IGVC2016-CAPRA7

CAPRA7

École de Technologie Supérieure

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I certify that the engineering design in 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

Capra is a student scientific club that has as its main goal the design and mounting of autonomous outdoor ground vehicles. The club was founded in 1999 by a group of ETS students who were passionate about the world of robotics. The team consists of engineering students from various different Bachelors degrees whom received no help from any of the professors or research professionals, meaning the club is entirely directed by its members.

Members work entirely voluntarily, totaling to hundreds of hours without receiving any additions credits or compensations. Members are motivated entirely by their passion to learn more by doing, and together presenting a product they are proud of.

As with previous years, Capra has yet again refined its software development process, based on the Test-Driven Development cycle (TDD) together with the DMAIC Improvement cycle (Define, Measure, Analyze, Improve, and Control). During our design process a small group studied the various concepts, and choices were made democratically with the complete Capra organization as to how to proceed.

Since last year, there was major mitigation of failure points as well as an overall improvement in reliability of the overall robot. The results evaluated come from the sum of the test scores, with specific scores being weighted according to short-term and long-term objectives. One month before IGVC, Capra7 was able to complete the real world basic course, and roughly half of the real world advanced course.

Organization

Capra is entirely administered and operated by engineering and students of various fields. Over the course of the years, Capra has developed and expertise in the conception and fabrication of autonomous vehicles, and well-defined procedures to optimize team efficiency and performance during competitions and official events. The team is lead by two captains, each responsible for administration, management, and project management. This allows the club to simultaneously advance on projects on the vehicle, seek out sponsorship, and coordinated with partners and suppliers.

Figure 1. Team Organization

Projects are not imposed on the members; instead they are encouraged to take on projects they feel they are best suited for. Each department has their own Google Group to discuss subject matter concerning their projects, for example the students working on the design would be able to converse on their own private Google Group before showing their plans to the entire club. GitHub is used specifically to centralize software resources, while Google Drive acts similarly for technical documentation. Trello, and online project management platform, helps in managing tasks and assignments showing all members which tasks are of the highest priorities, as well as has currently taken on the task. Capra has its own Slack Team allowing for more immediate communications between members while they are working on tasks. For new members, all relevant information is conveniently gathered in a private Wiki, this serves as the knowledge base. This Wiki is continuously updated with technical documentation, tutorials, and notes on team and robot performance. This data is used to carry over knowledge, and improve team organization by guiding decisions in following years.

During departmental meetings, members discuss different feasible solutions for problems that have arisen. Each solution is then evaluated individually and the members express their doubts and concerns to then be reviewed point by point, the pros and cons, of the presented solutions. Following the discussion, decisions are taken democratically within the department to then be presented to the membership as a whole. Each department presents their decisions during the general meetings, which are meetings of the entire membership to discuss problems arising within projects and solutions found to be implemented to ensure that everybody is aware of the decisions taken by each department and the impact of said decisions on the overall product.

Design Process

Capra has been continuously using the DMAIC improvement cycle (Define, Measure, Analyze, Improve, and Control) to guide the innovations of the vehicle. The cycle restarts following all tests we perform; new objectives are defined, new measures are compiled, among other things. During the design process, the software department defines their needs as they relate to the designed function, they present alternative measures that can be taken and ultimately the final decision is made by the membership altogether. Capra applies the DMAIC in the following way.

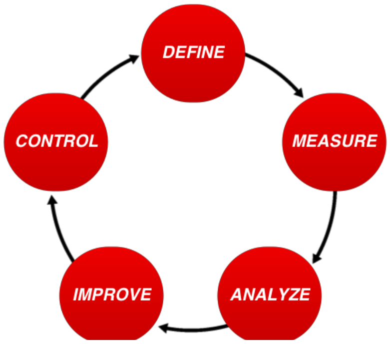


Figure 2. DMAIC Cycle

Design

The first step of any design process is to define the needs to be fulfilled. Since the team participated in the 23rd edition of IGVC last year with a new robot, Capra6.2, the assessed needs and possibilities of improvement for Capra7 were clear. Specific objectives were defined by these needs to guide the team's work. Outlined below are examples of some of the global objectives within different DMAIC cycles of the same project, they have been organized into three distinct categories:

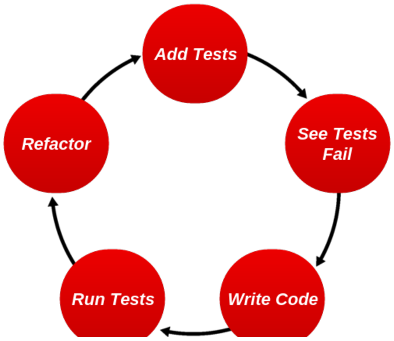


Figure 3. Test Drive Development Cycle

Reliability

- Define the working scope of the design process until the next IGVC involving 70% software and 30% hardware.
- Use a methodology of test driven development (TDD) based on experiences and data collected in previous years. Document test cases to ensure transmission of knowledge and repetition of tests.
- Collect new data each weekend in new environments, similar to IGVC conditions, from March to June.
- Use all collected data to conduct more precise tests.
- Replicate the basic and advanced routes of the simulation environment as accurately as possible.
- Establish guidelines and priorities to conduct the most relevant tests based on a predefined timeline.

Durability

- Reuse the vehicle's recordings as much as possible to avoid using the vehicle and causing wear on the hardware.
- Eliminate structural weaknesses.
- Conduct a complete check of the vehicle after every second exterior test.
- Clean the vehicle after each test.

Safety

- Define a procedure for diagnosis of the problems on the vehicle to avoid all risk of injury.
- Facilitate access for maintenance.
- A risk awareness session is given to each new member of the team and is mandatory before having the ability to take on projects.

Measure

Over the past year, the team has recorded measures, results, and statistical data of the vehicle's performance. Methods to analyze the performances based on different aspects of the vehicle's capabilities were already in place. The software advancements measure is based on the TDD principle. Last year, the team established scoreboards for components and route simulations, based on the complexity, time of implementation, and importance of the task for the realizations of the team's objectives. Experience acquired throughout the year allowed the team to review and update scores based on critical criteria of the components. The recalculated results were used to better define the objectives for this year. Long-term, this measurement step will be used to improve team processes continuously and systematically, an approach compatible with the norm ISO 9001.

Those who organize the tests have to update the documentation with the level of completion after each test. A completion of 1 (100%) represents a finished task. The total score of the project is calculated by adding the results of the following formulas; the underline…

Improve

This is where changes were initiated. The team leaders encourage their respective team members to be proactive and produce solutions leading to better results. Experience members teach the newer members and help then to find and focus on the simplest form to a complex problem. We found this year that the supervision offered by both DMAIC and TSS is making less experienced members feel more comfortable and more productive from the beginning. Several smaller goals will always be easier to achieve than a much larger one.

Control

Small teams test their respective improvements, control any changes, record their proper tests, and update their scores and they go.

Design Assumptions

Capra team have acquired solid expertise in the development of outdoor autonomous vehicles. Fundamental concepts from previous iterations have been brought into Capra7, based on successful experiences.

From the start, the team reviewed the IGVC rules to be assured to implement them in the development of a fully featured autonomous vehicle. Rules were integrated as requirements in the design of the vehicle without any feasible evaluation. It was also assumed that the vehicle will always progress in an environment between 14°F and 104°F, deemed to be the temperatures with which the electronic components and power distribution must be able to tolerate while operating, while not being equipped with heating or cooling systems. Based on past experiences, it was determined that a two motorized wheel vehicle was easier to maneuver and would reduce the error rate of encoders.

Effective Design Innovations

This year, the team focused on the development of innovative solutions to issues that have arisen during the last IGVC competition. Each problem identified during the previous competition resulted in at least one new strategy to resolve the issue, and have a more reliable performance.

Innovative Concept(s) from Other Vehicles

Waterproofing

In previous years it has been remarked that while testing at home is well and good, it is hard to be able to predict the weather on the day of the competition. Last year our vehicle was grossly unprepared for it to be raining and the team had to come together for a last minute mock-up of waterproofing.

This year the need for weatherproofing was clear and we decided to implement removable black waterproof canvas covering any critical openings to the inner workings of the vehicle. The fabric is attached to the robot, as needed using Velcro.

Figure 4. Stereoscopic Vision

Stereo-Vision and Obstacle Detection

Last year there were many problems in detecting certain obstacles, mostly those with reflective surfaces, including the cones and the ramp that seemed to confuse the vehicle. In order to solve the problems with the vision we integrated stereo vision to be able to detect depth and form of obstacles. This is fully integrated to the new vision architecture outlined above. There was also an improvement in the filters of the laser used in order to be able to detect when a surface is reflective, resulting in the vehicle not passing as close to the obstacles as it would previously.

Innovative Technology Applied to Capra7

Monitoring of Laptop Temperature and Charge

Our on board laptop is a critical component of the vehicle; it hosts the software architecture and controls the vehicle's path around obstacles and through the course in general. Last year the team experiences problems with abrupt shutdowns, a problem we had never encountered during our own tests. During following runs at the competition, high temperatures and low power warnings were monitored stringently. Unfortunately, extensive testing did not allow for identification as to whether the shutdowns were caused by loss of battery charge, overheating, or a combination of both factors.

One strategy to resolve this problem was to assist the on board computer by checking the temperature. A K-type thermocouple, connected in SPI to an Arduino, measures the temperature. During the upcoming competition the data retrieved from this unit will help to refine the cooling mechanism on board for future iterations. Two axial fans of dimension 172 x 155 mm assure a continuous airflow within the robot, thus cooling the laptop along with other electrical components found within the robot.

The second strategy employed is an auxiliary power source that was installed. A 500W inverter has been connected to the battery of the vehicle to create a constant and steady charge to the laptop, simultaneously optimizing performances throughout the run.

These measures were considered the best options considering the designed use of Capra7 along with the battery's capacity. The extra consumption on the battery should not hinder performances, thus being judged acceptable.

Vision Architecture Overhaul

The vision architecture put in place last year consumed too much memory and processing resources, this negatively affected the navigation performance of the vehicle. Problems were also encountered with the scalability, which limited optimization possibilities as well as the ability to add functionalities. Support of two cameras on the old system was equally impossible due to major impacts on performance rendering the effort moot. To this effect a brand new architecture, more open with better scalability, was developed similar to the previous model. Based on the previous iteration, the system has a base of filters used in independent transformations of the image across independent algorithms up to a point where the mapping system can exploit the result. The implementation of this system is integrated into ROS and completely modular, strongly parallel, and distributed. The considerable gain in performance was found to be pertinent to increase the efficiency of the system as a whole.

Course Management System

This year Capra has mounted a dynamic path finding management system. This system allows for the creation of a configuration file that defines the subsequent behavior of the robot on the course. This allows us to set the order of GPS waypoints on the course and assure that that the vehicle will attain each one using an efficient strategy. Each waypoint achieved results in a specific state of the vehicle, thus giving the ability to change parameters such as the speed, the cost map, as well as its navigation AI. In the end Capra7 is able to quickly define the most efficient course strategy without the need for supplemental code, resulting in a more flexible and adaptable system.

GPS Visualization Tool

As the vehicle progresses on the course it takes in GPS points and uses them as a tool to map a strategy, even those not listed as waypoints are noted and used as a reference as to where the vehicle is at any given time. These GPS points are in essence the map for all subsequent runs of the course allowing for the vehicle to be even more efficient on repeated passes of the same course. This mapping strategy allows for a larger tolerance of error and a map that is much easier to modify. The team customized a tool in order to more easily modify this style of map. This tool allows to upload all the GPS points the vehicle had passed and present them on a physical map, it is then easy to add, remove, extrapolate, and all manner of other modifications to optimize the map that the vehicle presents. This can then be exported as a configuration file usable by the course management system.

Ambient Light Detector

Capra6.2 had difficulty when the surroundings changed brightness, leading to erroneous lane detection, as well as approaching obstacles thinking they were much farther than reality. The previously required adjustment could only be done manually to the vehicle, thus requiring a full recalibration at any major light changes. Capra7 has an all new sensor that can detect minute changes in ambient light. This sensor allows the team to forgo the need to recalibrate between runs, as well as allows the vehicle to continue on its path by changing the exposure on the camera dynamically as it goes.

Mechanical Design

Overview

Capra 7 features a compact structure designed for mobility, and for the optimization of sensing its surroundings. The mechanical design is done using SolidWorks. Each idea, be it modifications or additions to the design, is discussed during the general meetings or on the team Slack in order to have input from all departments. Only a few members are tasked with the technical drawing of the vehicle during the conception phase, leaving the rest of the team time to concentrate on machining newly designed parts, or modifying parts that need to be redone.

Frame Structure, Housing, and Structure Design

Capra's frame consists of welded aluminum bars covered with folded aluminum plates. This material was selected for its low weight and relative robustness. The structure features three compartments for other vehicle components closed using a hinged cover, and one location for heavy object transportation. The electronic components are placed at the front of the robot; these components include the LIDAR. The GPS, wireless router, and all other components of this sort are located in the middle compartment under the antenna. The laptop is placed on the top compartment at the back of the robot with the cover open and help in place; this facilitates physical access for the software development team. The battery and the payload are located in the fourth compartment, near the ground to lower the center of gravity, improving stability and balance.

The mechanical structure provides support to electrical components and sensors, in order to optimize their performance and stability. As an example, the trapezoidal shape of the body was made in such a way so as to allow the LIDAR access to its full 270 degrees of range. The IMU is located near the center of gravity of the robot allowing for stable and representative measurements of the vehicle angle and acceleration.

Robot mobility is achieved with two SM23165D (motors?) from Animatics Corporation along with an SL1500 40:1 Gearbox from Parker, all located at the center of the robot in order to allow the robot to turn with a 0 degree turning radius. Only two engines in the center of the robot are used to avoid slipping on the grass when the robot turns; this kind of action reduces risk of error to the values of the encoders. Capra7 has two motorized wheels at the front, and two rear swivel wheels. The robot's body is as small as possible (37 inches long, 25.5 inches wide, the minimum dimensions permitted by IGVC), this facilitates maneuvering between closely places obstacles.

Figure 5. Hardware Conceptual Design

Suspension

The suspension system is made of four adjustable pneumatic shocks that are not directly fixed to the wheels, but instead installed on a suspension arm fixed to the wheels. This results in the vehicle being continuously dependable even where terrain is bumpy and uneven.

Cameras are supported by an auxiliary suspension system made of dampers; this consists of a piece of rubber enclosed by aluminum plates. This allows for a more stable imaging.

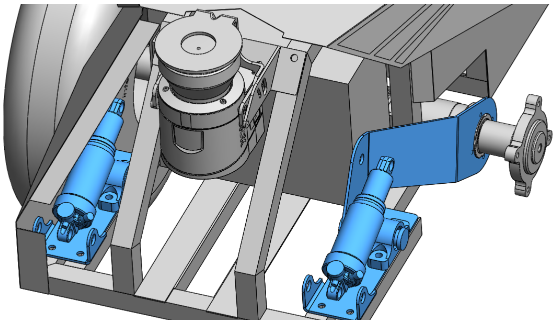


Figure 6. Suspension System

Weatherproofing

The Mechanical team opted for a modular and easy to install waterproofing solution. It consists of waterproof fabric being easily attached or detached from the existing frame to facilitate access in cases of maintenance.

Electronic Design

Overview

The electronic design has gone through many iterations to become a mature system supporting the vehicle's sensing and mobility, also providing an extremely reliable power distribution system. Data exchange components are united in the electronic box, which can be easily accessed for maintenance. The control panel features monitoring tools and switches to easily turn on and off the major electronic components as needed.

Power Distribution System

Our battery system consists of seventy-eight 4.2V 5Ah LiFePO4 cells from Amita Technologies Inc. of which every grouping of six cells are connected in series to form single batteries. Overall leading to there being a total of 13 batteries, each plugged in parallel for a total supply of 54.6V. The battery system was completely assembled by the Capra team.

The battery is directly connected to the electrical box; inside the power lines connect directly to the power supply, as well as the motors. The power supply has been designed by the Capra team and is based on the Vicor Corp micro DC-DC converter. The power supply produces different voltage rails to supply each sensor, generation 5Vdc, 9Vdc, 12Vdc, 19Vdc, and 24Vdc depending on the sensor being powered. Each rail is fused at the input and output.

The power supply is connected to the control panel through a power cable, and to the other PCBs through a mezzanine card connector. The control panel splits the power line to every sensor and actuator. The control panel allows the user to disable or enable any sensor or actuator individually, either through manual control using a switch or using software commands. A power-on LED indicates the state of each sensor and actuator.

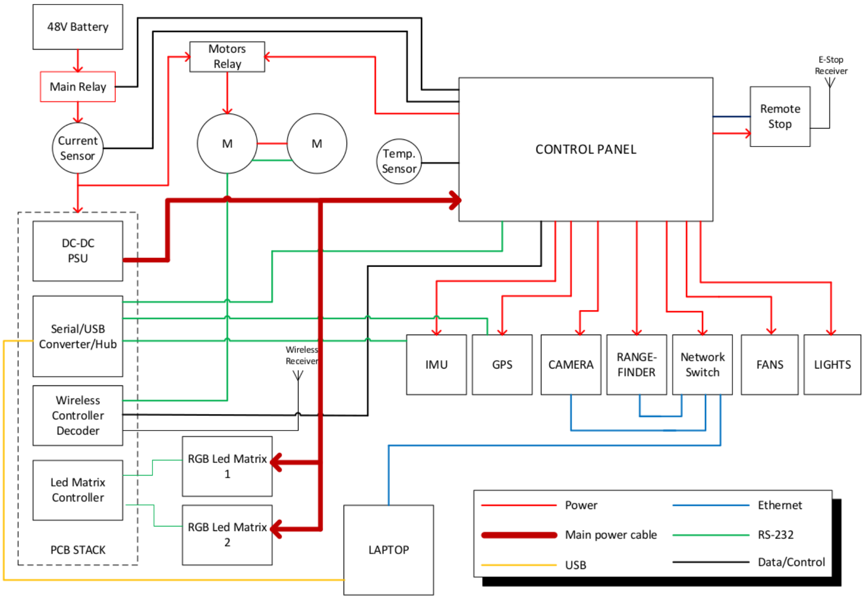


Figure 7. Electrical System

Electronics Suite Description

Control Panel

The control panel acts as the user entry point to the electrical system of Capra7. It provides manual and software accessed control for the power distribution. It also monitors information such as battery voltage, and the current serial port to the mezzanine card connector. Its internal temperature, problem indicator, consumption, and individual sensors states are shown using powered on LEDs. Finally, an ATC fuse (automotive model) for each power rail is present on the control panel.

This circuit board is a four layer PCD based on a PIC24FV32KA304 microcontroller; it has been completely produced by the Capra Team. The use of such a circuit considerably simplifies the maintenance of the vehicle as a result of the easy-connect configuration and the monitoring features. Each device has a unique connector that avoids any error that could arise from setup, and results in cleaner wiring.

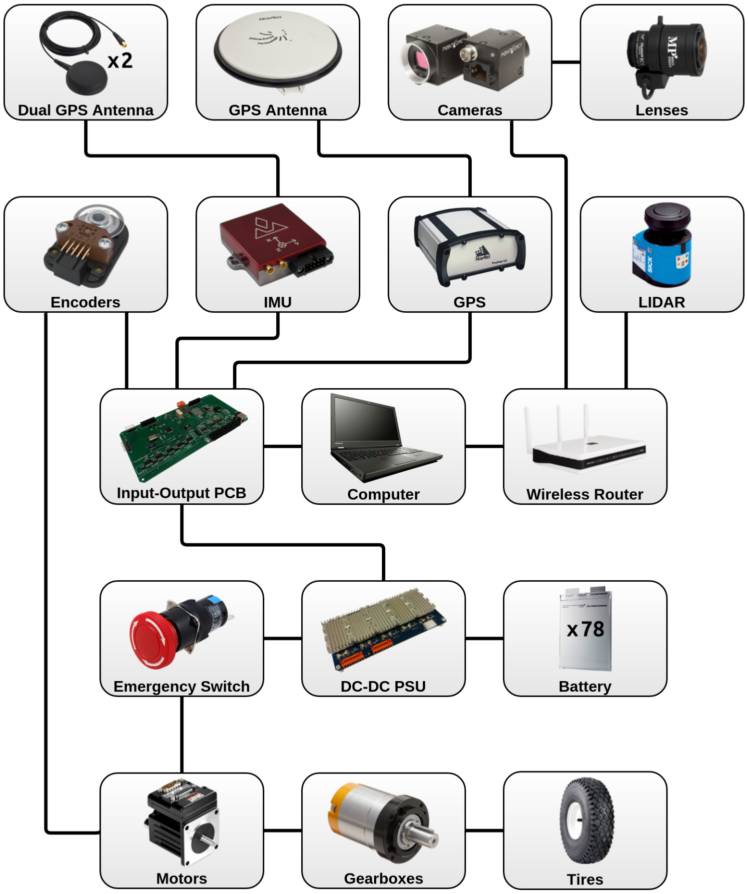


Figure 8. Components Overview

Input-Output PCB & DC-DC PSU

Capra's electrical team has designed a printed circuit board that allows easy scaling of the system. This circuit has two main safety related features: it provides five RS232 ports over one USB cable, and it allows an input-output PCB to take control over a RS232 line as a middleman.

Inertial Measurement Unit (IMU)

The VN300 from VectorNav Technologies uses a GPS antenna and an integrated Kalman filter to estimate the optimal positioning, velocity, and orientation. The use of the GPS allows for obtaining reliable measures without relying on the vehicle's dynamic or magnetic sensors. We chose this IMU for its reliability and durability. Measurements include readings from a 3-axis accelerometer, a 3-axis gyroscope, a 3-axis magnetometer, a barometer, and two 50-channel u-blox GPS L1 C/A GPS receivers.

Rotary Incremental Encoders with Index

Two 1000 CPR Optical Encoders from US Digital precisely measure the relative position and velocity of the two motorized wheels of the vehicle. These encoders are directly placed on the engine's shaft, in front of the gearboxes that have a 20:1 ratio, thus increasing their precision by a factor of 20. Each encoder has a precision error of 0.018 degrees corresponding to 0.0019 inches (0.048 mm) on the tires.

Global Positioning System (GPS)

One ProPak-V3 with a 702-GG antenna from NovAtel Inc. is placed in the center of the robot. The GPS sends 3.94-inch (100 mm) measures one hundred times per second with Omnistar HP. This device provides superior multi-path detection close to the antenna, and in high multi-path environments.

Computer

A W540 from Lenovo was chosen for its durability and reliability. We have one backup computer in case of failure or lack of charge. Software is constantly synchronized between the two computers. The computer specifications are illustrated in Figure **insert #**.

Light Detection and Ranging (LIDAR)

One LMS100 from SICK Group measuring at 270 degrees, with a precision of 1.77 inches (45 mm), at more than 59 feet (18 m), at 50 Hz. The measurements are taken between 1.64 and 65.62 feet (0.5 and 20 m) with an angular resolution of 0.5 degrees. Ultimately this LIDAR was chosen for its durability and reliability.

Luminosity Sensor

This year the vehicle has been equipped with a VL6180X expansion board mounted on a L053R8 board from Nucleo. The ambient light sensing ability fro the expansion board allows for detection up to 100K lux.

Camera Lenses

Two Blackfly 1.4 MP color with Fujinon YV2.8x2.8SA-SA2 lenses from Point Grey provide vision for the vehicle. It offers a resolution of 1296 x 1032 pixels at 60 frames per second. The lenses allow for instant, software driven, exposure correction. It is also possible to change the focus manually in order to test different strategies based on the depth and focus of the image. The Point Grey's cameras are an ideal replacement for the Manta G-095C from Allie Vision used in last year's IGVC as they cover a larger spectrum of colors, 25% more blue wavelengths, 22% more green wavelengths, and 2% less red wavelengths, these are optimal for line detection on grass.

Safety Devices & Integration

Capra7 features all the safety devices recommended by IGVC rules. The emergency switch is directly connected to the motors in order to allow an abrupt stop should there be an unforeseen obstacle in the path. The remote stop allows triggering the same abrupt stop without being directly next to the robot. The remote stop functions within a range of 100 feet of the vehicle.

Software Strategy

Overview

Capra's software architecture is built on the Robot Operating System (ROS). This system offers a reliable communications model between subsystems of the vehicle, an efficient distributed architecture, and an extensive set of debugging tools. Subsystems are implemented into nodes, which can be developed independently one from another and provide a perfect integration with the team's DMAIC processes. Every device in the system has its own set of nodes independent from each other. This makes the codebase modular and easier to maintain as each node does not have to know what the rest of the system does.

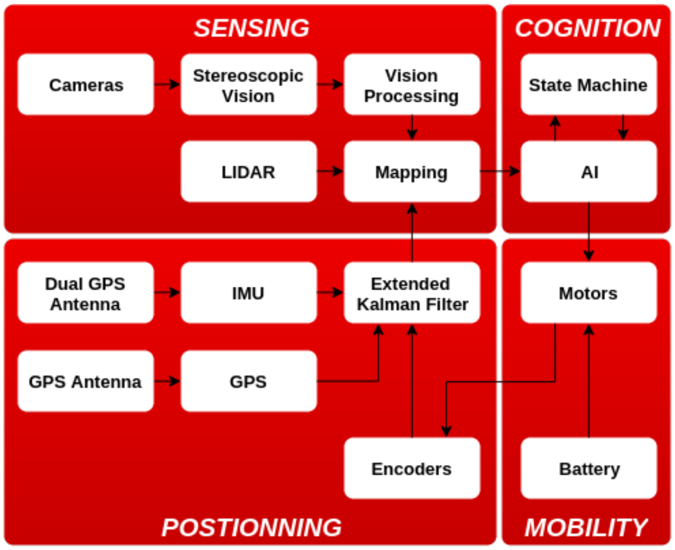


Figure 9. Software Design Overview

Obstacle Detection

Obstacles are detected with our Sick LMS100 LIDAR. The physical layout of the robot allows the sensor to detect obstacles within 270 degrees around the robot at 50 frames per second; with a precision of 0.5 degrees this is able to detect the poles of the flags of the auto-navigation challenge. The raw data is filtered to remove optical distortion and sent to the mapping subsystem. In order to add precision to the perception to the perception, the two camera images on Capra7 are combined to provide a depth of field map of surroundings using stereovision techniques. This allows the vehicle to more easily detect obstacles that can be difficult to perceive with the LIDAR such as reflective objects.

Lane and flag detection

To detect the lines and the flags, Capra vision architecture uses a set of filters based on OpenCV algorithms to perform the following actions:

- Resize the images to maximize performance
- Transform and align the images
- Apply a mask to hide the vehicle from the camera images
- Apply color filtering
- Detection of white lines
- Detection of flags
- Adjust perspective to adequately position the elements in the 3D environment
- Publish the images

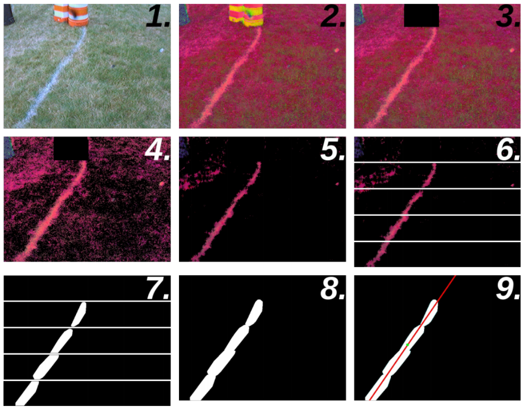


Figure 10. Image Processing

To detect the flags, we simply apply an HSV color threshold to the image since the colors of the flag (red and blue) have hue values that are quite different from the green grass.

The first step of the vision strategy is to convert the image in HSV; some obstacles are then removed using their typical orange colors to detect them. A filter removes the grass from the image using predefined hue parameters to output a binary black and white image. Some particle of grass may still be visible, so a particle filter is applied to remove the smallest bits.

The next step is to split the image in 5 rows. A convex hull is applied on each of these rows to make the detected grass areas bigger. Finally, the rows are put back together and a dilate function is applied to connect them.

This process allows Capra7 to accurately detect lines. The filter is calibrated automatically to adapt to lighting changes.

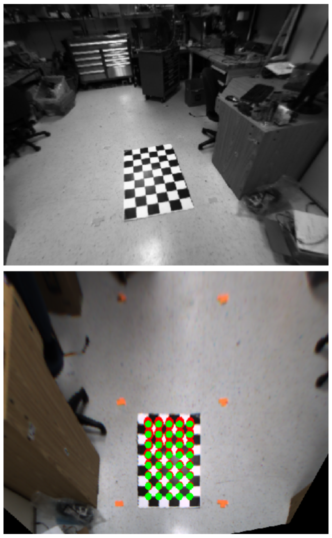


Figure 11. Visual Mapping Calibration

To position the various elements detected through an optical device in the vehicle's virtual environment, the team implemented a new calibration system. The idea was to design a system that would be simple to use and calibrate. A checkered board is placed at a specific distance in front of the robot (Figure 11), and is automatically detected. The perspective is then dynamically adjusted.

Mapping & Planning

Last year Capra6.2 introduced the 3D mapping library Octomap. Since then the vehicle wasn't using 3D sensors, the map used by the rest of the system only had one dimension. This year, Capra7 is bringing a whole new dimension to its mapping system due to the addition of the stereovision.

To navigate through its environment, Capra7 uses its sensors to create and accurate small-scale map of its surroundings. The map generation is based on the ROS package move-base is built with instantaneous data from the sensors and the persistence of this data is very low. Almost as soon as the sensors update, the map is refreshed to contain only the most current data. This allows the vehicle to plan a precise short-term plan meanwhile reliably avoiding obstacles using the current data.

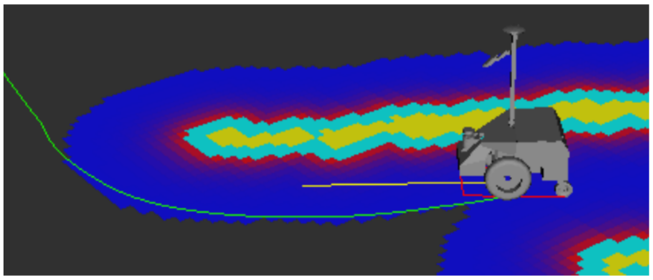


Figure 12. Path Planning

The disadvantage with the local map is that is does not take into account the position of the vehicle and is therefore useless for long-term use. This is why a second map, called the global map, is generated as the robot moves through its environment. The map is built by accounting for the current position and orientation of the vehicle as well as the currently detected obstacles and lines. Data is added to the map using the probabilistic model of Octomap; this model accounts for sensor noise and the map is dynamically resized as the vehicle explores its surroundings. The data structure allows the map to be stored and reused for later runs.

Both maps apply inflation to its input data; the inflation varies according to the type of obstacle, the type of the map, and follows a strict set of rules. By using this strategy, the vehicle plans its global path to avoid any obstacle or line, while simultaneously planning its local path by considering it can pass very close to lines. The difference between the lone and the physical obstacle inflations allows the robot to avoid obstacles at all cost while keeping close to the lines.

Failure Points, Modes, and Resolutions

Failure Modes & Resolutions

Due to previous experience at the IGVC competition, the team is aware of many failure points of the vehicle in terms of its software and some of the components that deliver data to our main laptop. In general encoders can easily be switched out for spares in the case of their malfunction.

Image Brightness & Focus

If the camera is to emit an image much too bright or too dark, our vehicle has a lot of difficulty differentiating obstacles, as well as the lines on the grass, due too colors being over or under exposed. Already, the ambient light detector outlined in the innovations above mostly solves this problem. To further fix this problem in case there is a problem with the new detector, the team can easily reconfigure camera settings to manually set an exposure, white balance, and color correction. In the case of an issue with the field of vision rather than the exposure, this is solely due to the focus on the lenses that can be manually changed.

GPS Points

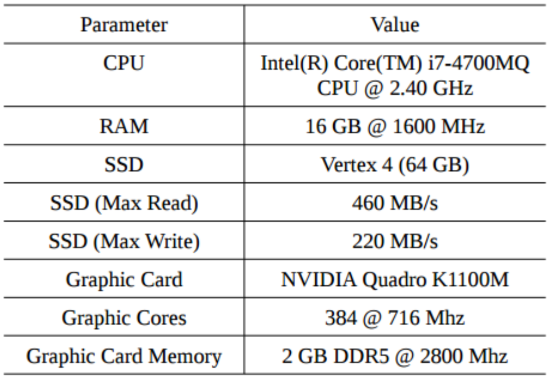
In times where the GPS seems to be lacking precision or accuracy, the connection to OmniSTAR can be verified quickly, following by its filtering of data, and its configuration. Should problems persist, filters can be adjusted, the configurations can be completely redone, and the data refresh rate can be lowered to pinpoint the problem. If all else fails, the team is equipped with a backup GPS in the case that the problem is hardware related.

IMU

In the case that the IMU emits erroneous data, all connections will be verified before moving on to verifications that the data is coherent. An investigation as to whether there are external interference sources will follow, and lastly the configurations can be reviewed. The filtering and the configuration can be adjusted in any case where the problem cannot be found, and a recalibration can be executed.

Laptop

There are multiple spares of the laptop powering our AI that can be used in case of problems. They are easily configurable, and have all the necessary software to direct the vehicle. Backup drives of a functional copy of the system are always kept on hand, and logs are kept to be able to check the root of problems stemming from the main programming. In the case of a lack of data being received, connections are double-checked and hardware is replaced to check if there is a failure of communication.



Parameter	Value
CPU	Intel(R) Core(TM) i7-4700MQ CPU @ 2.40 GHz
RAM	16 GB @ 1600 MHz
SSD	Vertex 4 (64 GB)
SSD (Max Read)	460 MB/s
SSD (Max Write)	220 MB/s
Graphic Card	NVIDIA Quadro K1100M
Graphic Cores	384 @ 716 Mhz
Graphic Card Memory	2 GB DDR5 @ 2800 Mhz

Figure 13. Computer Specifications

Failure Points & Resolutions

While the vehicle is sturdy and has proven itself rather resilient to damage, anything can happen in a competition setting. Thus the team has contingency plans should there be damage to the overall structure of the vehicle. Capra7 has at least one backup for each component, barring any that could not be ordered due to budgetary reasons.

Motors

Should a motor not be spinning, the logs are the first verifications step that the motors are in fact being supplied with power. Afterwards the communication between the motors and the laptop are to be checked for stability. Often a problem of this kind will be attempted to be replicated doing tests in order to find the exact issue and fix the problem, be it software or hardware. Capra is supplied with spare motors in the case that a change has to be made to the hardware.

Weather Proofing

There could be extenuating circumstances where the weatherproofing we have put in place proves to be less waterproof than expected. Unfortunately there can be no perfect environment to test this component, so instead extra material and Velcro is on hand in order to make quick patches to any areas that were not thought to lead directly to the core of the machine.

LIDAR

In the case that the LIDAR is constantly detecting obstacles, the line of sight will be checked for any components that may be directly interfering with the readings. After the position of the LIDAR will be checked to assure it is parallel to the ground.

Failure Prevention Strategy

In order to avoid the most likely damage stemming from transportation, strict procedures have been put in place. The vehicle rides strapped in its own trailer, that includes nothing that may shift into it and cause damage to the main structure during transport. All components are transported in their own proper cases and kept in a smaller space to again discourage any shifting during transport.

During maintenance, great care is taken in the handling of the lenses, the LIDAR, the IMU, and the Dual GPS Antenna. These are components too expensive to carry around spares. During the installation and removal of these components, the responsibility is assigned to the same team member in order to avoid any variance in their installation and removal. This also allows for less passing around of the components and less chance of them being misplaced.

Testing

To integrate with the TDD process described before, an exhaustive list of procedures is available to all team members. It was built quickly thanks to multiple outside tests that are very well documented. This tool allows for rapid diagnostics and problem solving, whether the problem is software-related or hardware-related. In addition, each component has its driver in the form of an ROS node. To make problem solving quicker during a failure, the diagnostic is made on these nodes.

Simulations

Virtual Environment Simulations

To test software strategies and analyze the decisions made apropos to Capra7, the team decided to use the ROS simulator, Gazebo, and configure it to accurately replicate sensor data perceived by the robot in a competition environment. Two complete courses were designed, one for the basic and one for the advanced challenge, and include lanes, obstacles, waypoints, potholes, and even alternating fence openings.

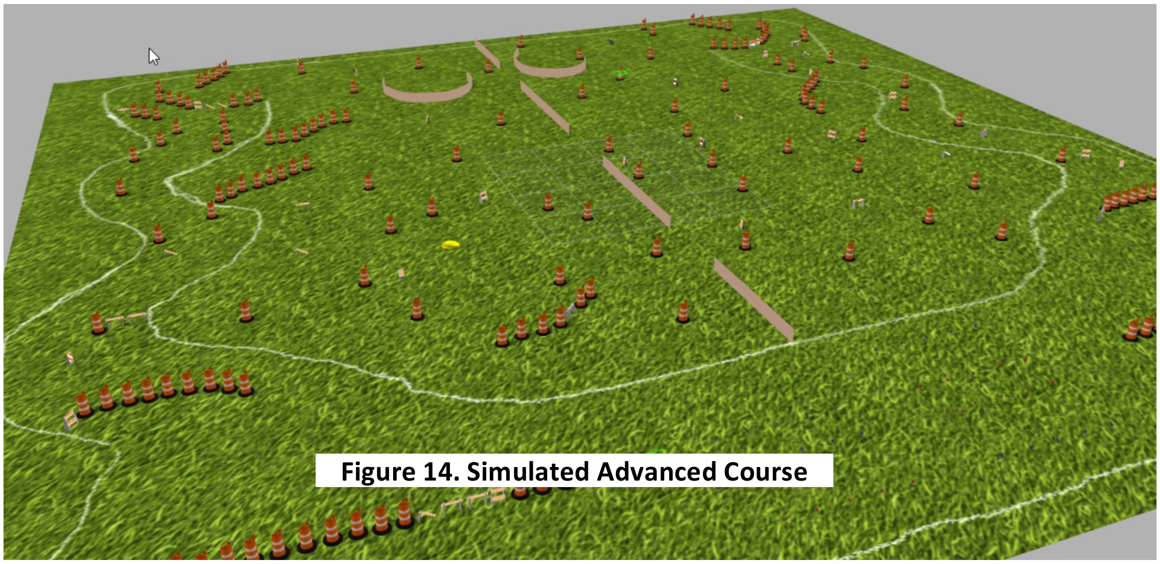


Figure 14. Simulated Advanced Course

Theoretical Concepts in Simulation

A random generator introduces a certain aspect of unforeseeable circumstances, such as a slight shift in GPS waypoints, encoders, colors, and any other noise that the vehicle could be exposed to on the outdoor course. The system is much more representative of the true experience of the competition.

Initial Performance Assessments

Performances to Date

Parameter	Theorical	Trial Data
Top speed	4.4 mph	~3.35 mph
Ramp vlimbing ability (15° slope)	3.8 mph	~2.79 mph
Reaction time	45 ms	~68 ms
Battery life	4 hrs	~4 hrs
Physical obstacles detection range	20m @ 270°	~20m @ 270°
Visual obstacles detection range	10m @ 120°	~10m @ 160°
Effectiveness in dealing with switchbacks	99%	~99%
Effectiveness in dealing with center islands	99%	~98%
Effectiveness in dealing with deadends	99%	~86%
Effectiveness in dealing with traps	99%	~95%
Effectiveness in dealing with potholes	95%	~83%

Figure 15. Overall System Performance