Ville Robotics AutoNav Design Report

Millersville University of Pennsylvania

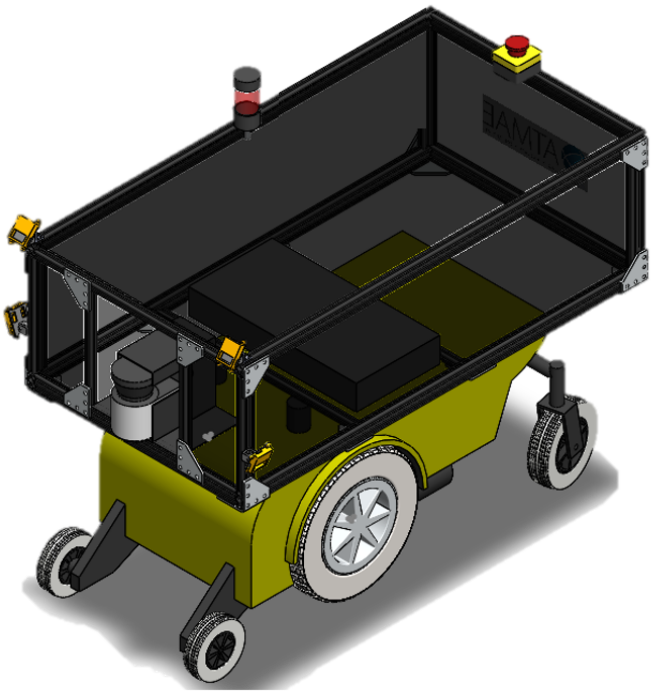

Figure 1 Autonomous LiDAR-Based Environment Navigator 2.0 3D Render

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Team Captain

Ian Troop | iptroop@millersville.edu

Faculty Advisor Names & Emails

John Wright Jr., Ph.D., CSTM, CLSSGB, GSCE, F.ATMAE | John.Wright@millersville.edu

John Haughery, Ph.D., CSCE | John.Haughery@millersville.edu

Team Member Names & Emails

Benjamin Ambler	bjambler@millersville.edu	Robert G Kiesel	rgkiesel@millersville.edu
Jerimiah Buck	jvbuck@millersville.edu	Elizabeth Maschke	ejmaschk@millersville.edu
Kevin Constantine	ktconsta@millersville.edu	Denis Nguyen	denguyen@millersville.edu
Evelyn Dais	evdais@millersville.edu	Ian Troop	iptroop@millersville.edu
Joshua Greineder	jmgreine@millersville.edu	Ermias A Wogari	eawogar1@millersville.edu
Daniel Haines	drhaines@millersville.edu	Benjamin Wright	brwrigh1@millersville.edu
Joseph Kaskel	jmkaskel@millersville.edu		

FACULTY ADVISOR NAME, STATEMENT & SIGNATURE

Dr. John Wright, Ph.D. | John.Wright@millersville.edu

Department of Applied Engineering, Safety, & Technology

I certify that the design and engineering of the A.Li.E.N. 2.0 robot has been undertaken by the team members listed above and that the efforts have met the demands of a senior level design course.

Signature:______________________________ Date: 5/14/2022

CONDUCT OF DESIGN PROCESS, TEAM IDENTIFICATION & TEAM ORGANIZATION

Introduction

This is Millersville University's 2nd year entering the annual Intelligent Ground Vehicle Competition (IGVC). To meet the demands of this challenge, we organized ourselves into three cardinal areas of research and development (R&D): Electrical, Mechanical, & Control. Our underlining objective was to adapt our A.Li.E.N. 1.0 robot design to meet the criteria and constraints of this year's challenge. We focused on improving our use of technology to complement a robust strategy of navigating the course autonomously while considering each other's perspective for effective problem solving. To execute this within the given time frame, we heavily relied on concurrent engineering.

Organization

Each area of R&D had a senior level student take lead on that domain of the project. The remaining students were then placed on each team by the faculty advisors based on their strengths and ability levels. Table 1 illustrates each team member's: name, academic standing, role, time contribution, and club position if applicable. Mechanical members produced models, CADD drawings, fixtures and incorporated the physical modifications to our robot. Electrical members generated power distribution schematics for all electronic systems and integrated power as needed. Members of the Controls team orchestrated algorithms and programmed sensors to automate A.Li.E.N. 2.0.

Table 1. Team Member Contribution Catalogue.

Name	Year	Mechanical	Electrical	Controls	Club Position or Role	Hours
Benjamin Ambler	Sr.		✓	✓	Project Coordinator & Controls Engineer	200 +
Jerimiah Buck	Fr.	✓	✓		Controls Engineer	50 +
Kevin Constantine	Sr.	Lead	✓		Sr. Manufacturing Engineer	150 +
Evelyn Dais	Sr.		✓	✓	Electrical Engineer	120 +
Josh Greineder	Soph.			✓	Public Relations & Sr. Controls Engineer	60 +
Daniel Haines	Jr.			✓	Sr. Controls Engineer	20 +
Joseph Kaskel	Grad	✓	✓	✓	Controls Engineer & Documentation Lead	200 +
Robert Kiesel	Sr.	✓	Lead	✓	Student Advisor & Sr. Electrical Engineer	200 +

Ryan Martin	Sr.				President & Controls Engineer	60 +
Elizabeth Maschke	Fr.	✓			Treasurer & Manufacturing Engineer	70 +
Dennis Nguyen	Fr.	✓			Secretary & Manufacturing Engineer	50 +
Ian Troop	Soph.	✓	✓	Lead	Project Lead & Sr Controls Engineer	200 +
Ermias Wogari	Jr.		✓	✓	Electrical Engineer	120 +
Benjamin Wright	Fr.	✓			Vice President & Manufacturing Engineer	150 +

Design Assumptions & Design Process

Our team followed the International Technology and Engineering Educators Association's (ITEEA) 12-step cyclical engineering design process to fabricate the systems of A.Li.E.N. 2.0, see figure 2.[1] Leading up to the preparation of the competition we were individually tasked with familiarizing ourselves with microcontrollers and various electronic sensors. Many of us employed Chris Odom's text to familiarize ourselves with a programing and robotics environment.[2,3] We undoubtedly ran into issues periodically, making troubleshooting a significant phase throughout the construction of this robot. Discovering and alleviating the underlying issues of each sub system led to new insights. This improved the robustness of the team and enhanced the design of A.Li.E.N. 2.0.

During the active R&D of this competition, our first objective was to define the criteria of this challenge as described by the official IGVC competition details and rules.[4] To be thorough, we distributed a quiz to test each team member's familiarity of the regulations. After this, we discussed a plan of action for our remaining time of the semester and set expectations as a group. We took inventory of our equipment and brainstormed well rounded ideas to solve this challenge. After choosing specific approaches that were guided by research, we set off to develop models, algorithms, and schematics and frequently documented our individual progress.

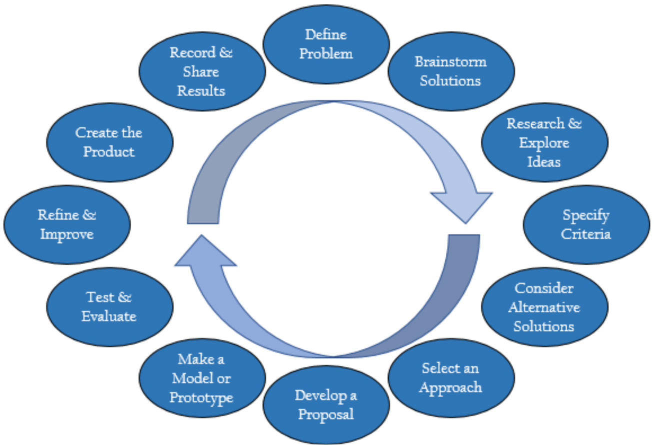

Figure 2. Engineering Design Process Graphic.

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[1] ITEEA 2017, Engineering Design Process Learning By Design. Vol 6.1

[2] Odom, C. D. 2020, Physical Computing & Robotics with the Arduino IDE, Vol. 1

[3] Odom, C. D. 2017, Physical Computing & Robotics with the Arduino Websites for MV

[4] IGVC Rules committee, "Official Competition Details, Rules, and Format"

EFFECTIVE INNOVATIONS IN VEHICLE DESIGN

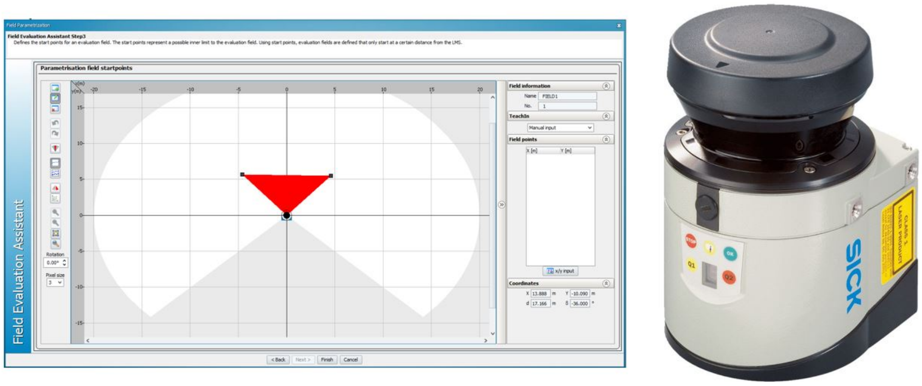
Distributed Control & Concurrent Engineering

While we have observed many distinguished entries from previous years utilizing Robot Operating System (ROS), we opted to pursue a distributed control system for this build. A.Li.E.N. 2.0 is based on obstacle avoidance and waypoint navigation. To achieve this, different process controllers were strategically placed on our robot to intake information from the surrounding environment. These standalone systems include: a SICK LiDAR system, two Open-MV H7 cameras for line detection, two additional H7 cameras for pothole detection, a GT-U7 GPS module system & GY-273 triple axis magnetometer for waypoint navigation, finally a Teensy 3.2 microcontroller for the main processor.

Due to the four-month time frame, we concentrated on maximizing productivity and testing time. With this modular setup, we were able to capitalize on concurrent engineering and avoid bottlenecking. We systematized ourselves into groups and incorporated these standalone systems into the robot as each individual unit was refined. Because our team, as a whole, was capable of researching and programing independently, individual groups were able to test their sensors before porting them over to the robot. This mitigated the volume of issues at a given moment and allowed us to reach milestones at a faster pace. After teams would integrate their system into the robot, they were able to contribute to other aspects of the build such as electrical integration or assisting with the manufacturing build.

LiDAR

To manage physical object detection, we used a SICK LMS111-10100 LiDAR. This unit uses laser imaging to identify objects within a specific range.[5] The system is programmed in the SOPAS Engineering tool. Figure 3 illustrates the LiDAR unit on the right and the user interface with a live simulated environment on the left. This software has multiple functions however, we primarily used it to program the fields of view. These fields dictate the distance in which the unit can detect an object in front of it. Two fields were setup, one on the left and the other on the right. In this way, either side will be protected during navigation at any given point. The LiDAR was programmed to send a high signal, interacting with the central Teensy microcontroller. This feedback would trigger a drive function to move A.Li.E.N. 2.0 away from the detected object(s).



Field Evaluation Assistant Step3

Defines the start points for an evaluation field. The start points represent a possible inner limit to the evaluation field. Using start points, evaluation fields are defined that only start at a certain distance from the LMS.

Name: FIELD1
No.: 1
TeachIn: Manual input
Rotation: 0.00°
Pixel size: 3
X 13.888 m Y -10.090 m
d 17.166 m δ -36.000 °

Figure 3. LiDAR User interface & Unit

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[5] SICK AG Germany 2019, LMS1xx Laser Measurement Sensors, SICK Sensor Intelligence

Light Bar

During the heavy testing period, around that last quarter of the semester, we opted to invest in a 26” Nilight LED lightbar. The utility of this lightbar was primarily to increase testing time during evening hours. The lightbar, as seen in Figure 4, was installed on the front of A.Li.E.N. 2.0.

Figure 4. Robot With Lightbar

Internal Storage and Battery Access

In order to provide simplistic maintenance, our housing structure hood is easily removable. We desired easy access to internal components so assembly or troubleshooting connections would be effortlessly executed. The team can lift off the top which creates a convenient space for reaching electrical elements which are clearly labeled. Beyond that, our batteries, which are stored underneath the frame, can be accessed by pivoting the frame upwards. The frame is fixed in place with two cotter pins for quick installation and removal. In order to charge the batteries, we wanted a straightforward entry point, void of obstructions.

DESCRIPTION OF MECHANICAL DESIGN

Overview

The mechanical design for A.Li.E.N. 2.0 builds upon the design from Millersville University’s 2019 IGVC robot, A.Li.E.N. 1.0. This revised rendition is based on a different wheelchair chassis requiring a new frame and shell to be built. Key improvements include weatherproofing, increased sensor utilization, and improved wire management.

Decision on Frame Structure, Housing, & Structure Design

Our frame is similar to the design from A.Li.E.N. 1.0. The frame is constructed out of 80/20 10-seris, T-slot aluminum extrusions. 4-slot, 1” x 1” extrusions were used to connect to the base’s trapeze bars, while 6-slot 1” x 2” extrusions were used to build the frame. The extra slot in the T bar was utilized to route wires between sensors, microcontrollers, and power. 10-series M5 fasteners and 12-hole right angle plates were used to connect the extrusions. 90-degree gussets were also used to mount the top pieces. The ¼” smoked polycarbonate was used to encase the robot and mount the internal electronics, light, and mechanical emergency stop button. The same polycarbonate sheet was used for the lift-off top, along with handled screw fasteners to make the top easily removable.

To increase sensor mobility, custom camera cases were made, see Figure 5. These cases had a hinge joint on the back, allowing for North-South pivoting camera adjustments. The hinge joint mounted directly to the 80/20 frame and allows for 360-degree rotational motion, expanding the camera angle customization or modification. Another addition to improve sensor functionality, was a LED light bar mounted underneath the front of the frame. Cable management was a problem in the A.Li.E.N. 1.0 design. To remedy this, 3/8" polyethylene spiral wire loom was used to consolidate smaller wires for easier routing between electronics.

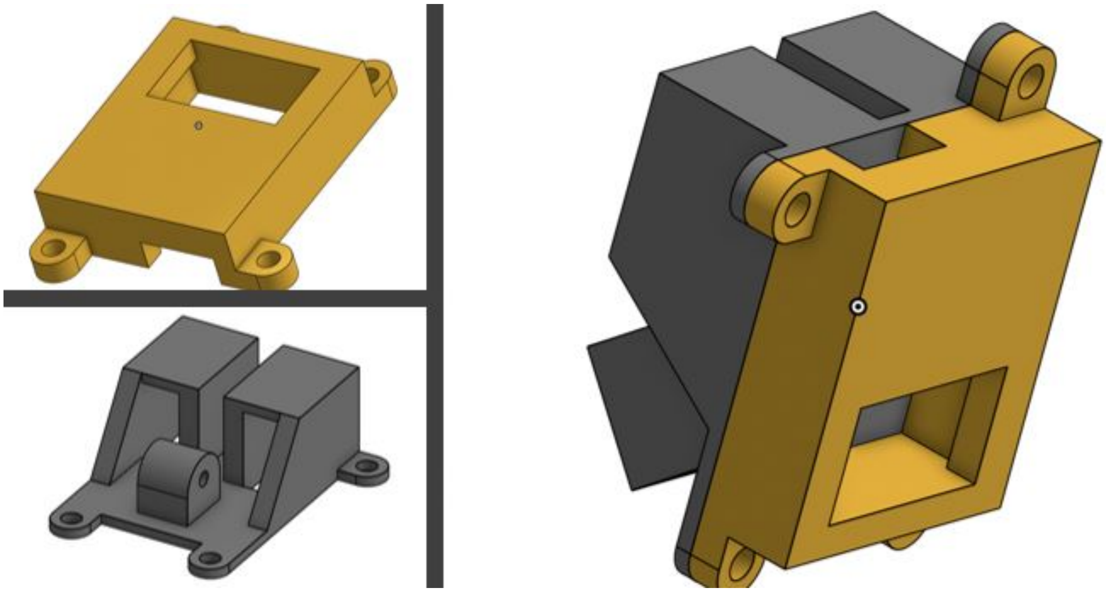

Figure 5. 3D Printed Machine Vision Camera Cases

Suspension

A.Li.E.N. 2.0 was built on the base of a donated electric wheelchair. This Jazzy model 1122 power wheelchair made by Pride Mobility features 14" pneumatic drive wheels, 8" solid articulating wheels in the rear, and 6" solid wheels in the front, refer to Figure 6. [6] It includes electronic regenerative disc parking brakes on both motors. In addition, there are disengagement levers in the front of the chair which allow for the uncoupling of drive motors from the wheels. The Jazzy 1122 has 3.25" of ground clearance, a turning radius of 21", and a carrying capacity of 340 lb after removing the chair.

The wheelchair chassis is driven by stepper motors and is equipped with Active-Trac Suspension (ATS) which links the front anti-tip wheels to the motors and drive wheels. When the anti-tip wheels encounter an obstacle, they are moved into an upward position and force the motors and drive wheels downwards. This assists the wheelchair to climb small obstacles. The ATS works in union with a coil spring rear suspension that moves the rear caster wheel forks

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[6] Pride Mobility Products Corp. 2006, Jazzy 1122 Owner's Manual, INFMANU1489

which respond to weight transfers. The frame was attached using the pre-existing trapeze bars that were used to mount the chair.

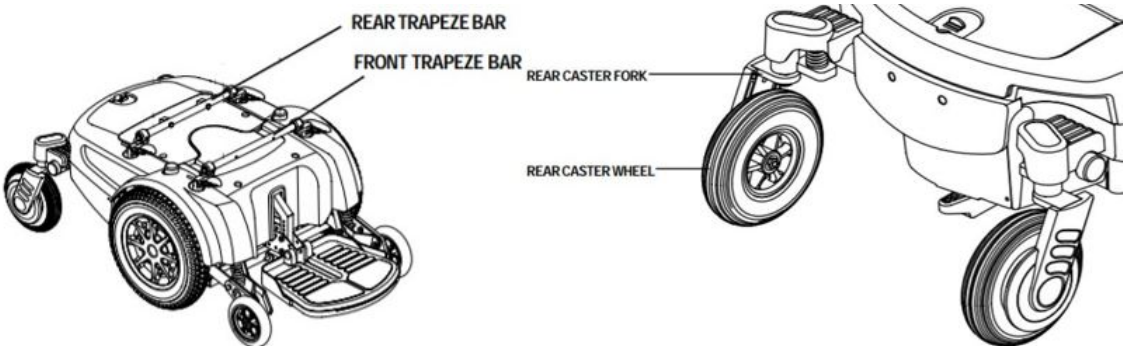


Figure 6. Wheelchair Jazzy Model 1122

Weather proofing

In our previous robot design, weatherproofing was an afterthought. A.Li.E.N. 1.0's open-air design allowed for the team to easily work on the components, but left it vulnerable to the rain, which spawned last minute waterproofing measures consisting of a tarp to act as a "rain jacket". With A.Li.E.N. 2.0's design, we considered the waterproofing needs early in the design. The enclosed body structure provided protection for most of the robot. Black silicone was used to seal a gap in the polycarbonate shell where the camera wires were routed. To protect our cameras, the custom cases were designed with openings for port connections only. These ports were sealed with a removable plug, and the backplate was given hoods to protect wire connections. The opening around the camera lens was less of a concern since the cameras are faced downward.

DESCRIPTION OF ELECTRONIC & POWER DESIGN

Overview

A.Li.E.N. 2.0 is powered by three 12V batteries. Two 12V Sealed Pb-Acid Gel batteries is wired in series to produce a 24V supply to power the LiDAR unit, wheelchair breaks, and DC/DC converters (24V/12V & 24V/5V). The third 12V Li-Ion battery is solely used to supply power to the on-board lightbar, used for nighttime testing. One 24V/5V DC/DC converter is used to power the machine vision units, Teensy 3.2 microcontrollers, and waypoint navigation module (GPS & Magnetometer). Finally, one 24V/12V DC/DC converter is used to power the wheelchair drive motors.

Power Distribution System

The power distribution specifications and schematic for A.Li.E.N. 2.0 are illustrated in Table 2 and Figure 7, respectively.

Table 2. Power Distribution Specifications

Type	Quantity	Voltage	Capacity	Max Run Time	Recharge Rate
Sealed Pb-Acid Gel	2	24 V	150 Ah	6 h	2 A continuous
Li-Ion	1	12 V	12 Ah	12 h	2 A continuous

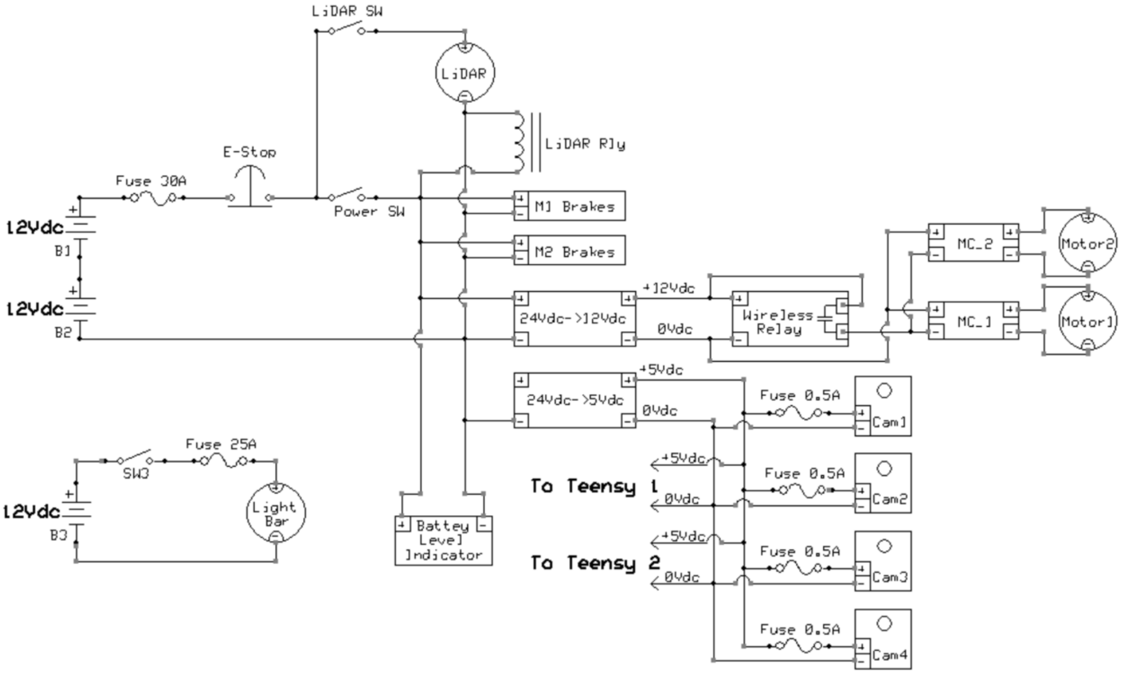


Figure 7. Power Schematic

Electronics Suite

Table 3 is a compiled list of all sensors or controllers used in the distributed controls of this robot. Refer to Figure 7 for a wiring diagram for how power is distributed to each device.

Table 3. List of Devices, Voltage, and Descriptors

Device	Operating Voltage	Description of Component
Lidar	24V	Object detection. Sends high signal to main Teensy.
Motors (2x)	12V	Rotate the wheels, driving the robots forward
LED Lightbar	12V	Illuminates course ahead
Open MV H7 Cameras (4x)	5V	Smart sensors in 4 locations. 2 are used for pothole detection. 2 are used for line detection
Teensy 3.2 Microcontroller (2x)	5V	1 used for brains of robot. Other is used for GPS/Compass for waypoint navigation

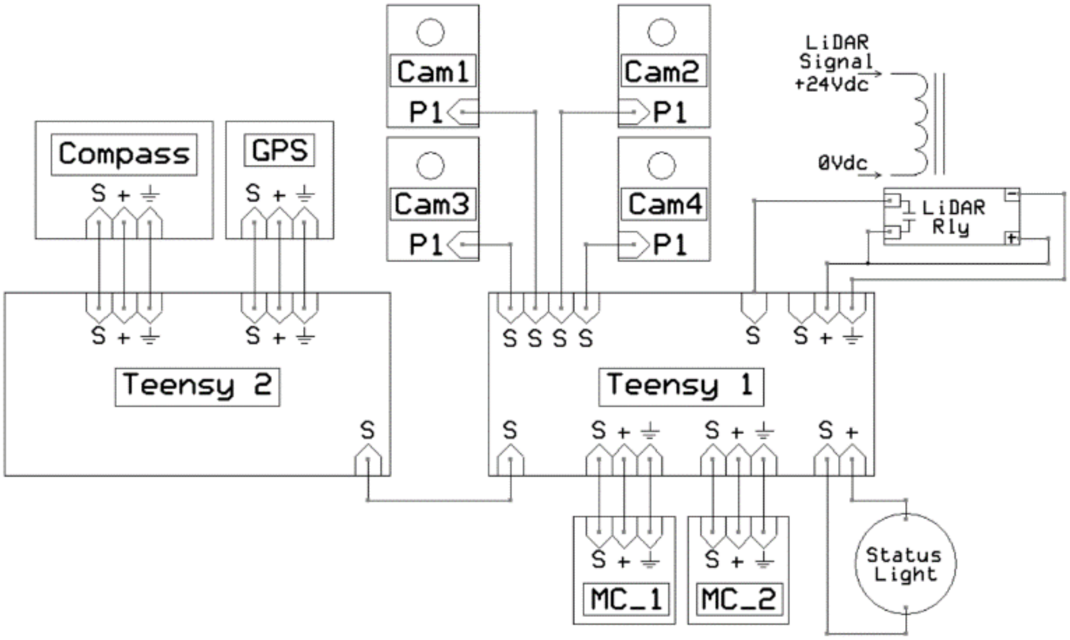


Figure 8. Device Pinout Schematic

Safety Devices & Their System Integration

The primary safety devices included in this system are fuses, mechanical emergency-stop switches, and a physical battery disconnect. Fuses are used to protect sensors and other electrical components from a current overload. During the early stages of testing simple drive code, we burned out two emergency-stop switches. This was due to the engagement of brakes on the drive motors. This high resistance of the breaks generated a massive current draw. Once we learned of the issue, we energized the break circuit, and alleviated the issue. In addition, we placed fuses in series with components to prevent a more costly repair in the event of something similar arising again. The mechanical emergency-stops are a sure way of disengaging the robot in a timely manner.

DESCRIPTION OF SOFTWARE STRATEGY & MAPPING TECHNIQUES

Overview

Our software strategy was based on the Teensy 3.2 ARM based microcontroller. The Teensy is the center hub for controlling all of the drive code. Our basic algorithm follows obstacle avoidance and waypoint navigation. If the Teensy receives data from any of the standalone processors, it will react accordingly.

Obstacle Detection And Avoidance

Our physical obstacle avoidance is entirely based off the SICK LiDAR system. As described in our Effective Innovations section of this report, a threshold was set in the LiDAR's programming. If an object gets within roughly 3 meters of the left or right field of view of the LiDAR, it will send a high signal to the Teensy. The Teensy has specific drive instructions for respective inputs from the GPS module, four machine vision cameras, and the LiDAR unit. We are not logging any data points when or where an obstacle has been detected, we only send avoidance instructions.

Software Strategy And Path Planning

Our waypoint navigation system uses with both a GT-U7 GPS module system & GY-273 triple axis magnetometer. The GPS functions as a means for the robot to locate its current position. The GPS in tandem with the magnetometer allows the robot to adjust its angle to move a specific cardinal direction toward the given waypoint. The integration of both modules allows the robot to guide itself without human assistance.

Map Generation

Due to our four-month R&D timeframe, our robot did not employ a mapping strategy. We felt we could successfully participate in this challenge without implementing this feature on A.Li.E.N. 2.0. In short, our university recognizes the potential that map generation possess. Due to teamwork and an advanced ability in two of our classmates, we were able to participate in a second entry this year with A.Li.E.N. 3.0. We concurrently engineered two designs. A.Li.E.N. 2.0 which uses power distribution using Teensy microcontrollers and A.Li.E.N. 3.0 which uses ROS and includes map generation.

Goal Selection & Path Generation

Refer to Appendix A for the drive code flowchart. The highest priority of our robot is to avoid boundary lines. If it does not detect a line on either side, it will receive input from the left pothole seeking camera and the left LiDAR field of view. If those are clear, it will seek input from the right pothole seeking camera and the right LiDAR field of view. If any obstacle detecting system throws a high pin, the Teensy will send drive instructions to the motors to turn and avoid. Lastly, while assuring the path ahead is safe for travel, our robot will pivot accordingly in the direction of the waypoint. This completes the main loop.

Additional Creative Concepts

One of our more creative concepts revolved around convenience. Our manufacturing leads have blessed the team with the attribution of cupholders. There are four cupholders mounted to the frame of our vehicle. What originated as a fun and joking modification has evolved into something we will include in later iterations. Dr. Wright has been a particular fan of this due to his frequent coffee consumption.

Another creative concept employed on A.Li.E.N. 2.0 is color-coding of all electrical wiring. Specifically, all 12 V and 24 V power wiring was colored using red (+ V) and black (ground) wire, all 5 V wiring was colored using yellow (+ V) and black (ground) wire, and all signal wiring was colored using white wire.

DESCRIPTION OF FAILURE MODES AND RESOLUTIONS

Vehicle Software Failure Modes and Resolutions

Throughout construction we ran into many troubleshooting issues and failure modes that have improved our robot platform entry. In the event of a failure during testing, individuals would work through the problem in several ways. If the issue was particularly difficult, individuals would record it, research the issue, plan a work around, and continue implementation or find a different means to the same end. Table 4 illustrates some of the most notable digitally encountered issues during our build as well as how we overcame the issue.

Table 4. Digital Failure Modes

Area of R&D	Recorded Issue	Resolution
Electrical	The GPS or Compass can receive incorrect output for the corresponding set pins.	Check the code output through the serial monitor to ensure it is reading correctly. Double check wiring.
Software	The LiDAR system takes around 30 seconds to boot and become operational.	We put the LiDAR on its own circuit, so we would not have to reboot it every time we stopped the robot.
Software	The line detection was picking up too much noise.	Using line length to filter noise as well as a gaussian filter helped to provide reliable line detection.
Software	Machine Vision pothole detection thresholds are either too wide or too narrow for effective detection.	Incorporated more data points for reliable object detection and generated optimal threshold values for a variety of lighting scenarios.
Software	The GPS or Compass were miss calibrated at times.	Edit code and solve the navigation algorithm to work more reliably.
Software	Shadow interference with machine vision cameras.	Converted the view into a bitmapped image.

Vehicle Failure Points & Resolutions

Our physical issues seemed to be solved more easily. Due to their tangible or visible malfunction, the diagnosis stage of troubleshooting was brief. Correct and rapid diagnosis made solving the issue straightforward decreasing our down time. There were however rather challenging moments. Table 5 outlines some of the more noteworthy physical failure modes and resolutions we encountered throughout construction and testing.

Table 5. Physical Failure Modes and Resolutions

Area of R&D	Recorded Issue	Resolution
Mechanical	Camera mount print failure	Splice supports were added to the print.
Mechanical	Machine vision unit micro-USB access too small	Mounting point shifted and extra room was added.
Mechanical	Inadequate wirer outing space	Switched from 1" x 1" (4 slots) 80/20 to 1" x 2" (6 slots).
Mechanical	Instability with 1" x 2" 6-slot extrusions	Increased angle plate surface area size (from 5 holes to 12 holes).
Electrical	Loose wires on camera sensors	Soldering where possible, or using multiple pin connections
Electrical	Overvolting cameras because of converter malfunction	Purchased more robust converter and put fuses in series with camera power input
Electrical	Brakes were engaged, increased resistance, and drew too much current	Figured out how to energize brake coil circuit to release them during testing.
Electrical	Troubleshooting the "rat's nest" circuitry configuration.	We color coded the wire to make a visual tracing of the circuit effortless
Controls	We have had issues with correctly wiring the LiDAR unit to kernel Teensy microcontroller	It has been re-wired with a permanent circuit which is secured in the internal housing

Controls	Camera field of view was not satisfactory for environmental scanning early on	We used a gauge to assure it is at the correct nod and tilt angle
Controls	The physical mount of the way point module (GPS and Compass) would provide weak signal or incorrect data.	Mounted the module in front of the robot. It has adequate signal strength, and compass is mounted rigidly in correct orientation.
Controls	The lead control's engineer was the sole programmer of the drive code.	We reviewed their code as issues arose and provided feedback as much as possible.

All Failure Prevention Strategy

To mitigate reoccurring issues, and to avoid potential failure points or modes in the future, we kept a log of our issues and design ideas. Problems such as shorts or loose wires were refined through neatness, soldered connections, and mechanical connections. We standardized the hardware which fastens our robot together. We have the appropriate tooling available for quick adjustment. Our MV units and waypoint navigation system are easily replaceable. The inexpensive modularity of our electronic components makes verification or substitution easy.

Testing

Authentic testing was at the heart of our engineering and design process. Through concurrent engineering individual teams would develop and test their standalone processors, circuitry, or 3D designs. Controls team members focused on refining the MV units, LiDAR unit, and waypoint navigation module. In addition, manufacturing and electrical distribution teams would follow suite. We all started with brainstorming, would slowly incorporate theory into practical device integration, refine it at the bench, and then port it to the system. Electrical team members, for instance, would build a circuit, verify it with another team member, test it with a multimeter, and then integrate it into A.Li.E.N. 2.0's housing.

Vehicle Safety Design Concepts

While we are still compiling our build, safety has been a consideration throughout this build. Some safety additions include local and remote emergency stops. These e-stops kill the power to the drive motors, microcontrollers, and most all sensors. When pressed, they bring the robot to a sudden and complete stop. In addition, we have a physical battery quick disconnect plug. This plug allows us to de-energize the entire circuit during charging. This disconnect has a mechanical feature, making a reverse polarity connection much less likely. Several fuses were placed in crucial locations, assuring the circuit does not destroy specific components due to an overload or short-circuit condition.

SIMULATIONS EMPLOYED

Because we chose to pursue distributed control, we heavily relied on performance testing over employing simulations. In order to retrieve feedback, we capitalized on using the serial monitor, printing outputs to an LCD screen, or using each process controller's software package. For example, the LiDAR uses the SOPAS Engineering Tool software package to program. This platform allowed us to set the device thresholds, test its function, and then finally integrate it to the system. Likewise, the Open-MV H7 cameras have their own IDE. As we programmed, we were able to test our program by viewing the live video output and comparing it to outputs provided in the serial monitor.

PERFORMANCE TESTING TO DATE

As stated in our effective innovations in the vehicle design, we focused on integrating smart sensors in our system through concurrent engineering. Simply put, individual teams would test their respective sensor on the bench, modify them as needed, add it to the robot, test the integration of the robot, and then we would continue onto the next integration. See Table 6 for a timetable of when milestones were met.

Table 6. Onboard Integration Performance Testing Dates

Date	Line Avoidance	Object Avoidance	Pothole Avoidance	GPS Navigation	Compass Navigation
April 13th	✓ Outdoor	✓ Outdoor	-	-	-
April 18th	✓ Indoor	✓ Indoor	✓ Indoor	-	-
April 20th	✓ Outdoor	✓ Outdoor	✓ Outdoor	-	-
April 25th	✓ Outdoor Night	✓ Outdoor Night	✓ Outdoor Night	-	-
May 6th	✓ Outdoor	✓ Outdoor	✓ Outdoor	✓ Outdoor	✓ Outdoor

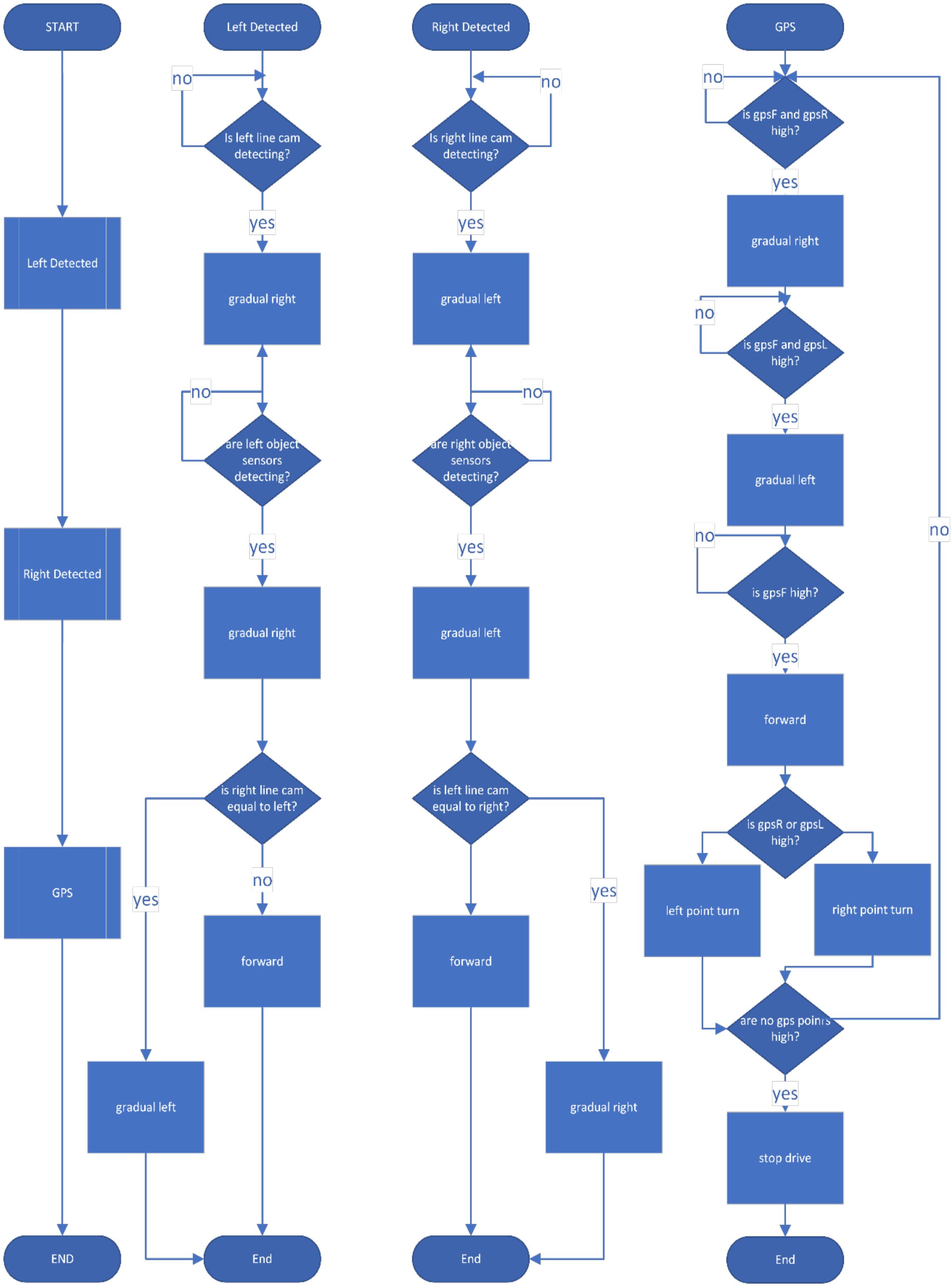
INITIAL PERFORMANCE ASSESSMENTS

At the moment of this submission, A.Li.E.N. 2.0 has successfully demonstrated basic obstacle avoidance in its preliminary stages. We have also integrated waypoint navigation in tandem with obstacle avoidance. Continuing past these milestones, our primary focus will be tuning our waypoint navigation, improving our obstacle avoidance code, testing with final weight, assuring we have exceeded the competition criteria expectations, and to expand upon our safety features.

CONCLUSIONS

Our biggest lesson from this build is understanding the strength of effective teamwork. As individuals, we made vigorous efforts in our contributions. However, without one another, this project would not have been feasible. The varied perspectives of each member added a robust characteristic to this robot. The viewpoints from Mechanical, Electrical, or Controls teams forced us to come together and often allowed us to preserver through integration and testing. While we still have minor things to integrate, we are comfortable with our progress thus far. We are looking forward to participating in the competition and networking with other institutions at the event.

APPENDIX A: DRIVE CODE FLOW CHART



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