IGVC 2023 – A.Li.E.N. 4.0

Ville Robotics AutoNav Design Report

Millersville University of Pennsylvania

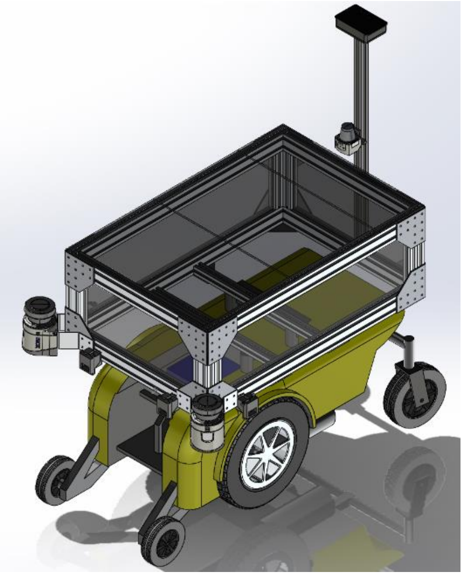

Figure 1. Autonomous LiDAR-Based Environment Navigator 4.0 3D Render

Submitted May 12, 2023

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I certify that the design and engineering of the A.Li.E.N. 4.0 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: May 12, 2023

1. Conduct of Design Process, Team Identification & Team Organization

1.1 Introduction

The Millersville Mobile Robotics Research Team (Ville Robotics) has a long history of developing competition grade robots. Since 2001, the team has won 45 individual 1st-3rd place awards in numerous national/international competitions, including seven national championships. In 2018 the team began developing self-driving autonomous applications using LiDAR, Machine Vision, GPS, and other technologies organized via a distributed control system architecture. Specifically, the team has used SICK LiDAR products due to their industrial grade, local programmability, and intuitive graphical user interface (GUI). This is Millersville University's 3rd 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 primary objective was to adapt our past Autonomous LiDAR-Based Environment Navigator (A.Li.E.N.) robot platform 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.

Table 1. Team Member Contribution Catalogue.

Name	Year	Mechanical	Electrical	Controls	Club Position or Role	Hours
Camdyn Brunner	Soph.	X			Manufacturing Engineer	100 +
Jeremiah Buck	Soph.		X		Public Relations Chair & Electrical Engineer	10 +
Joseph Favoroso	Soph.	X			Manufacturing Engineer	10 +
Nicholas Forte	Sr.	X			Manufacturing Engineer	10 +
Joshua Greineder	Jr.			X	President & Controls Engineer	10 +
Paige Guinther	Fr.	X			Manufacturing Engineer	50 +
Chad Hayes	Jr.	X			Manufacturing Engineer	60 +
Elizabeth Maschke	Soph.	X	Lead		Treasurer, Documentation Lead, Manufacturing Engineer & Sr. Electrical Engineer	400 +
Dennis Nguyen	Soph.	X		X	Secretary & Manufacturing Engineer	75 +
Patrick Rock	Soph.	X			Manufacturing Engineer	20 +
Natalie Snyder	Soph.	X	X		Manufacturing & Electrical Engineer	60 +
Ian Troop	Jr.	X	X	Lead	Vice President, Project Lead, Manufacturing & Electrical Engineer & Sr. Controls Engineer	400 +
Matthew Way	Fr.	X			Manufacturing Engineer	50 +
Zane Weaver	Soph.		X	Co-Lead	Chief LiDAR Engineer, Electrical & Sr. Controls Engineer	400 +
Ermias Wogari	Sr.			X	Chief GPS Engineer & Controls Engineer	50 +
Benjamin Wright	Soph.	Lead			Sr. Manufacturing Engineer	250 +
Cody Zook	Grad.	X	X		Support Engineer/Lab Supervisor	30 +

1.2 Organization

Each area of R&D had a student take the 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 when applicable. Mechanical members produced models, CADD drawings, fixtures and incorporated the physical modifications to our robot. Electrical members generated control and power distribution schematics for all electronic systems, and wired all systems together. Members of the Controls team developed algorithms, programmed sensors, and finalized the systems integration needed to automate A.Li.E.N. 4.0.

1.3 Design Assumptions & Design Process

During the 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[1]. After choosing specific approaches that were guided by research, we set off to develop models, algorithms, and schematics and frequently documented our individual progress. We undoubtedly ran into issues, 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, combined with the 1,985 engineering hours contributed to this build, improved the robustness of the platform, and enhanced the design of A.Li.E.N. 4.0.

2. Effective Innovations in Vehicle Designs

2.1 Innovative Concepts from Other Vehicles Designed into A.Li.E.N. 4.0

2.1.1 Distributed Controls & Concurrent-Engineering

We have once again opted to pursue a distributed control system for this year's build. A.Li.E.N. 4.0 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 two SICK LMS111 LiDAR and one SICK TiM881P systems for obstacle avoidance, four Open-MV H7 cameras for line and pothole detection, one GT-U7 GPS module system with a GY-273 triple axis magnetometer integrated with a Teensy 3.2 microcontroller for waypoint navigation, and one Teensy 3.2 microcontroller for navigation and main drive control.

Due to the four-month timeframe, we concentrated on maximizing productivity and testing time. With this modular setup, we were able to capitalize on concurrent engineering and avoid bottlenecking. We organized ourselves into groups and incorporated these standalone systems into the robot as each individual unit was developed. Because our team could research and program independently, individual groups could test their sensors before porting them 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 integrated their system into the robot, they contributed to other aspects of the build, such as electrical integration or assisting with manufacturing aspects.

2.2 Innovative Technology Applied to Vehicle

2.2.1 LiDAR

The A.Li.E.N. concept has been developed since 2019 for the Intelligent Ground Vehicle Competition (IGVC). Our team has refined the robot's design and is on the fourth iteration. A.Li.E.N. 4.0 utilizes sensor fusion of multiple technologies to achieve autonomous self-driving. The robot's design centers around the use of LiDAR technology for safety reasons, as it is far less prone to give false negative readings. In low light or low visibility scenarios, vision-only systems might not "see" people or obstacles, resulting in injury. To mitigate these issues of missed or false reads, multi-sensor systems were deployed.

2.2.2 TIM-881P

The TiM881P LiDAR performs two unique operations to supplement A.Li.E.N. 4.0's obstacle avoidance capabilities. First, it conducts a scan of the front of the robot to identify the closest point or object, providing A.Li.E.N. 4.0 with the necessary information to prioritize objects that require immediate attention. Additionally, the TiM881P LiDAR scans for obstacles near the rear of the robot, ensuring that the back end of the robot does not collide with any objects during turns (see Figure 2).

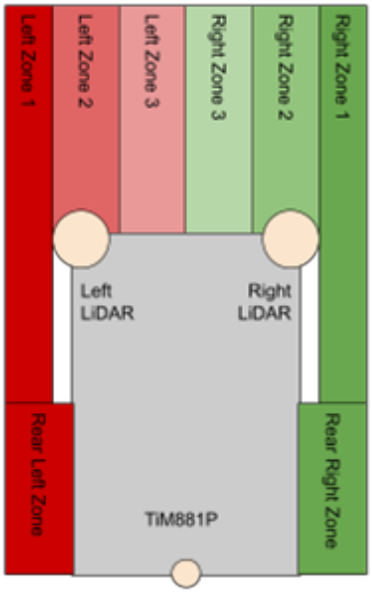

Figure 2. Zones (red and green rectangles) observed by A.Li.E.N. 4.0 (gray rectangle) LiDARs (white circles).

The built-in tuning feature of our custom TiM881P LiDAR graphical user interface (GUI) allows for the adjustment of two predefined zones on the TiM881P (green to detect the left side, red to detect the right side, black for no object detected). For our application, these serve as detection zones, positioned at the rear or back of the robot. In the early stages of developing with AppStudio (SICK, USA), updating zone size and position proved to be slow due to the requirements of packaging and reinstalling on the TiM881P. Additionally, tuning was challenging without graphical vision since changes could not be seen without extensive testing. Our GUI addressed these issues, making tuning far simpler. The minimum values indicate how far from the origin point the zone should start, while the maximum values indicate how far from the origin point the zone extends to. These changes will "live" update but will not apply to the actual zone until the "Apply Changes" button is pressed in the GUI. This allows for the zones to be visualized without being permanently changed.

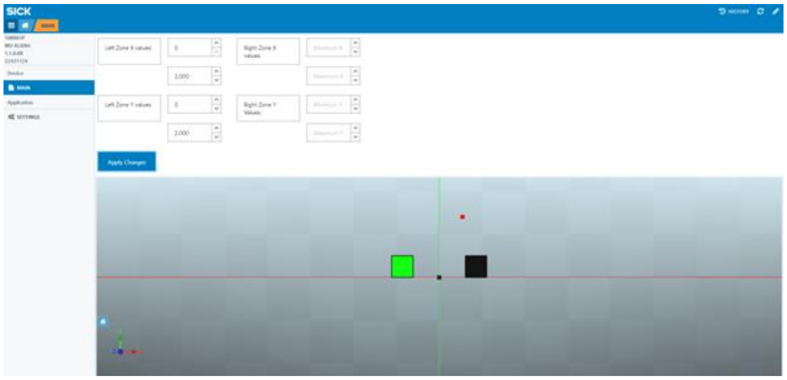

Figure 3. Custom GUI designed for TiM881P.


Left Zone X values: 0 / 2,000
Right Zone X values: Minimum X / Maximum X
Left Zone Y values: 0 / 2,000
Right Zone Y Values: Minimum Y / Maximum Y

Figure 4. GUI Rear zone adjustment dialog (right zone set to default value, left zone adjusted to a user defined value).

Another feature linked to our GUI is its ability to allow its developers to visually see the closest object in front of the robot as shown on the GUI as a green or red dot (see Figure 5). This GUI illustrates A.Li.E.N. 4.0's field of view, helping the developer fine tune the robot to its environment. Again, green indicates the object is on the left side while red indicates the object on the right side. This information is critical to the robot's control algorithm as it sets a priority status for a condition when both LM111s positioned at the front of the robot trigger their digital zones. The TiM881P serves as a "tie breaker" by determining which object is closest to the robot so it can adjust its path to avoid this object.

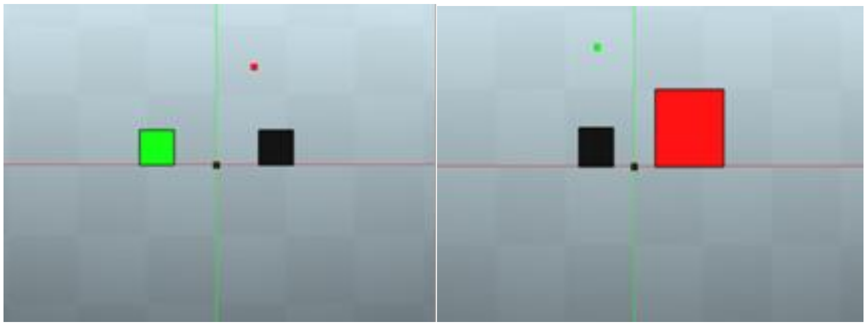

Figure 5. Graphical representation of the rear zones before (left) and after (right) resizing the right zone within the GUI.

2.2.3 LMS111-10100

The LMS111 LiDARs are deployed to identify six distinct zones in front of the robot, as depicted in Figure 1, and thus allow for efficient detection and analysis of potential hazards. The data acquired from these zones is then analyzed, enabling A.Li.E.N. 4.0 to determine the nature and severity of any obstacles within these zones.

To manage physical object detection, we used two SICK LMS111 LiDAR units. These units use laser imaging to identify objects within a specific range.[2] The system is programmed with the SOPAS Engineering tool (SICK, USA). Figure 6 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. Six fields were set up (Figure 2) with two of the fields extended along the sides of the robot to prevent accidental collision of the robot with objects, such as barrels. 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. 4.0 away from the detected object(s).

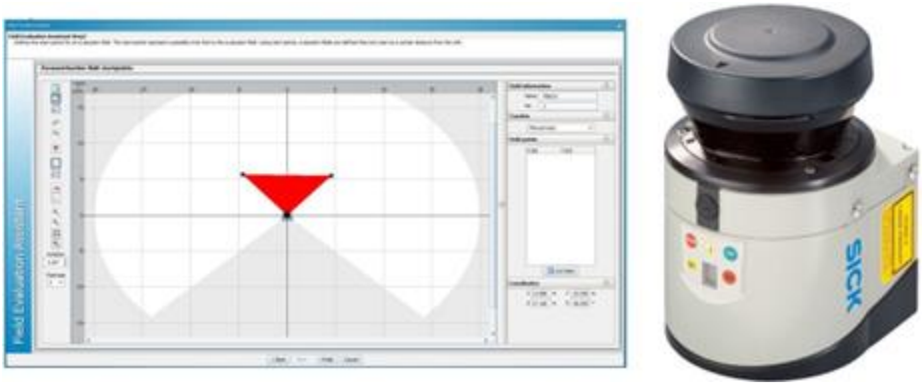

Figure 6. LiDAR User interface & Unit

3. Description of Mechanical Design

3.1 Overview

The mechanical design for A.Li.E.N. 4.0 builds upon the design of both Millersville University's 2022 IGVC robots, A.Li.E.N. 2.0 and 3.0, as well as the 2019 IGVC robot entry, A.Li.E.N. 1.0. This revised rendition is based on a different wheelchair chassis, which warrants a new frame and shell to be built, and additional sensors, which require new mounting hardware to be developed. Key improvements include weatherproofing, increased sensor utilization, and improved wire management.

3.2 Decision on Frame Structure, Housing, & Structure Design

Our frame is similar to the design of A.Li.E.N. 2.0. The frame is constructed out of 80/20® (80/20 Inc., USA) 30-Seris, T-slot aluminum extrusions. Four-slot, 30mm x 30mm extrusions were used to connect to the base's trapeze bars, while 6-slot 30mm x 60mm extrusions were used to build the frame. The extra slot in the T bar was utilized to route wires between sensors, microcontrollers, and power. Ten-series M6 fasteners and custom made 12-hole right angle plates were used to connect the extrusions. Ninety-degree gussets were also used to mount components vertically. The 1/4" smoked polycarbonate was used to encase the robot and mount the internal electronics, and mechanical emergency stop button. The same polycarbonate sheet was used for the hinged top, along with handled screw fasteners to make the top easily removable.

To increase sensor mobility, custom camera cases were developed, see Figure 7. These cases had a hinge joint on the back, allowing for North-South pivoting camera adjustments. The hinge joint mounted offset from the 80/20 frame and allows for 360-degree rotational motion, expanding the camera angle customization or modification.

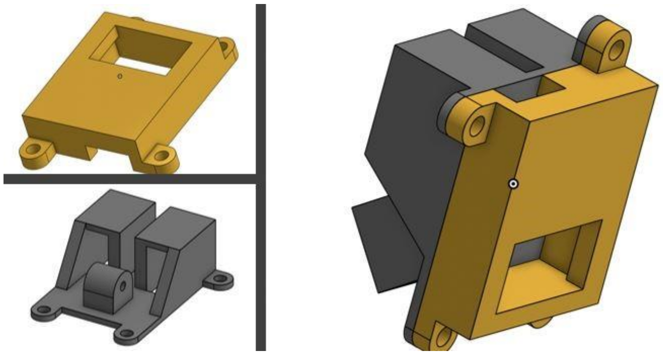

Figure 7. 3D Printed Machine Vision Camera Cases

Cable management was a challenge in all previous A.Li.E.N. designs. To remedy this, 3/8” polyethylene spiral wire loom was used to consolidate smaller wires for easier routing between electronics. A secondary solution for A.Li.E.N. 4.0’s wire management was the design and manufacturing of clips, that simply fit into the 80/20 extrusions and when rotated 90-degree, become locked in place and limited movement. Wires were then run through these clips along the chassis of the 4.0 platform, creating a cleaner, more organized and put together system internally.

When designing A.Li.E.N. 2.0, the LiDAR unit had its own purpose-built casing which allowed it to be mounted on the front of the robot. With A.Li.E.N. 4.0’s design, we increased the number of LiDAR units threefold, thus requiring the development of specialized brackets. We designed two mounting brackets to hold the large LiDAR units at 45-degree angles off the frame to allow for an increased detection range, and had a smaller mount designed to hold the smaller LiDAR unit on the GPS Tower. This mount allowed for the unit's position to be varied to allow for any changes necessary in the field.

3.3 Description of Drive-by-Wire Kit & Drive Train

A.Li.E.N. 4.0 was built on the base of a donated electric wheelchair. This Quantum 614 power wheelchair made by Pride Mobility features 14” pneumatic drive wheels, and 6” solid caster wheels in the front and rear (refer to Figure 8).[3] The Quantum 614 has 1.625” of ground clearance, a turning radius of 20”, and a carrying capacity of 340 lbs. after removing the chair. The robot receives pulse-width modulated (PWM) signals from the Teensy 3.2 microcontroller through a pair of VEXpro Jaguar motor controllers (one per side). This methodology allows for zero radius turns, with speeds from 1-5 miles per hour.

3.4 Suspension

The wheelchair chassis is driven by two gear motors and is equipped with Pride Mobility’s Active-Trac Suspension (ATX). The suspension system consists of coil-overs, which use linear compression springs to absorb the impact of oncoming obstacles. The system links the front caster wheels to the frame with the motors and drive wheels. When the front casters encounter an obstacle, they are moved upwards, subsequently forcing the motors and drive wheels downward. This action assists the wheelchair in climbing over small obstacles. Additional extension springs assist in performing this action. The ATX works in unison with the rear suspension to respond to weight transfers. The frame was attached using the pre-existing trapeze bars used to mount the chair.

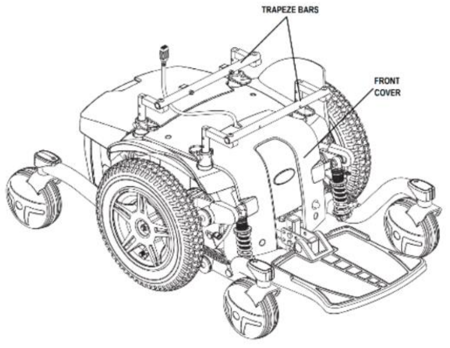

Figure 8. The Pride Mobility Quantum 614

3.5 Weather Proofing

In our previous robot designs, weatherproofing was an afterthought. A.Li.E.N. 1.0's open-air design allowed the team to easily work on the components but left it vulnerable to the rain. A.Li.E.N. 2.0 was enclosed in a polycarbonate shell with holes for wire routing. Camera cases were also designed with watertight openings for wiring and port connections. Silicon was also used to seal gaps. A.Li.E.N. 3.0 had non-waterproof components sealed in a pelican case.

A.Li.E.N. 4.0 followed a design similar to that of A.Li.E.N. 2.0's design. The upgrades that were made were to develop grommets to hold wires being routed through the polycarbonate panels in place and keep them watertight. Another innovation that was made to this year's iteration of A.Li.E.N. platform was a hinged lid. The hinged lid allowed for the removal of only four thumb screws, rather than all thumbscrews and the entire polycarbonate panel, to access internal components. A strip of weatherproofing was installed in between the seams of the polycarbonate panels to reduce the gap between. We used rubber weatherproofing strips to allow for flexibility in movement, but also to prevent water from entering the chassis of A.Li.E.N. 4.0 and to eliminate the possibility of a short occurring due to water contamination.

4. Description of Electronic Power Design

4.1 Overview

A.Li.E.N. 4.0 is powered by two 12V Sealed Pb-Acid Gel batteries, which are wired in series to produce a 24V supply to power the LiDAR unit, and DC/DC converter (24V/5V). The 24V/5V DC/DC converter is used to power the machine vision units, Teensy 3.2 microcontrollers, and waypoint navigation module (GPS & Magnetometer). A change from previous iterations of A.Li.E.N. platforms, is that instead of utilizing one 24V/12V DC/DC converter to power the wheelchair drive motors, we tapped off a singular 12V battery. The single battery supplies power to the 12V circuit, mitigating the use for a 24V/12V DC/DC converter. The main goal of eliminating the 12V/24V DC/DC converter was to eliminate a failure point that had resulted from the converter at IGVC in 2022. When A.Li.E.N. 2.0 was in the field, the 24V/12V DC/DC converter malfunctioned, effectively eliminating the use of motors on the platform, and stopping any further progress from being made that day until repairs and substitutions were able to be made.

4.2 Power Distribution System

The schematic and power distribution specifications for A.Li.E.N. 4.0 are illustrated in Figures 9 and 10, in addition to Table 2, respectively.

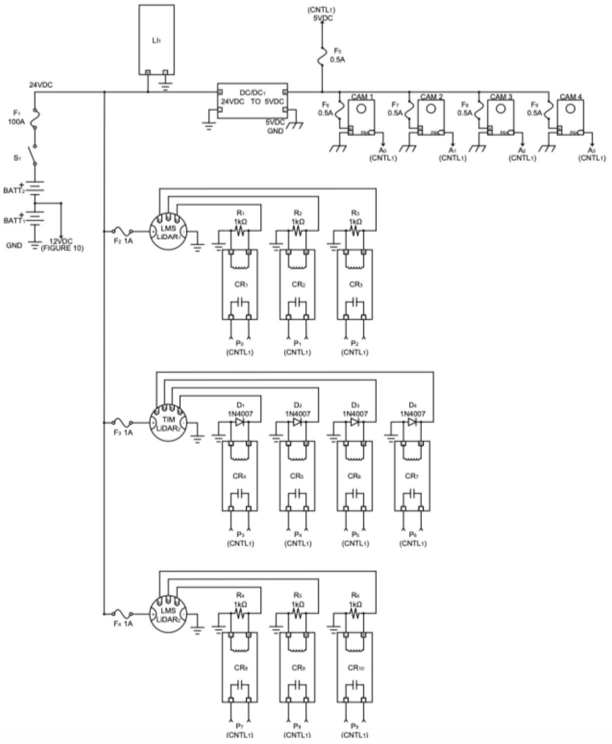

Figure 9. 24VDC & 5VDC Circuit Schematics

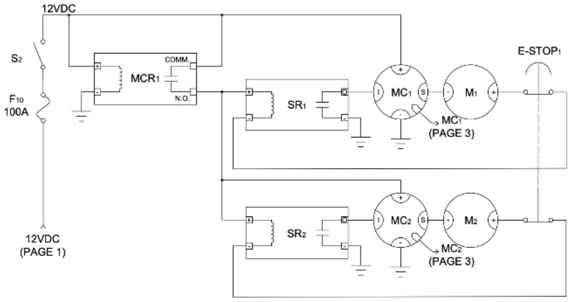

Figure 10. 12VDC Circuit Schematics

Table 2. Power Distribution Specifications

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

4.3 Electonics Suite Description

Table 3 is a compiled list of all sensors or controllers used in the distributed controls of A.Li.E.N. 4.0. Refer to Figures 9 & 10 for a power distribution wiring diagram for each device.

Table 3. List of Devices, Voltage, and Descriptors

Device	Operating Voltage	Description of Component
LiDAR (3x)	24V	Object detection. Sends high signal to main Teensy.
Motors (2x)	12V	Rotate the wheels, driving the robot forward
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 controls of robot. Other is used for GPS/Compass for waypoint navigation

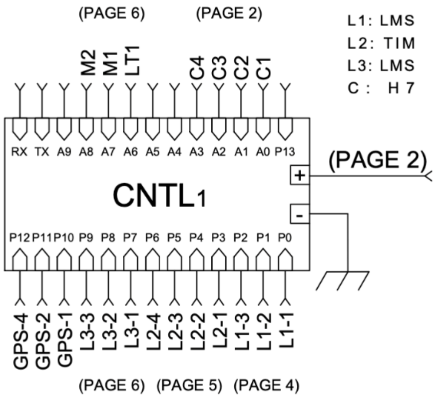

Figure 11. Control$_1$ Teensy 3.2 Device Pinout Schematic

4.4 Safety Devices with Integration into System

The primary safety devices included in this system are fuses, mechanical emergency-stop switches, and a physical battery disconnect. Fuses were used to protect sensors and other electrical components from a current overload.

During the preliminary stages of testing the simple drive code last year, we burned out two emergency-stop switches due to the engagement of brakes on the drive motors, leading to the high resistance of the brakes generated a massive current draw. This year, the wheelchair chassis did not have a brake system integrated into their design.

We placed fuses in line with components to prevent a more costly repair in the event of large current draws or malfunction occurring. Mechanical emergency stops are a sure way of disengaging the robot promptly, should an emergency arise.

5. Description of Software Strategy & Mapping Techniques

5.1 Overview

Our software strategy was deployed on a Teensy 3.2 ARM-based microcontroller (CNTL$_1$, Figure 11). The Teensy is the central hub for controlling our drive motors and runs an obstacle avoidance and waypoint navigation algorithm. For object detection, the Teensy receives control signals as parallel binary inputs from the two LiDARs, and four cameras which are condensed into zone patterns, as indicated in Figure 2. Additionally, the GPS module sends binary directional signals for waypoint navigation.

5.2 Obstacle Detection & 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 approximately 3 meters of the front of the robot its detected in one of the eight zones by the LiDAR, it will send a corresponding high signal to the Teensy. The Teensy will combine this with the four-machine vision camera into a 6-bit binary number used to react accordingly. We are not logging any data points when or where an obstacle has been detected, we only send avoidance instructions.

5.3 Software Strategy & Path Planning

Our waypoint navigation system utilizes a GT-U7 GPS module and GY-273 triple axis magnetometer system. This module has its own Teensy 3.2 ARM-based microcontroller to process GPS and magnetometer data. 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 direction the robot needs to go is communicated to the drive controller ($CNTL_1$) using a 3-bit octal variable. The integration of both modules allows the robot to guide itself without human assistance.

5.4 Map Generation

While A.Li.E.N. 4.0 does not store GPS data, it does store line and pothole data collected by the four machine vision cameras and the LiDAR zone data to make a decision based on the full situation the robot finds itself in. This local map is made and used recursively at 50Hz as the robot navigates the course. These eight zones have two pairs of logically equivalent zones making for six zones that are treated as a 6-bit binary integer referred to in the code as Zone Case Number (ZCN).

5.5 Goal Selection & Path Generation

Refer to Appendix A for A.Li.E.N. 4.0's drive algorithm flowchart. This drive algorithm processes all sensor input and then determines what to do based off all the available information. This is in contrast to its predecessor, A.Li.E.N. 2.0, which checked and processed the data in a sequence leaving some inputs prioritized over others. The use of this method (i.e., treating inputs as binary lookup values and performing the corresponding action) allows for an increase in data processing that A.Li.E.N. 4.0 has over previous iterations.

To make path planning decisions, A.Li.E.N. 4.0 uses the six zones discussed above to react to obstacles based on the proportional severity each exhibits to the robot's path trajectory (see Appendix A). The robot has a choice of five levels of turns in each direction, with a lower number corresponding to a less aggressive turn. If there is no viable path for the robot, it will pivot towards the farthest obstacle until it finds a viable path forward. If there is nothing obstructing the robot it falls back to GPS navigation which has six possible turns to guide it towards the next GPS waypoint. Additionally, there is a stop and move straight command corresponding to the octal value mentioned above.

5.6 Additional Creative Concepts

One of our more creative concepts revolved around convenience. Our manufacturing leads have added four cupholders, which are mounted to the rear 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, however the team has adopted this pastime, as we are all drinking coffee and now require many more cup holders.

Another creative concept employed on A.Li.E.N. 4.0 is color-coding of all electrical wiring. Specifically, all 5V, 12V, and 24V power wiring was colored using red (+ V) and black (Ground) wire, and all signal wiring was colored using white wire. Each wire has a label on it, which corresponds to the circuit the wire originates from

6. Description of Failure Modes, Failure Points, & Resolutions

6.1 Vehicle Failure Modes & 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 were particularly difficult, individuals would record it, research the issue, develop a work around, and continue implementation or find a different means to the same end.

Table 4 illustrates some of the most notable software failure modes and resolutions we encountered throughout construction and testing.

Table 4. Software Failure Modes and Resolutions

Area of R&D	Recorded Issue	Resolution
Software	The LiDAR system takes ~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 through the use of an emergency stop, whether onboard or remote.
Software	The line detection machine vision cameras were picking up too much noise.	Using line length to filter noise and a gaussian filter helped 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 & Compass were mis-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.

6.2 Vehicle Failure Points & Resolutions

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

Table 5. Hardware Failure Modes and Resolutions

Area of R&D	Recorded Issue	Resolution
Mechanical	Camera mount print failure	Splice supports were added to the print.
Mechanical	Camera mounts were not strong enough	Increased infill percentage on 3D printers
Mechanical	Did not have proper hardware for protoboards developed in house	3D printed brackets for protoboards to be secured onto the platform with
Mechanical	Protoboard brackets kept breaking at mounting points	Protoboard brackets were printed at a 45-degree angle to increase structural stability
Mechanical/Electrical	Metal screws were contacting the protoboards and shorting the connections	Metal fasteners were insulated on all components
Mechanical	Holes drilled for wiring were not waterproof	Grommets were developed and 3D printed for security and additional waterproofing
Electrical	Loose wires on camera sensors	Soldering where possible, or using multiple pin connections
Electrical	Wire loomed wire lines did not fit in the extruded sections of 80/20	Wire clips were designed to fit directly into the slots of 80/20 extrusions, holding wires in place
Electrical	The light on the Teensy 3.2 remained on for eight minutes after all power was disconnected	We made multiple adjustments and then the light went out with time
Electrical	Troubleshooting the “rat’s nest” circuitry configuration.	We color coded the wire to make a visual tracing of the circuit effortless
Electrical/Controls	Camera signal was connected to the wrong signal pins on the Teensy	Placed pins correctly and updated schematics
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 the 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.

6.3 All Failure Prevention Strategies

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 and fasteners on our robot. We have the appropriate tooling available for quick adjustments in the field. Our machine vision cameras and GPS waypoint navigation system are easily replaceable. The inexpensive modularity of our electronic components makes verification or substitution easy. We also have spare parts ready to go if necessary, such as spare hardware, 3D printed parts, and wire with surplus connectors.

6.4 Testing

Authentic testing is 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 machine vision cameras, LiDAR units, and a GPS waypoint navigation module. In addition, manufacturing and electrical distribution teams would follow suite. All teams started by coming up with the best design possible in the beginning. Systems were then integrated into the platform after revision on the bench. 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. 4.0's housing.

6.5 Vehicle Safety Design Concepts

While we are still completing our robot build, safety has been a consideration throughout the entire process. Some safety additions include local, hard wired, and remote emergency stops. These e-stops kill the power to the drive motors, microcontrollers, and most sensors. When pressed, they bring the robot to a sudden and complete stop. In addition, we have a knife switch separating the batteries from their respective circuits, which allows us to de-energize the entire circuit. Several fuses were placed in crucial locations, assuring the circuit does not destroy specific components, such as LiDAR units, cameras, or entire circuits due to an overload or short-circuit condition (see Figure 9 and Figure 10).

7. Simulations Employed

We heavily relied on performance testing over employing simulations because we chose to pursue distributed control. 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 LM111 LiDAR units use the SOPAS Engineering Tool software package, and our in-house developed GUI (for the Tim881P LiDAR) to program and test. These platforms allowed us to set the device thresholds, test its function, and then finally integrate it into 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.

8. 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 project milestones were met.

Table 6. Onboard Integration Performance Testing Dates

Date	Line Avoidance	Object Avoidance	Pothole Avoidance	GPS Navigation	Compass Navigation
April 4	-	√	-	-	-
April 7	√	√	√	-	-
May 9	√	√	√	√	√

9. Initial Performance Assessments

9.1 Vehicle Performance to Date

At the time of this submission, A.Li.E.N. 4.0 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.

10. Conclusion

The Millersville Univerity Mobile Robotics research team has a proven track record of success in developing competition-grade robots and has recently ventured into the field of autonomous self-driving applications. Our collaboration with SICK LiDAR products, specifically the TiM881P, has allowed the team to develop an innovative and efficient autonomous navigation system for their latest robot, A.Li.E.N. 4.0.

Overall, the team's use of the SICK LiDAR demonstrates its effectiveness as a powerful tool for autonomous robotics and its potential to be applied to a wide range of applications in various industries. 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 persevere 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.

11. References

1 IGVC Rules committee, “Official Competition Details, Rules, and Format” http://www.igvc.org/rules.htm

2 SICK AG Germany 2019, LMS1xx Laser Measurement Sensors, SICK Sensor Intelligence, https://cdn.sick.com/media/docs/1/31/331/operating_instructions_lms1xx_laser_measurement_sensors_en_im0031331.pdf

3 Pride Mobility Products Corp. 2009, “Quantum 614 Series - Owner's Manual”. https://www.pridemobility.com/pdf/owners_manuals/us_jazzy/us_quantum_614_om.pdf

11.1 Appendix:

Appendix A: Drive Code Flow Chart