassis. They were left off for ease of access while additional work was done on the project.

3.3 Suspension

The design of our suspension subsystem was performed by a previous group. Their decision to utilize pneumatic shocks has been proven successful. The durability and effectiveness of their use reflects well upon their initial design and we have chosen to continue utilizing said design.

3.4 Weather Proofing

The chassis is water resistant and falls within the minimum and maximum dimensions for the competition. We have had to make small repairs in regards to the Plexiglas panels and the waterproof weather stripping, as they have suffered normal wear and tear over the years. Other than minor repairs, we are satisfied with

4. Description of electronic and power design

4.1 Overview

Our electronic and power design is largely the result of previous year’s work. However, testing and verification of all systems has been conducted by our current group in order to ensure the accuracy and quality of previous designs.

4.2 Power distribution system (capacity, max. run time, recharge rate, additional innovative concepts)

The robot operates remotely using a series of 320Wh battery pack on the undercarriage of the chassis. The power is routed using DIN rail high power wire, terminals and circuit breakers and each circuit breaker feeds into one component of hardware so that each component can be powered on or off independently from the rest. The circuit breakers also prevent damage to the hardware due to overload or short circuit.

The DIN rail is not necessarily new to this year's project. It was used in the past, but was removed last year. We quickly realized that adding or removing hardware devices to the vehicle was more difficult than it should be, and all devices of the robot had to be powered on or off together. This year, we decided to reinstall it to provide some key development and safety features. As a start, the DIN rail's modularity adds to the flexibility. Each hardware component has its own circuit breaker which enabled independent usage of each component. Additionally, the DIN rail allows for safe development of the vehicle. The DIN rail makes it easy to determine which devices are currently drawing power, thus when someone needs to disconnect a device, they can do so without electrocuting themselves or damaging any hardware. This enables our computer science team and electrical engineering team to work on the vehicle in parallel. The computer science majors can power on the motherboard and any necessary devices to develop the software suite, while the electrical engineers power down anything else they need to work on. Hence, the DIN rail prevented work interruptions and ensured the safety of anyone working on the vehicle.

4.3 Electronics suite description including CPU and sensors system integration/feedback concepts

The computer is based on a custom-built computer and serves as the nerve center of the vehicle. Previous teams determined that neither laptops nor pre-built computers could provide the features or performance required for this project for a reasonable price. This year we maintained the same computer hardware including: a Bulldozer core AMD FX-8350 CPU running on an ASUS M5A99FX motherboard equipped with 16GB of DDR3 RAM and an EVGA GTX-660 TI GPU. At the time of selection, the CPU provided the greatest multi-threaded performance.

The computer is connected to a wireless router that enables a remote desktop application to mirror the computer's operation onto an iPad or remote laptop. This allows wireless connection to the computer so that users can make adjustments on the fly or even remove the on-board monitor (to reduce weight and power consumption) and still be able to see what the computer is doing.

4.4 Safety devices and their integration into your system

The safety requirements of the navigation course implemented onto Iggy are the physical and remote emergency stops, speed limit max, and lights along the top of Iggy that indicate whether the robot is in autonomous or manual control mode. We also included an optional battery monitor that indicates the state of charge on Iggy's batteries, this acts as a secondary safety system when driving Iggy, if the vehicle is about to die from loss of battery power the user can take precautions to avoid damage to surroundings.

Integration of the emergency stops was done for the 2016 competition and is done through ROS. The physical emergency stop (red button on Iggy) works by sending an interrupt to the current mode running that stops the drive motors on the vehicle until the button is no longer pushed. The electronic emergency stop works in a similar way, when the user feels the vehicle is out of control he or she can switch Iggy into manual mode from autonomous mode to gain steering control of the drive wheels. The user also has the option to completely stop the vehicle by switching the toggle on the controller all the way in the up position which will immediately bring the vehicle to a stop in extreme emergency situations.

The battery monitor on Iggy is integrated using an Arduino Uno board with a shield featuring three different colored LEDs. The green, yellow, and red LEDs indicate the state of charge on the batteries inside Iggy. The Arduino board has pre-loaded code on it that lights up the correct LED with respect to the charge read from the batteries. The battery monitor is a significant improvement to the safety of the vehicle because it allows the user to mitigate risk when using Iggy. The battery monitor eliminates situations where Iggy would die from lack of battery power which could result in damage to surrounding environment or people.

5. Description of software strategy and mapping techniques

5.1 Overview

The main goal of our navigation was to be able to receive a series of GPS waypoints to traverse to in latitude and longitude and then go to them in order. We accomplished this by storing the GPS points' latitude, longitude, a predetermined amount of time for Iggy to spend trying to traverse to those points, and a tolerance in meters for how close it should get to the points. This file is then read by a python executable in order looking for each of the parameters. It publishes the first GPS waypoint as a goal to the action server in Iggy's odometry frame, and Iggy develops a path to the goal. Once it reaches the first goal, the executable will publish the next waypoint as a goal, and will continue this process until all goals have been navigated to. For orientation we chose to utilize a magnetic compass in the global frame to determine initial direction, and then orient off of the CNS5000's fiber optic gyro.

5.2 Obstacle avoidance and detection

Last year's code for obstacle avoidance was tested and implemented this year, however one major improvement was the tuning of the Velodyne sensor and improving the accuracy of our obstacle detection. This 'tuning' consisted of running many different calibration files and determining the minor changes that may have a beneficial impact on our Lidar. Additionally, we performed countless tests to identify and remediate a distortion problem that had developed last year. We determined that it was largely due to individual laser calibrations. One minor issue to be improved in the future is due to the size of our robot frame, getting too close to an obstacle can cause error.

5.3 Software Strategy and Planning

For the navigation software portion of Iggy, we chose to utilize the robot_localization package of the Robot Operating System (ROS) in conjunction with our GPS sensor. This package in conjunction with a series of transforms and python executables allows us to take the readings from our GPS, convert them into a robot-centric frame, and get the odometry that allows Iggy to recognize where it is in the world and how many meters it is moving in the x,y,and z coordinates. We created a python executable that can take a list of latitudes and longitudes in a .csv file and publish these points as goals to an action server that Iggy subscribes to.

5.4 Map Generation

Iggy utilizes sensor data to create a cost map, consisting of obstacles and white lines. White lines and obstacles are assigned high cost values. As it traverses the course Iggy uses dynamic mapping and odometry to build the cost map, which can be analyzed and improved upon during consecutive runs. Utilizing localization in conjunction with mapping allows Iggy to use the LiDAR sensor and White Line Detection algorithms to create a 3 Dimensional view of its surroundings. The 3D representation is constantly being updated with information from the IMU and GPS, so that when Iggy moves the locations of obstacles nearby are also being updated.

5.5 Goal Selection and Path Generation

White lines and obstacles are assigned high cost values, so when pathing the robot does not attempt to go through them, but goes around them. With 3D mapping in place, Iggy can calculate the shortest obstacle-free path to the next point. ROS is essential to pathing around obstacles, as we use its local planner for pathing in the map.

5.6 Additional creative concepts

By completely redesigning our vision system, we hope our creative solution will directly impact our success during the competition.

6. Description of failure modes, failure points and resolutions

6.1 Vehicle failure modes (software, mapping, etc) and resolutions

As part of our mapping failure mode, our software has been designed to enter into a ‘searching’ mode if it loses connection at any point. For example, if the robot were to lose GPS data, our strategy is to enter a searching mode. In this mode it will attempt to gain a better understanding of where it is in the world and what is around it by spinning slowly in place.

6.2 Vehicle failure points (electronic, electrical, mechanical, structural, etc) and resolutions

In order to prevent overall system failure, we have utilized our predecessor’s contributions on the DIN rail. This has truly helped us eliminate unwanted power issues and ultimately kept us safe throughout our work and testing. Additionally, we have identified that major problems result from the unexpected shock due to loss of power to the complete system. We have developed two resolutions to this. First, we added the capability to power our robot from wall AC, which eliminates problems resulting from battery charge. Additionally, we have developed a battery indicator that alerts us to low battery conditions. Both of these resolutions will surely facilitate our success.

6.3 All failure prevention strategy

Our entire vehicle has undergone testing for several years, and there have been varying degrees of failures and successes. Fortunately, our advisor has provided advice and hard-learned lessons so that we do not experience similar disasters.

6.4 Testing (mechanical, electronic, simulations, in lab, real world, etc.)

All mechanical, electronic, real world testing is conducted with safety in mind. It is imperative that we maintain vehicle and personnel safety throughout the design process but also at the competition.

6.5 Vehicle safety design concepts

Previous teams had identified a problem with the high center of mass for our vehicle. This often resulted in accidents where the vehicle would tip over, at huge risk to our Lidar. A resolution this year was to lower the Lidar and the center of mass respectively.

7. Simulations employed

7.1 Simulations in virtual environment

We created a virtual model of our robot to allow for rapid testing in our laboratory. We used a Gazebo 2.0 to create a world that emulated a mock course of the IGVC competition. The course featured white line, traffic cones, gps points, and red and blue flags. Our virtual robot emulated the dimensions, weight, driving transmission, and visual appearance of our physical robot. The robot used a differential drive to publish navigation goals to our ROS topic cmd_vel. The robot also features a virtual GPS system, Zed camera, and Velodyne 64. Our model uses a ROS launch file to employ the environment and the simulated robot.

7.2 Theoretical concepts in simulations

In the Future, the simulation will be used to test robot behavior. Our physical robot uses several code files that all modify the robot behavior. The simulation will enable us to make changes to the files and rabidly test them in a simulated environment. Another advantage of our simulation is the ability to control the environment in order to do more robust testing. With our simulated environment we have the ability to test the effects of environmental constraints like hills, different shades of color, and daylight for our robot. With this testing we can modify our code in order to make our robot operate effectively in different environments.

8. Performance Testing to Date

8.1 Component testing, system and subsystem testing, etc.

Our first semester of working on this capstone largely consisted of component familiarization and calibration. For example, the Velodyne Lidar is a complex component and the obstacle detection subsystem is very important to our success during the competition. As a result, it was critical that we developed an in-depth analysis of each component and that we developed a solid baseline to build our success.

In regards to the Velodyne Lidar, previous groups had varying degrees of success. While some groups have successfully utilized it to reach success, more recent years have fallen short of their objectives due to large amounts of distortion. As a result of our testing, we determined that these issues were largely due to calibration errors, and this facilitated our work from there on out.

One major set of subsystem tests we performed consisted of GPS navigation tests on an open grassy field. We plotted out a series of points using the data readings from our GPS sensor and marked each point on the field with a flag. We then ran trials attempting to traverse to each of these points, and tweaked our parameters to improve our accuracy in getting close to those points. This was extremely helpful as it helped us determine that when Iggy travels at max speed (5 mph) it will sometimes overshoot a point it’s traversing to. As a result, we lowered our speed cap. We also found that when given a very small tolerance Iggy wastes time trying to get too close to the exact GPS point, so we hardcoded in a tolerance of 1 meter, so as soon as it is within 1 meter of the goal it will automatically mark that goal as reached and begin traversing to the next goal. We chose to do these tests in a moderately grassy and bumpy field in order to test in an environment similar to the competition.

9. Initial Performance Assessments

9.1 How is your vehicle performing to date

IGVC at West Point has notoriously shown up to the competition with the best equipment, but we have been plagued with inexperience technical issues. This year, we have set ourselves up for success and will be arriving at the competition with a working robot. Very recently, we had a huge success while integrating our navigation subsystem with the rest of our robot. We hope to ride this success in testing as we continue preparing for success at the competition.

Our vehicle is performing our subcomponent tests with accurate results, but one main challenge has been testing these subcomponents in conjunction with one another. Currently as we prepare to enter the competition our main focus has been ensuring that these subcomponents work well together. One main issue we’ve had is with the amount of noise associated with obstacle and white line detection outdoors when integrated together. As we continue to prepare for the competition we are doing integration tests and attempting to improve the results of all components working in conjunction with one another.