IGVC Design Report - 2013

University of Calgary

I certify that the design and engineering of the vehicle by the current student team has been significant and equivalent to what might be awarded credit in a senior design course.

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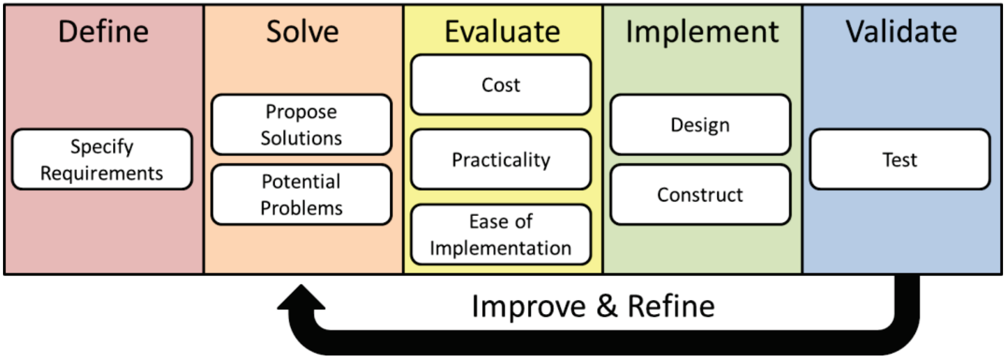
Introduction

Taurus (τ-RUS) is a four-wheeled autonomous ground vehicle utilizing a LIDAR, GPS, camera, and other sensors for information gathering and navigation. Taurus has been designed and developed to navigate autonomously through an obstacle course while staying within a set path and seeking GPS waypoints in order to compete in the Intelligent Ground Vehicle Competition (IGVC). Taurus has been designed and constructed by Team Taurus of the University of Calgary Robotics Club at the University of Calgary (UofC).

Design & Planning Process

In order to design and plan for the IGVC we first defined the requirements necessary for Taurus to compete and succeed in the competition. Based on these specific requirements, several solutions were proposed and analyzed for any potential problems each solution may have. Requirements and proposed solutions considered everything from drive system configuration, chassis design, sensors, and computation technologies. Each solution was then evaluated based on criteria that focused on completing Taurus for its first competition such as cost, practicality, and ease of implementation. Design and construction then commenced in order to implement the solution or modified solution that was selected. Each implementation whether hardware, software, or other was then tested in order to validate the success of the solution. Improvements and refinements to the solution and implementation were then made in order to address any new problems that unearthed during the development of each solution. This process was repeated several times until we were satisfied with the results. We estimate that approximately 500 man-hours have gone into the vehicle for the 2013 competition.

Figure 1 - Design Process



Team Organization

Team Member	Role	Academic Department	Class
Adam Medley	Administrative Lead	Business, Finance Major	2015
Andre Bexiga	President & Engineering Co-Chair	Engineering, Electrical	2013
Keith Wu	Business Co-Chair	Business	2014
Matt Angus	Software Lead	Computer Science	2015

Table 1 - Taurus Design Team Information

The design team working on Taurus throughout this past year was comprised entirely of undergraduate students. We decided to take advantage of the fact that we currently have a rather small team working towards the 2013 IGVC by implementing a synchronous type of team organizational structure which normally requires a small team size. This type of team structure allows for a high level of interaction, offers the freedom to explore new ideas, and encourages active participation from every team member. In this type of structure, the manager acts more like a facilitator than an autocrat.

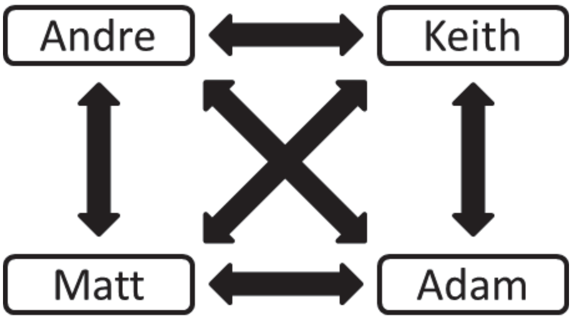


Figure 2 - Synchronous Team Structure

Decision-Making

In accordance with our synchronous team structure, decision-making responsibilities are shared within the group and it is encouraged to be open to new ideas and to explore them. However, when the best decision was not clear to our group, the president made the final decisions based on best judgement and practicality of the option with regards to the completion of Taurus and for competing in the IGVC.

Software Development

Most of the software for Taurus has been developed in MATLAB. Our team decided to code using MATLAB because of the ease of implementation and rapid prototyping ability. However, we understand that MATLAB is not the ideal language for robotics in the IGVC and we would like to translate all code from MATLAB to a more effective language in the future.

Through the design process discussed earlier, once a software solution was selected, it was broken down into smaller components. These small components were clearly defined and specified such that integration of these components was a seamless as possible. By breaking down software solutions into smaller coding tasks we were able to delegate different pieces of code to different members of the team for more effective software development. Similarly, larger sections of code and their requirements were clearly defined prior to actual coding in order to more effectively facilitate later integration.

Mapping Technique

A map is first produced using information gathered from the LIDAR and camera. Once this raw map has been constructed, several masks are applied in addition with GPS data in order to create a map representing the most desirable final position of the vehicle given the current available information regarding the surroundings. Based on this desirability map, the next waypoint is chosen for the vehicle to move towards.

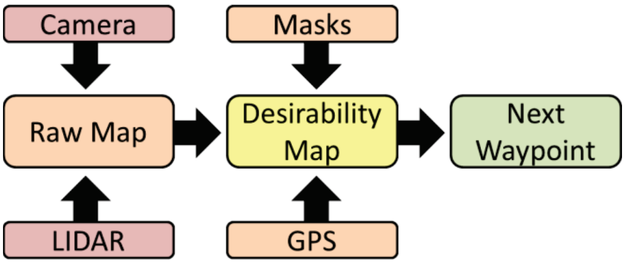


Figure 3 - Mapping Technique

The information from the LIDAR is used to create a 2-D map of the surrounding environment to aid in obstacle avoidance. This gives the vehicle localization data of nearby obstacles and free space. However, the LIDAR is unable to provide any information regarding paths or lanes painted on the ground or the color of any obstacle. The camera is used to obtain information regarding the lanes/paths, obstacles, and colors (for flags). By first transforming the image produced by a camera to a 'bird's eye view' perspective, we are able to overlay the camera data with the LIDAR data in order to create a local map of the surrounding area that provides information on free space, obstacle location, lanes or paths, and obstacle colors.

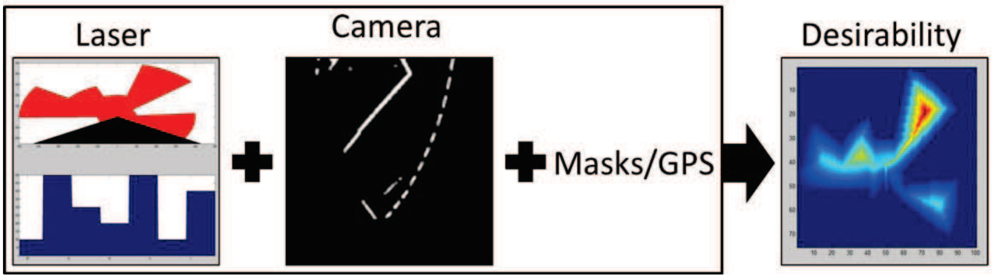


Figure 4 - Mapping Technique Visualizations

Once a raw map of the consolidated data is created, several data masks are applied in order to tune the data to properly accommodate the vehicle and its operating conditions. The masks are as follows:

- **Current Speed Mask** – A spearhead shape is masked onto the area surrounding the vehicle. The size of the spearhead grows with the current speed of the vehicle. If an obstacle is detected within this shape, the vehicle will stop and re-evaluate the surrounding area and plan a new path around any obstacles detected. The growing feature of the spearhead shape allows for more time for the vehicle to reach a full stop at higher speeds.
- **Vehicle Dimension Mask** – This mask creates an invisible barrier around every obstacle detected in the local area. This allows the vehicle to be simulated as a single point of zero-size within the software. The size of the invisible barrier is set in such a way that if the simulated point of the vehicle were to stay outside of the barrier there would be no chance of a collision with any obstacle.
- **Delay Compensation Mask** – This mask takes the current trajectory of the vehicle and transforms the local map to estimate the position in space the vehicle would occupy after any required computations. This mask compensates for any computational delay by simulating the future position of the vehicle based on estimates of current wheel speed and angular velocity.
- **Steadfast Selection Mask** – This mask gives a higher desirability to the area in the direction of the current heading of the vehicle, given that there may be two or more paths of similar desirability. This mask produces a tendency of the vehicle to continue on its current trajectory unless a much better option becomes available.
- **Ambition Mask** – This mask gives a higher desirability to areas further away from the vehicle. In the case that there are two or more areas of similar desirability, the vehicle will move towards the area that allows for a further progression of the vehicle.

Finally, higher desirability values are applied to areas in the direction of the next GPS waypoint.

Electronic Design

The electronic design consists of sensors, computers, actuators as well as two wireless controllers. The sensors are used to collect data regarding obstacle location, free space, lanes or paths, obstacle colors, vehicle location, wheel rotation, and vehicle orientation. Information is then sent to the computer for interpretation and use in navigation algorithms. The motor controllers control the motors according to the navigation system decisions. A wireless gamepad is used for manual control of the vehicle through the laptop and a wireless controller is used for activating the emergency stop which is completely independent of any computational systems onboard. The emergency stop will still work despite any possible hang in the software, systems crash, or power failure.

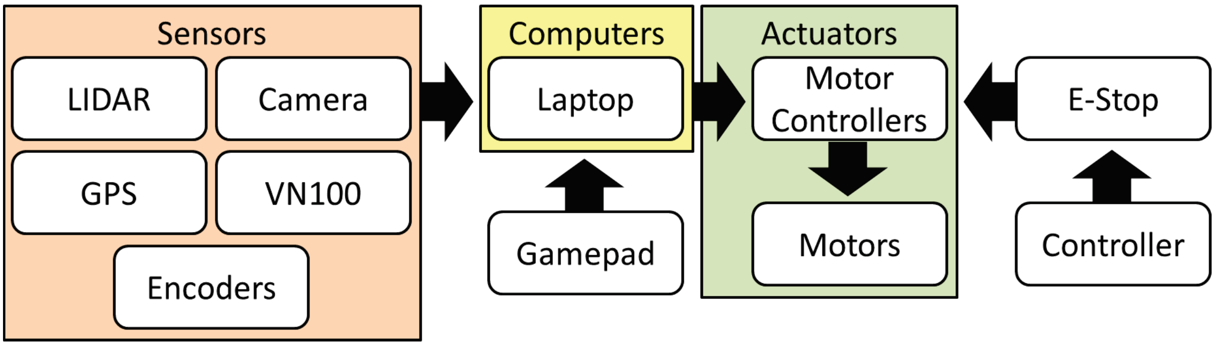


Figure 5 - Electronic Design

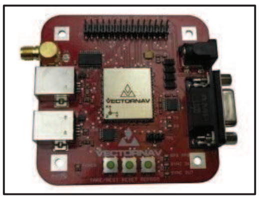
Electronics

- Sensors
    - **GPS** – A Hemisphere GPS is used to provide location data for current spatial location and waypoint locations as well as heading. Data from the GPS is used in the navigation system and for path planning.

    - **Camera** – A video camera is used to capture an image of the surrounding information for data regarding lanes/paths as well as obstacle locations and color. This data is used in the navigation system for mapping and path planning.

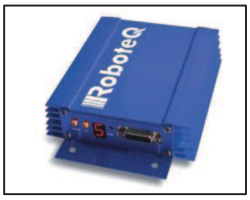
  - **LIDAR** – A Hokuyo laser scanner is used to provide information regarding the location and distance to obstacles in the surrounding area. The measurements from this sensor are used for mapping and path planning.

  - **Encoders** – Encoders are used with each motor in order to accurately provide data regarding the physical location of each wheel. This information can be used to provide distance as well as speed data and is used to accurately track the vehicles movement.
  - **VN100** – A VectorNav AHRS (Attitude Heading Reference System) is used to provide data regarding the pitch, yaw, and roll of the vehicle. This information is used to feed heading data to the navigation system.



- Actuators
  - **Motors** – Two NPC motors are used to propel the vehicle along its planned path. These motors receive commands directly from the motor controller.

  - **Motor Controllers** – Two RoboteQ motor controllers utilize a built-in PID control system to control the motors as well as provide data such as battery levels back to the computer. The motor controllers are themselves controlled directly by the computer on the vehicle.



- Computer
  - **Laptop** – An onboard HP laptop does all of the computation required for the vehicle. This includes receiving and interpreting data from all sensors, planning a path using the navigation system, and sending commands to the motors through the motor controller in order to follow and track the planned path.

- Other
  - **Gamepad** – A Logitech controller is used to provide user input to the navigational systems onboard the vehicle for manual user control.

  - **E-Stop/Controller** – An E-Stop activated through a Futaba radio control system provides a safe and reliable way to make the vehicle come to a complete stop.

  - **Batteries** – Several 12 volt batteries provide power to the entire system. There are separate power circuits for the motors, sensors, and E-stop.

Electrical System

There are separate power circuits in place to isolate motors from all other components. Additionally, the E-stop is powered by a power circuit independent of every other component. Three 12 volt batteries connected in parallel supply the power for the GPS and sensors via the laptop. These batteries also supplement the internal battery of the laptop. The radio control and E-stop system is powered by four AA batteries that are not connected to anything else in the system. Finally, two large 12 volt deep-cycle batteries are connected in series to provide 24 volts to power the motors.

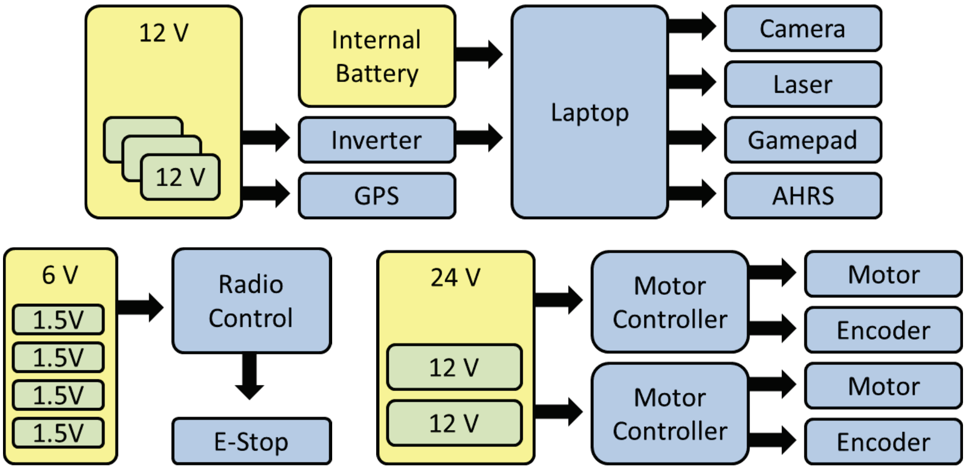


Figure 6 - Electrical System Power

Software Strategy

As discussed earlier, the first part of the software strategy is to create a map based on data from the laser, camera, and GPS. This map is then run through several masks in order to produce a custom desirability map. At this point, a most desirable waypoint is selected and set for the path-finding step. Using a modified A-Star (A*) search, a path is computed using the desirability map as localized weightings as well as the distance to the next waypoint and the distance from the current position. This path is then smoothed in order to create a more natural path for the vehicle to follow. Individual wheel paths are created through a projection to either side of this smooth line is done to calculate the exact distance each wheel must traverse. Using this distance, wheel velocity and travel time is computed. This data is set up as a series of instructions that is fed to the motors through the motor controller in order for the vehicle to physically follow the path that has been computed.

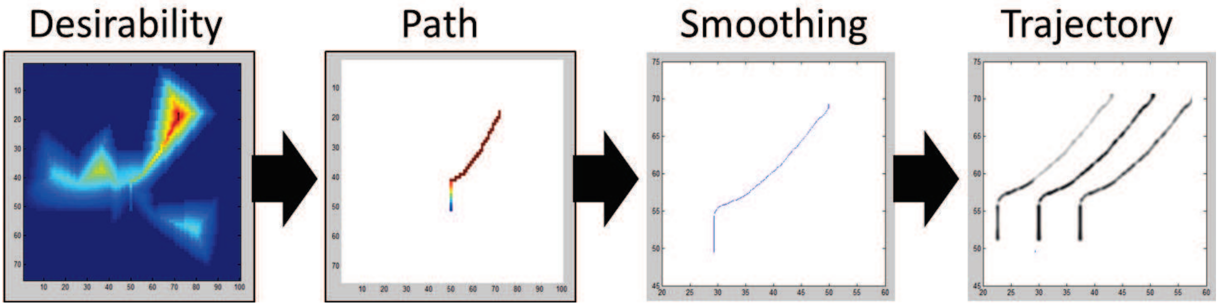


Figure 7 - Software Strategy

Plan for Path Following

As just discussed, once a path is created using the A* search the path is then smoothed and a projection is done to find individual wheel paths. At this point, there are still a few steps before the motors start to react to this data. The individual wheel paths are analyzed and split into several curved segments. A ratio is found based on a comparison between the curves each wheel traverses at any given time. A speed multiplier is compounded onto this ratio that allows the vehicle to follow the path at specified speeds. From these curve segments, the speed of each wheel and time for each wheel to turn at that speed is calculated and a set of instructions is generated and sent to the motor controllers to move the vehicle along the path.

Systems Integration

While discussing software development, it was mentioned that code was designed and produced with future integration in mind such that the integration of software systems was as seamless as possible. While most of the code was written in MATLAB, pieces of the software were also written in C. MATLAB allows MEX files to be created from C such that we are able to call subroutines written in C directly from MATLAB. Compatibility was heavily taken into consideration while procuring or designing hardware. Almost all hardware is able to communicate over USB (some components required a RS232 to USB converter) which simplified the integration of hardware systems.

Lane Following

The lane following system relies entirely on input from the camera and output to the motors and Motorcontroller. After an image has been taken of the current surroundings, it is run through a conversion that produces a bird's eye view of the previous image. This bird's eye view allows us to directly combine the data from the camera with the data from the laser. The image is then run through filters to identify dashed and continuous lines. Pixels identified as anything but grass will be considered a physical object or wall by the navigation system. At this point, the navigational system will deal with lanes/paths the same way it deals with physical obstacles detected by the LIDAR and will avoid going through any dashed or continuous lines. The spaces between dashed lines will be too small for the vehicle to consider any path through them a valid option.

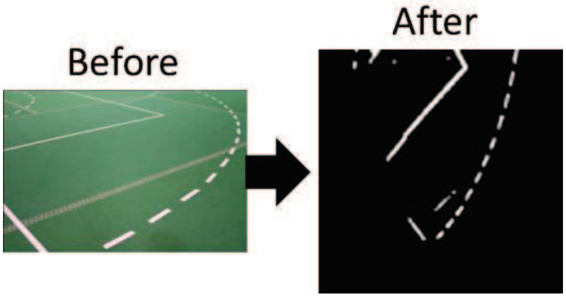


Figure 8 - Lane Detection

Obstacle Detection & Avoidance

The obstacle detection and avoidance system includes data input from vision and camera systems as well as output to the motors through the motor controllers. The laser produces a 270 degree sweep of the local area to provide data on obstacle location and distance to obstacle. The camera provides information on dashed and solid lines as well as flags. As the camera detects flags, the navigation system will create virtual walls and extend them outwards such that the only viable options are through the flags as appropriate. All this information is ultimately combined to form a map that provides data on the special locations that the vehicle is allowed to physically exist. Path planning and locomotion is planned and carried out with paths running through areas of the map that are furthest away from any obstacle or wall. Any path that runs the vehicle through an obstacle or wall is not valid and is not considered at all by the navigation system. Through this method, all planning and locomotion will avoid colliding with any object or running over any continuous or dashed line.

Waypoint Navigation

The waypoint navigation system relies on data input regarding current location and the location of the next waypoint. This information comes from the GPS. The direction to the next waypoint is given a high weighting in the consideration of path planning and the vehicle will ultimately end up at the next waypoint. Once the current location and next waypoint are within a specified threshold, the next waypoint is located and the process is repeated.

Materials

Cost Estimate & Breakdown

Component	Quantity	Unit Cost	Cost
Hokuyo URG-04LX-UG01 Scanning Laser Range Finder	1	$1,334.47	$1,334.47
Razor Dune Buggy Frame & Shock Absorber	1	$493.49	$493.49
Hemisphere Crescent A100 Smart Antenna GPS	1	$1,680.00	$1,680.00
Wheels & Mounting Hardware	2	$70.35	$140.70
NPC T64 Motor & Gearbox	2	$345.09	$690.19
RoboteQ AX2850 Motorcontroller	1	$704.14	$704.14
Solarbotics GM2/3/8/9 Wheel Watcher Kit Encoder	2	$107.44	$214.88
HP Laptop	1	$503.99	$503.99
OCZ Vertex 2e 60GB 2.5" SATA II Solid State Drive	1	$136.49	$136.49
VectorNav VN-100 Attitude and Heading Reference System	1	$892.96	$892.96
Logitech Gamepad	1	$0.00	$0.00
Misc. Electronics, Materials, & Hardware	1	$1,050.39	$1,050.39
Camera	1	$0.00	$0.00
Futaba Radio Control System	1	$78.75	$78.75
Optima YellowTop D34/78 12V Motor Batteries	2	$272.99	$545.98
12V Accessory Batteries	3	$47.25	$141.75
Caster Wheels	2	$0.00	$0.00
		TOTAL COST	**$8,608.17**

Table 2 - Breakdown of Cost by Component

Safety, Reliability, & Durability

Safety, Reliability, and Durability have been considered throughout the design and development of Taurus.

Safety

- E-Stop – A wireless emergency stop is installed on Taurus that is independent of any computation such that if the software were to hang, the wireless E-stop would remain fully functional.
- Kill-Switch – A large, visible, and accessible kill-switch is located on the rear of the Taurus to allow for a quick shut-down of the power-train system to bring the vehicle to a complete stop.

- Continuous Scanning – While following the planned path, the LIDAR is continuously scanning the surrounding area for unexpected objects. If an unexpected object is identified, Taurus will plan a new path around any new objects.

Reliability

- Isolated Power Systems – The power systems on the vehicle (sensors, motors, E-stop) are electrically isolated from each other to improve reliability of the systems. This makes the E-stop especially reliable as it is not affected by any other system error or failure.

Durability

- Frame – A frame was selected that would support the expected weight of the vehicle.
- Wheels – The wheels are not filled with air so they will not go flat or blow out.
- Shell – A shell provides a degree of water resistance to the vehicle such that it will be able to operate successfully through precipitation.

Expected Performance

- Speed – At the rated operation of the motors (230 rpm) and current tire diameter (10 in), Taurus' maximum speed is approximately 11 km/h (just under 7 mph).
- Ramp Climbing Ability – Taurus is capable of easily combing slopes of over 15 degrees.
- Reaction Times – The current reaction time of Taurus is 200 milliseconds. However, safety laser scans are run continuously in order to prevent any possible collision.
- Battery Life – The battery life of the robot lasts well over an hour.
- Obstacle Detection Distance – The LIDAR is able to detect obstacles within a 3 meter radius with 95% accuracy.
- Complex Obstacles
    - Switchbacks – The vehicle will take whatever option is available to it even if there is no option that is in the desired heading of the vehicle.
    - Center Islands – The path finding algorithm for the vehicle tries to maintain an equal distance between any objects. Additionally, one of the masks increases the

    tendency of the vehicle to stick with one option. The vehicle with pick one side of the center island to go through and will stay roughly in the middle of that path.
    - Dead Ends – If there is no option to move forward even though the GPS heading is ahead, the vehicle will take whatever option is available to it which includes doing a 180 degree turn and heading backwards to attempt another option.
    - Potholes – The vehicle will avoid detect potholes as obstacles and will avoid them in the same way as regular obstacles.
- Navigation Waypoint Arrival Accuracy – The GPS provides 50 centimeter accuracy 95% of the time.

Conclusion

Taurus is an autonomous intelligent ground vehicle capable of obstacle detection and avoidance as well as path following while seeking out GPS waypoints. Despite our design and planning process, we have been faced with large and varied amount of unexpected challenges. The experience in working towards the IGVC has been invaluable for all members of our team. Team Taurus is excited to have to opportunity to compete in this year’s IGVC.

Acknowledgements

Team Taurus and the University of Calgary Robotics Club would like to take this opportunity to thank the people and organizations that have supported us throughout this experience. We would first like to thank Dr. Macnab for his enthusiasm and support for our project as well as for being our faculty advisor. Thanks to the University of Calgary and the Schulich School of Engineering for their generous funding and work space provisions. Thanks to Chris Simon for his invaluable support and guidance. Thanks to our sponsors, CDL Systems and Mentor Engineering, for their gracious donations. Finally, thanks to our past members for their hard work and contributions. This project would not have been possible without your support.