Intelligent Ground Vehicle Competition
Spring 2024 - Fall 2024

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ACRONYMS

IGV – Intelligent Ground Vehicle
IGVC – Intelligent Ground Vehicle Competition
CAN – Controller Area Network
ECE – Electrical and Computer Engineering
ODU – Old Dominion University
GPS – Geographic Positioning System
3D – Three Dimensional
FEA – Finite Element Analysis
G-Forces – Gravitational Forces
MAE – Mechanical and Aerospace Engineering
DC – Direct Current
BLDC – Brushless Direct Current
ABS – Antilock Braking System
ROS – Robot Operating System
AI – Artificial Intelligence
IDE – Integrated Development Environment
PWM – Pulse Width Modulation
USN – United States Navy
ASME – American Society of Mechanical Engineers
IEC – International Electrotechnical Commission

ABSTRACT

This report documents the progress in developing a novel IGV slated for competition in IGVC 2025 at Oakland University. The team's primary goal is to deliver a remote-controlled vehicle by August 2024 that is capable of integrating a state-of-the-art autonomous driving suite. This goal will be met by enhancing an existing frame, redesigning an inherited wishbone suspension system, and creating a newly designed deck plate while simultaneously developing a purpose-built motor and speed control algorithm utilizing Arduino and CAN bus capabilities. Careful considerations regarding material choice, design geometry, and system architecture were made with respect to factors such as manufacturability, serviceability, cost, and strength. The result of the team's efforts throughout this semester culminated in an improved wishbone, wheel hub, and speed control systems that are ready for prototyping and implementation onto the IGV. Planned for the summer and fall of 2024 is verification testing of all components to confirm proper functionality in the anticipated operating environments. Additionally, in cooperation with the ECE department, the remote-controlled IGV will be retrofitted and tested with lidar sensors and computational hardware to enable autonomous operation and the collection of training data.

INTRODUCTION

IGVs are becoming increasingly prevalent within many industries, some of which include automotive, food delivery, manufacturing, and military-industrial complexes [1]. Applications like lane detection in driverless taxis, autonomous delivery robots, and military transport vehicles all fall under the IGV classification [1]. In the case of ODU's IGV, autonomous mobility will be executed by an onboard autonomy suite that enables the vehicle to navigate a course without human input. The autonomy suite will be designed around a type of autonomous navigation known as behavioral cloning which utilizes training data collected from human-navigated trials and creates navigational guidelines based on observed patterns. This method of autonomous training enables the human operator to define reactions to observed phenomena and implement algorithmic learning to efficiently learn how to navigate a predetermined environment [2]. Previous implementations of autonomous driving at ODU have explored a method known as fuzzy control, which consists of an algorithm that sends out virtual tentacles to determine the system's distance from obstacles and maneuver around them [3]. Both methods mentioned above can be assisted by GPS positioning and lidar sensors to determine if the autonomous system is on the appropriate course [4].

To encourage the development of novel designs for autonomous navigation systems, the IGVC was created in 1993 for engineering students to develop intelligent vehicles to compete in a nationwide competition [5]. The primary objective of this competition is to develop a system capable of navigating autonomously through a standardized course. Critical design considerations that impact an autonomous platform are the range, size, distance, overall weight, payload weight, and expected terrain it will experience [1]. In the past, ODU has participated in the IGVC, where an electric mobility chair was adapted to satisfy the aforementioned criteria. Since ODU's IGVC debut, a new platform designed from the ground up has been in development and inherited by our team. This existing platform will be adapted to fulfill the needs of the competition while defining its speed, motor size, and bed size. As a result, the purpose of this project is to continue the development of an efficient

IGV platform from the ground up that can be adjusted continuously for future competitions. This will enhance the team's ability to create a more robust vehicle with higher reliability, greater payload capacity, and a wider range of tasks that can be accomplished.

METHODS

Project Management

Within the world of project management, two main methodologies drive how products are manufactured and developed: lean manufacturing and agile. Lean manufacturing can be described as traditional manufacturing that focuses on reducing waste and standardized procedures. The management of IGV needs to be flexible, quick-reacting, and fluid in communication. Agile can be described as a way to produce products in a more flexible and adaptable manner than traditional lean manufacturing [8]. This is accomplished through weekly check-ins, constant communication, and the determination of requirements from the beginning. Laying out the requirements in a list enables all team members to know what is expected and the tasks that must be accomplished. Since the team has a low budget and needs to reduce waste while producing products quickly, the blended agile and lean management style seen in Figure A.1 was adopted. The list of requirements and constant communication mentioned above facilitate this process. To create a work environment catering to the needs of the team, the manager schedules meetings through a group message board to keep all members informed of goals, requirements, changes, and deadlines approaching. The manager also takes a similar approach to communicating with the advisors, holding weekly meetings between the team and advisors. The manager can quickly track all progress and issues that arise with a quick check on parts and assemblies utilizing a cloud-based storage system and then inform the team to move forward with rapid prototyping. To produce prototypes and products quicker and at the same time reduce waste and cost; the manager utilizes rapid prototyping technologies such as additive manufacturing processes and CAD software.

Wishbone Suspension

Completed Methods

The IGV project encompassed significant knowledge of mechanical systems and took time to understand the current state of the inherited vehicle. After an overview of the full vehicle, some multiple key systems and components required redesign. The wishbone and hub assemblies will be discussed in the following section.

Previous teams left behind a wishbone suspension system that takes advantage of two wishbone-shaped control arms that mount to the top and bottom of the extruded aluminum vehicle frame and connect to the wheel hub assembly. The suspension system will dictate how the vehicle will support its weight as well as the degree of caster, camber, and toe of the hub assembly. The first issue identified with the previous team's wishbones is the material choice used for manufacturing. The material is Pa12-CF; a carbon fiber-infused nylon mixture meant for 3D printing sturdy but lightweight parts. The previous team printed them at low infill and wall thickness, greatly reducing the overall strength. This was deemed ineffective for sustaining the vehicle's full weight and, like two of the inherited wishbones, would most likely break at the ball joint connection.

It is difficult to determine the exact cause of this failure as they had already failed before the examination; however, due to the fracture occurring at the apex of the ball joint, it can be assumed that one of the contributing factors was high-stress concentrations in that region. Another suspected contribution to this component's failure is the composition of the material itself. PA12-CF is inherently hygroscopic with the absorption of water negatively impacting its structural properties. This hygroscopy can be mitigated by annealing the part at a temperature of 176 degrees Fahrenheit for 6 hours, however, upon visual inspection there was no evidence of this process having occurred. This led the design team to conclude that failure occurred as a result of absorbing water from the humidity of the environment at which it was stored and the prevalent stress concentrations at the apex of the ball joint's fitting.

To improve the design, the original wishbone design was measured thoroughly with a digital caliper and drawn in all relevant angles to ensure proper dimensions were taken. This allowed the suspension team to model new wishbones for improved strength and durability based on existing constraints. All designs here and going forward were modeled in SolidWorks (Dassault Systemes Corp., Waltham, MA) because it offers the best functionality and most efficient FEA software. A common feature of the new design was a stricter triangular shape with an arch between the frame mounting points. The arch helps distribute the mounting stresses more evenly while providing increased strength. The first iteration of the new design incorporated a thicker ball joint area to counteract what occurred with the original parts see Figure A.4. In the second iteration, this feature became a removable, off-the-shelf part that bolts through the end of the wishbone. This gives future teams a greater selection between potential ball joints and wheel hub mounting options while remaining repairable see Figure A.4.

As part of this redesign, a new material needed to be chosen that functioned differently compared to the previous Pa12-CF filament. The material needs to preserve mechanical integrity over a much longer period of time, be sturdy enough for the full weight of the IGV, and, importantly, be non-hygroscopic for a more reliable manufacturing turnaround. The FEA run on both iterations came out to be structurally sound with the most suitable material choice being a derivative of milled aluminum. For both iterations, the axial loading was fixed and a point load was applied at the hub joints. The type loading being considered during the analysis of the wishbones are – (i) static forces due to gravity and (ii) wheel-hub reaction forces with the ground. Utilizing an estimated maximum weight of the IGV of 100 lbs and an additional 18 lbs for each of the four wheel-hub assemblies, the following table of boundary conditions is generated:

TABLE 1. Quasi-static forces at 4x gravity

Quasi-Static Forces at 4G (Lbf)	
Wishbone Suspension	1765.8
Wheel-Hub Assembly	313.92

The fixed axial forces make the simulation easier as the wishbones act as cantilever beams; not too dissimilar to how the vehicle should operate in the field. The extreme loading conditions also help ensure that unexpected loading across the whole vehicle, such as a larger-than-expected payload, would not cause a catastrophic failure. Applying the loading conditions in Table 1 onto our team's newly designed wishbone, it was determined that Al 6061-T6 would provide both sufficient strength and the necessary resistance to displacement needed to ensure that there are no adverse effects to the steering of the IGV. With a maximum displacement of 0.0055", the functioning of the automated control system will not need to account for any steering deviations caused by flexure within the wishbone control arms.

Motor Hubs

Completed Methods

The next portion of the suspension system that needed redesigning was the inner component of the aluminum wheel hub assemblies. This portion is where both the top and bottom wishbones bolt onto, where the steering rack connects, and where the hub motor is fixed. The wheel hub assembly is split into three separate components: an outer hub, a top connector, and an inner hub, which all bolt together to create a "C" shape over the electric motor see Figure A.3. The main issue here is the interference fit that the top wishbone has with the connecting bolts for the top section of the hub. When all components are assembled, the top wishbone joint needs to be offset vertically by a significant distance, enough that it creates a lever arm. This was one explanation the design team came across for the joint failure on the previous Pa12-CF wishbones.

Since the main fix for the wishbones was increasing the ball joint thickness, the bolts on this hub piece needed to be half the height and countersunk significantly to allow for clearance, the inner hub is already a thicker part, so there is adequate room for milling down the region where the top wishbone bolts. In the area around the bolts, the design team concluded that milling down .13” of material and recounter sinking the bolt holes would solve the clearance issue. This solution was simple which made for low machining cost and a quick turn-around time on all four inner hubs. However, this decision also required new bolts that were half the head height of the original bolts to be purchased. These new bolts now sit flush with the newly milled surface, further reducing interference. A master assembly with this updated milled-out area was created to demonstrate the viability of this solution see Figure A.5.

Another issue is how the hub motor is fixed to the inner hub piece. The motor was found to be seated improperly and required two team members to pry the wheel from the hub. The shaft hole was discovered to be undersized slightly, which meant the motor was press-fit into the hub and did not require a retaining nut where one should be used. Once the motor was successfully removed from the inner hub, metal shavings were discovered. The motor shaft and casing are both an alloy of steel, which has a hardness greater than the aluminum inner hubs. The rotation and high torque of the motors caused the wheel to shave aluminum from the inner hub which is most likely why metal shavings were found.

Located at the base of the hub motor shaft is an extruded piece that should have rested flush on a shelf milled into the center of the inner hub. This shelf was meant to give enough clearance for the motor’s rotation but was not utilized because of a miscalculation on behalf of the previous team with their depths. The design team opted to both expand the area where the motor case comes close to the inner hub and mill the shaft hole down further to allow the extruded piece to rest on the existing shelf. This solution is also simple, which makes machining easier and cheaper.

A third issue was found when the hub motors were removed from the inner hub component; the wires providing power and sensor data were improperly routed and began getting sheared from the motor rotation. If left unchecked, the wires could become cut creating a short and disabling the wheels, ultimately requiring either new wheels to be purchased or an arduous disassembly and resoldering. The design team decided that milling the existing wire routing hole through the inner hub would be the most efficient solution. This solution also meant the area around the retaining nut needed to be milled out to account for the wires feeding through it. Expanding this area also fixed a minor problem with the fastening of the retaining nut as it was previously done by hand instead of with a ratchet.

Proposed Methods

With all these designs completed, prototyping was the best path forward in testing tolerances and interference fits. This is especially important for the inner wheel hubs because these parts already exist and cannot have material added back onto them. To ensure that the inner hub does not continue with any more interference issues, the suspension team is opting to 3D print the new hub designs before getting the existing parts machined. These 3D prints will be done with resin since this is a high-precision manufacturing process and the material offers the best resolution for checking tolerances. The new wishbone designs will also be 3D printed to ensure the billets of aluminum being purchased will have enough material and that the SolidWorks model is accurate see Figure A.4 .

After checking tolerances and fitments, the final designs will be sent to the Old Dominion machine shop on campus to get them fabricated. Once these parts have been fabricated, the entire wheel hub and suspension system will be set up on the vehicle for static load testing. If the suspension can keep the frame off the ground completely, then the redesigns and new parts will be a success.

Deck Plate Methods

Completed Methods

The deck plate of the IGV is responsible for supporting the load associated with the IGVC payload and electronics. The measurement process, design iterations, and analysis conducted on the deck plate were done using SolidWorks software suite, which aided in determining material requirements. The current ground vehicle (inherited by a previous team) consisted of an earlier deck plate that required the utilization of more resilient material (measurements taken of the plate consisted of a 36’’ by 24’’ width by ⅛’’ thick, adding 1’’ by 1’’ square cutouts at the four corners where the deck plate is localized in the chassis laying on all 4 sides as shown below in Figure 1). On all four sides, ¼’’ slot screw clearances were added to ensure equal integrity across the deck plate. With this information, the design's first version was formulated using SolidWorks, which has an analysis/simulation tool to perform FEA at the center of mass (Dassault Systemes Corp., Waltham, MA).

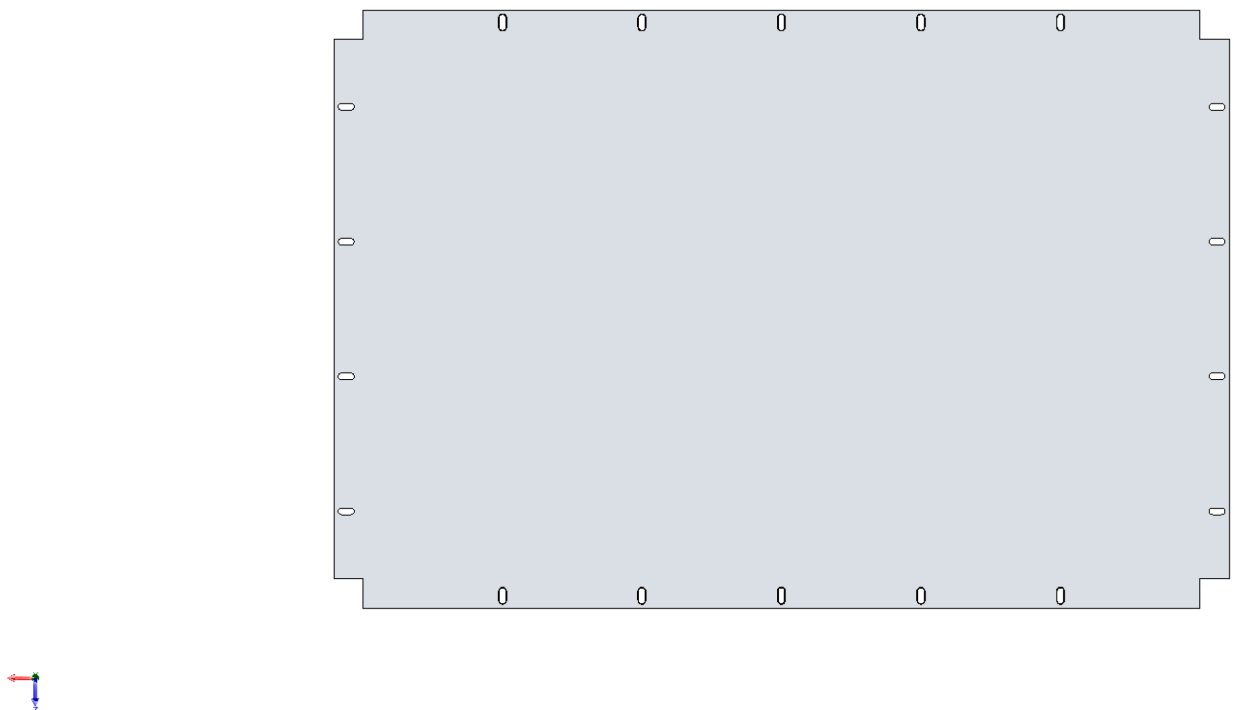


FIGURE 1: Deck Plate with all the measurements and screw clearances incorporated

With version 1 of the design being completed, the following process entailed the selection of a suitable material that best aided the deck plate construction for the ground vehicle. Choosing a material involved notation of all aspects the deck plate needed to go through for this project: vibrations, G-forces, weight (combined weight of 35 lbs), speed (0 to 5 mph), and deflection (less than ¼’’). Based on these parameters, aluminum was chosen for the deck plate. The most suitable variety of aluminum that meets all requirements is aluminum 5052-H32.

This material is usually the desirable option for ground vehicle application, as it is lightweight, has an excellent strength-to-weight ratio, making it favorable for maintaining stability and safety, and has good impact resistance, which helps absorb shocks and vibrations without compromising the integrity of the deck plate and electronic components, and excellent heat dissipation as the thermal conductivity prevents overheating and ensures optimal performance of the ground vehicle. The use of slots, an application to the screw clearances, provides substantial freedom when it comes to ensuring adaptability and the serviceability of the plate as they are opened up.

After these steps were completed, the next steps entailed placing a considerable amount of weight on the deck plate to test how sound the deck plate was. A 16’’ by 8’’ by 8’’ cinder block weighing 20 lbs was placed on the deck plate. The load is located at the vehicle's rear, providing a greater down-force on the rear tires to increase traction. Furthermore, the location of the cinderblock enables the electronics suite to be integrated at the front of the vehicle. Following the load are the electronics and battery, which will be the principal applications to make this vehicle function as intelligent. These together give off a resulting force of 603 lb-f. With the load, electronics, and battery on the deck plate see Figure A.2, an FEA with 4x G-forces with fixed geometry at all screw clearances was performed to calculate how much deflection the loads enact on the deck plate, in this case, was less than 0.02’’. The deflection, determined to be negligible, indicates that the deck plate maintains rigidity under applied loads, underscoring the structural integrity of the plate itself see Figure 5.

Proposed Methods

The future of the deck plate involves conducting research and development to address accessibility issues, particularly focusing on improving the vehicle's serviceability. This endeavor will require a significant amount of time and effort. The deck plate would benefit the team if it were removable without disassembling the chassis.

Upon the arrival of the aluminum deck plate, the subsequent action involves cutting out corners measuring 1” by 1” and creating ¼ ” clearances for screws. This process will be carried out using a water jet, as depicted in Figure A.2.

When the deck plate is completely polished, the electronics will be integrated. The batteries, wires, and other components will be set accordingly onto the plate, where they cooperate best. In addition to the integration process, a boom for instrumentation will be added to the plate, making it accessible.

As noted above, the main focus of the proposed methods section is to aid in future accessibility and serviceability options, implement the deck plate, electronic/boom integration, and increase modularity.

Electronics Integration and Control Systems Methods

Completed Methods

Developed in tandem with the mechanical platform of the IGV is a purpose-built control system that fulfills the requirements of motion: speed control, directional control, and their necessary safety features. The control system's design began as a continuation of a previous MAE group's attempt at making a self-contained motion system. The previous team had purchased 6 brushless DC motors, which were shown to have ample speed and torque to meet customer requirements of 5 mph at approximately 100 lbs of vehicle weight. Supporting the IGV is an inherited wishbone suspension system that utilizes 4 of the 6 brushless DC motors. Considering the wishbone's heritage and the suspension team's decision to iterate upon its design, the determination was made to develop a control system focused on manipulating a traditional four-wheeled rover through the BLDC motors on hand. From this determination arose a few engineering questions: how are the motors powered, what microcontroller is the best option to power the motors, does the motor send a feedback signal, and what signals are sent from the autonomy kit being developed by the ECE team, and how can the same signal be sent to several motors simultaneously?

The motors are powered through a three-channel input connected directly to the center of the hub; also connected to the center of the hub, is a hall-effect sensor embedded within the motor that serves as the feedback system discussed later in the paper. The three motor channels are connected to a motor controller which alternates power to each channel in a variable square wave to produce a turning motion. This process is made simple using a BLDC motor controller with a hall-effect sensor reader, the DC 6-60V 400W BLDC Three Phase DC Brushless Motor Controller PWM Hall Motor. This controller was chosen for its low cost, high availability, and its ability to integrate with motors. Unable to generate their commands, these motor controllers require a microcontroller to manipulate the speed, direction, and braking signals. While there are many microcontrollers, the Arduino Uno Rev 3 (BCMI, Italy) was chosen for its cheap, modular, and effective nature. In the IGV's proposed controller design, each of the four motors has a motor controller and a microcontroller to control the operation of each wheel. Figure 2 shows the basic layout for one motor.

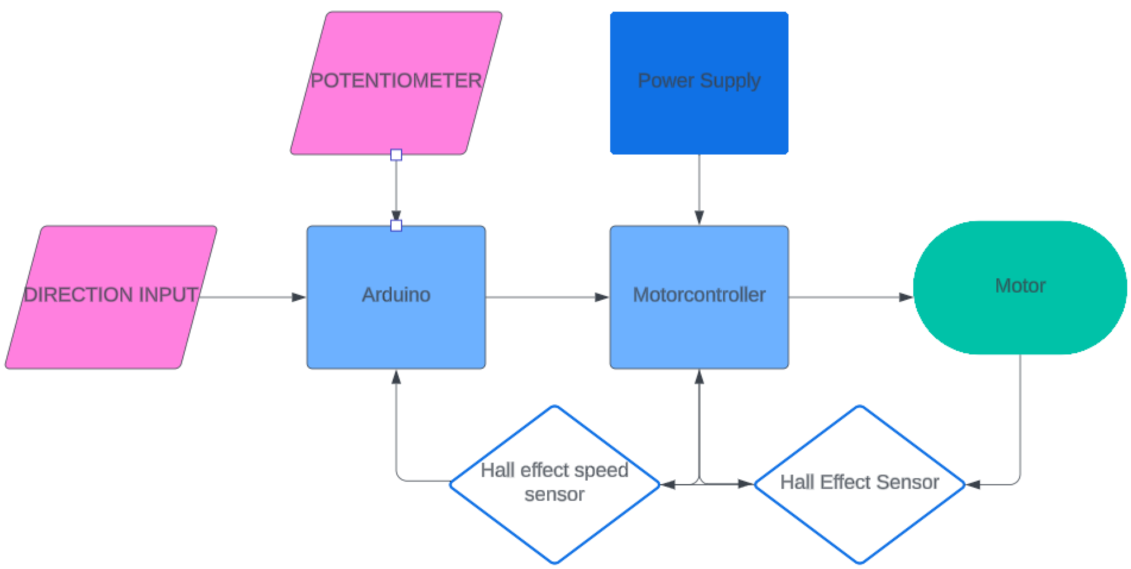


FIGURE 2: Block diagram showing system architecture for single tabletop controller

Currently integrated into this system is a real-time speedometer, functioning as feedback to the motor's user. This speedometer uses the aforementioned hall-effect sensors located inside the wheel. Hall-effect sensors detect wheel rotation by measuring changes in the magnetic field near a rotating component. These sensors are commonly used in vehicle ABS to monitor wheel speeds and prevent skidding. The hall-effect sensors generate a voltage signal, and the coded speedometer tracks this voltage signal, converting it to readable revolutions per minute. This code measures the signal when the wheel is at specific rotational positions and divides it by the time since the last signal. This is shown in Equation 1.

$$60/(period) = rpm$$

EQUATION 1: Hall-sensor to (RPM) revolutions per minute

$$Vehicle\ Speed = Wheels\ RPM * Tire\ Diameter * \pi * 60/63360$$

EQUATION 2: RPM to vehicle speed in miles per hour

This RPM data is then manipulated from Equation 1 to determine a hypothetical vehicle speed in miles per hour in Equation 2.

Proposed Methods

The Autonomy kit on the previous iteration of the IGV communicates from a black box, defined as an artificial intelligence system whose inputs and operations aren't visible to the user or interested party [7]. The black box is programmed to learn from human-controlled trials, analyzing their reaction to phenomena within the surrounding environment and using that information to map its autonomous reactions. This is done via an onboard Raspberry Pi (Broadcom, Palo Alto, CA) using ROS programmed by the ECE sister team. The Raspberry Pi sends commands to the main control Arduino that manipulates a single motor. The current IGV iteration is proposed to incorporate a redesign of the communication hierarchy from the inherited control scheme to one that utilizes Arduino control. This design replaces the single motor and motor controller with four self-contained Arduinos, each controlling its own motor and motor controller. This is all commanded by a CAN bus hub receiving data from the main control Arduino sending data to the four subordinate control systems. This method will be a seamless way to integrate the existing AI kit into the new multi-motor platform.

Research was done on multi-system controllers within the industry to solve the problem of multi-motor communication. A standout control approach utilized in the aerospace and automotive industry is the CAN bus. CAN bus is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other [6]. The proposed method for multi-motor communication involves a CAN bus that uses a main controller CAN bus shield to send signals to a CAN bus hub and down to four sub-controllers.

The first step in adopting the CAN architecture will be learning to control a singular motor with the CAN bus controllers. This will establish a starting point for adding more motors to the system while monitoring their feedback. The goal is to control all four motor Arduinos with the control Arduino currently utilized by the ECE team. Figure A.7 explains the hierarchy of the control system.

Preliminary Results

Wishbone

The results of the wishbone suspension design process as mentioned above meet strength requirements, cost, and functionality. The team achieved this by designing the wishbone with an already existing ball joint end. The result is the team only had to redesign the Wishbone body. As shown in Figure A.4 below you can see how the ball joint end connects to the wishbone.

Hub

With the hubs being already machined the team is only fixing issues that were mentioned above in completed methods. Once the new design shown below in Figure A.3 has been resin printed, the team will verify all issues are resolved and tolerances are correct, the team will proceed with machining the hubs with the in-house machinist.

Deck Plate

An FEA was assimilated across three different simulations: stress, strain, and deflection to ensure the deck plate's optimal performance. Stress articulates how applied loads and boundary conditions affect the plate's structural behavior; strain displays how deformation impacts the plate's structural integrity, and deflection conveys displacement/bending. In this case, shown in the three following figures, they relay negligible effects on the deck plate.

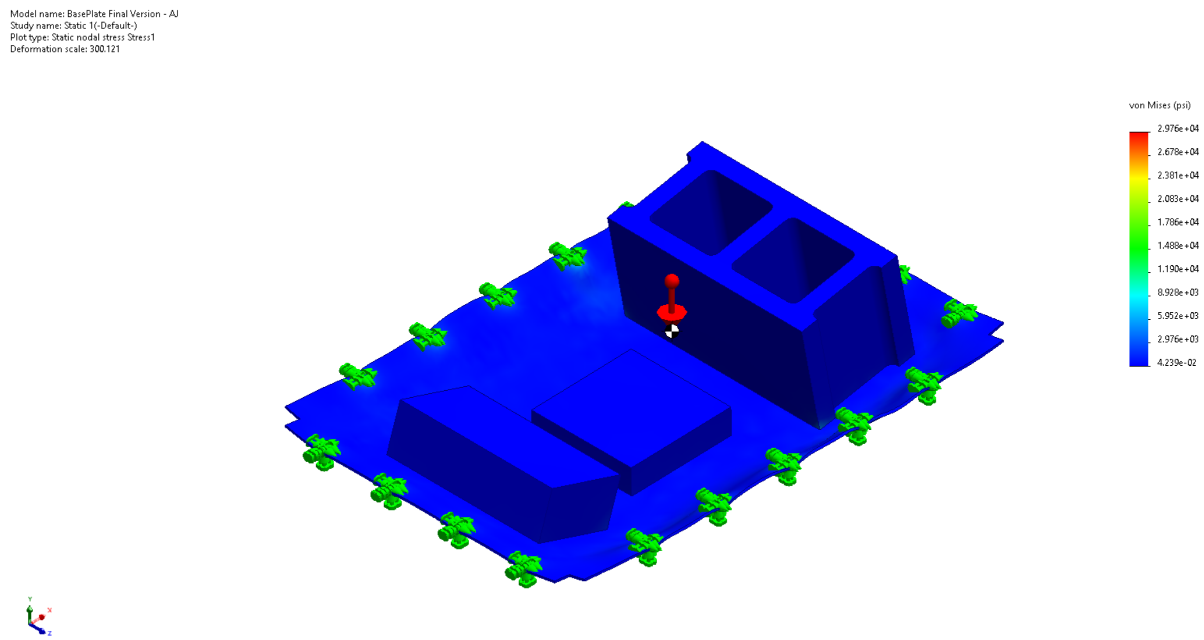


FIGURE 3: FEA of stress for the deck plate showing 0.04239 psi in Von Mises with a deformation scale of 300. The deformation scale demonstrates how the deformity on the plate is at such a greater magnitude.

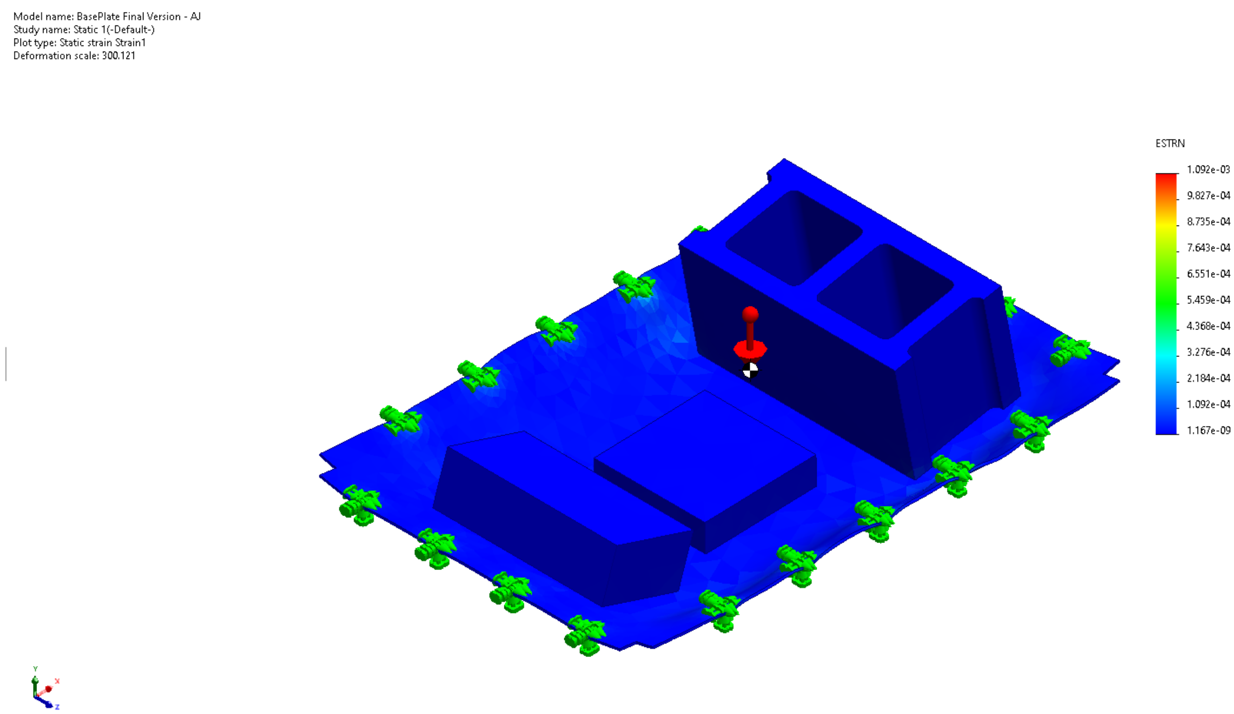


FIGURE 4: FEA of strain for the deck plate showing an equivalent of 1.167E-9

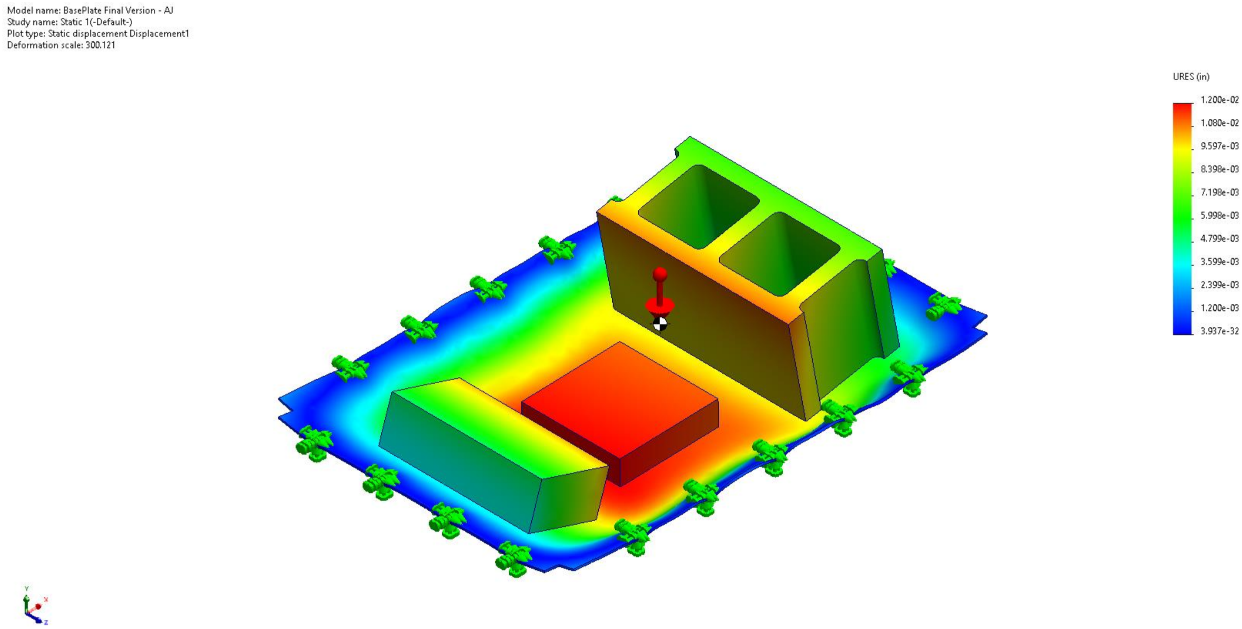


FIGURE 5: FEA of Displacement for the deck plate showing a deflection of less than 0.02’’

Electronic Integration

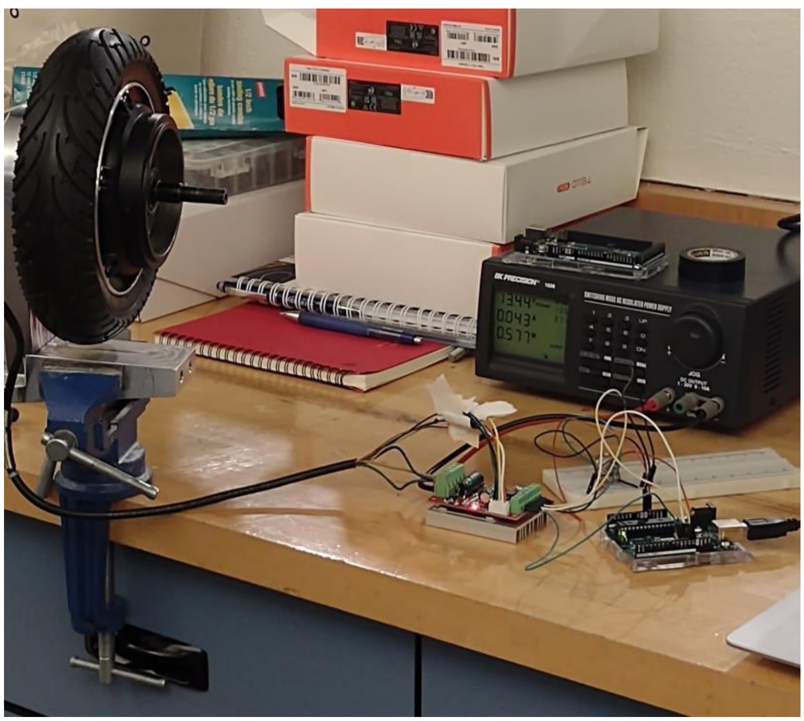


FIGURE 6: Completed single motor tabletop speed controller

A result is a tabletop controller for a single motor. This system features a throttle, a real-time speed controller, and a real-time speedometer read in from an integrated motor hall-effect sensor. This piece is crucial to the overall project, as the overall vehicle can not be controlled if a single motor can not be controlled. This subsystem, once ruggedized, will fit as one of four complete systems that will act as subsystems receiving commands from one main controller.

This entire process, from the direction control to speed control to the feedback system is done via code written in the Arduino IDE. In a broad yet intuitive outline, the code waits for a user input for direction, currently in the form of a selected integer. Once a direction is chosen, the user is free to modulate speed with the potentiometer, which also sends an integer to the program which is then output as a PWM signal. While the motor spins, a jumper attached to the motor controller reads the voltage signal from the Hall sensor into an interrupt pin on the Arduino which is then stored as a float variable and manipulated into a mph reading using Equations 1 and 2. The codebase is featured in Figure A.9 in the appendices.

DISCUSSION

Purpose

The project's purpose is to continue the development of an efficient and reliable intelligent vehicle platform from the ground up that can be adjusted continuously to compete and win in an autonomous robotic competition requiring a robust platform controlled by an articulate AI-commanded drive system. While this is the main objective of the IGV project, the implicit purpose is to understand and add to the ever-growing AI through interdisciplinary engineering efforts.

Limitations of the project

The limitations for IGV are time, money, complexity, and rules given by the IGVC rulebook. The team has a budget of $2000 for the entire vehicle. At the same time, we have received outside funding from the USN. The complexity of the vehicle needs to be simple to reduce manufacturing time, design, and calculation feasibility.

With only 6 months to prototype and build a final vehicle ready to receive a state-of-the-art autonomy suite is significantly shorter than standard practice.

Future work

As MAE 434W is the first portion of the overall undergraduate capstone project but also the portion with a higher focus on planning, there's still much work to be done on the IGV platform. Much of this future work will mimic the proposed methods section in the paper.

Hub and Wishbone Future Work

The upcoming tasks to be completed for the hub and wishbone section of the IGV include adaptive manufacturing of both wishbone and hub assembly to check the fitment and tolerances for machining. At this additive manufacturing stage, the materials for the final assembly and the aluminum blocks will be procured. Once the resin printed parts dimensions match with the SolidWorks model and fitment is checked, the final machining of the hubs and wishbones can be done by Old Dominion's Machine Shop. After the parts are machined preliminary assembly to verify tolerances and clearances are accurate.

Deck Plate Team Future Work

As previously mentioned in the methods section, the forthcoming tasks for the deck plate involve completing a solution for ease of access: setting and removing the deck plate from the vehicle. As well as a physical implementation of the plate itself with all the measurements, screw clearances, electronics, and boom.

Electronics Team Future Work

As stated in the methods section, the completed portion of the electronic drive system from MAE 434W consists of one complete wheel system with speed control and a real-time speedometer. This being said, there is much work still to be done. The very next step is the CAN bus controller integration, validation that two complete motor systems can be controlled simultaneously from one controller is crucial for planned system success. From there, it should be simple to get four complete motor systems integrated into the existing system, giving a full vehicle motion mock-up. It is one of the loose requirements that the system is operated via remote control. For the MAE team purposes, the remote control system will be done via the main control Arduino, but for the final system, the remote controls will come from the ECE team's ROS program Then the team can take a final step up, and begin to adapt the control system to speak in terms of the ECE team's ROS command to make the autonomous integration as seamless as possible.

Standards Used

The design of the deck plate and wishbone suspension requires an understanding of clearances for the fasteners. ASME B18.2.8 1999 R2017 elaborates and allows for the creation of loose fit, normal fit, and close fit clearance hole sizes for all holes for machining.

The electronics integration team carefully conducted their testing on the BLDC motor following the IEC 61010-1:2010, a list of safety requirements listed on the Arduino Uno for casual usage. These safety requirements were what allowed for testing upon hardware and software limitations of the Arduino Uno.

APPENDIX

FIGURE A.1: Lean vs agile project management methodology

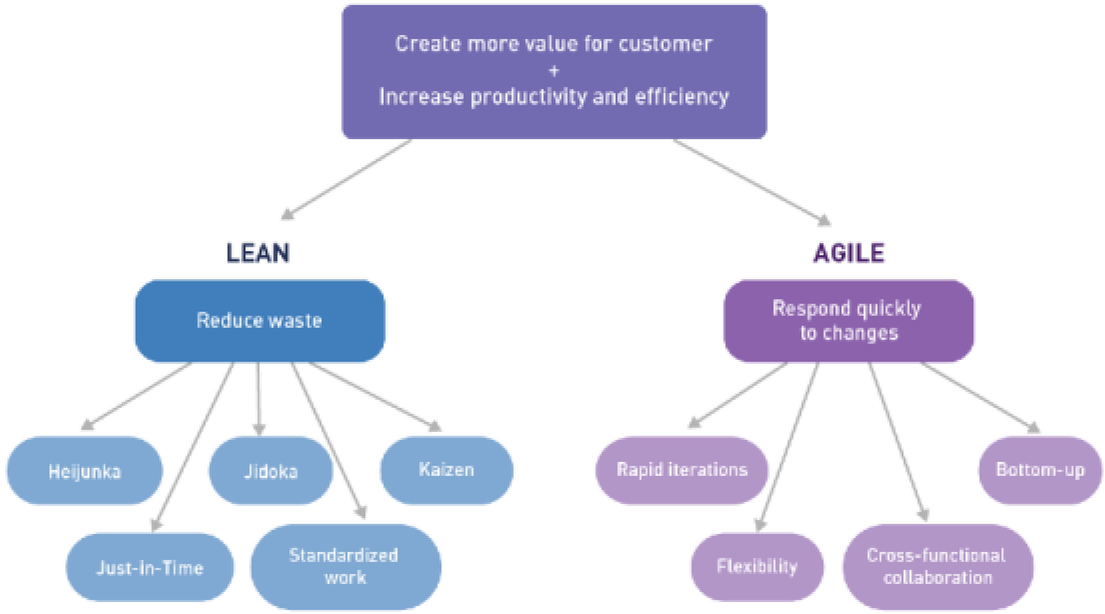


FIGURE A.2: Deck plate and loads

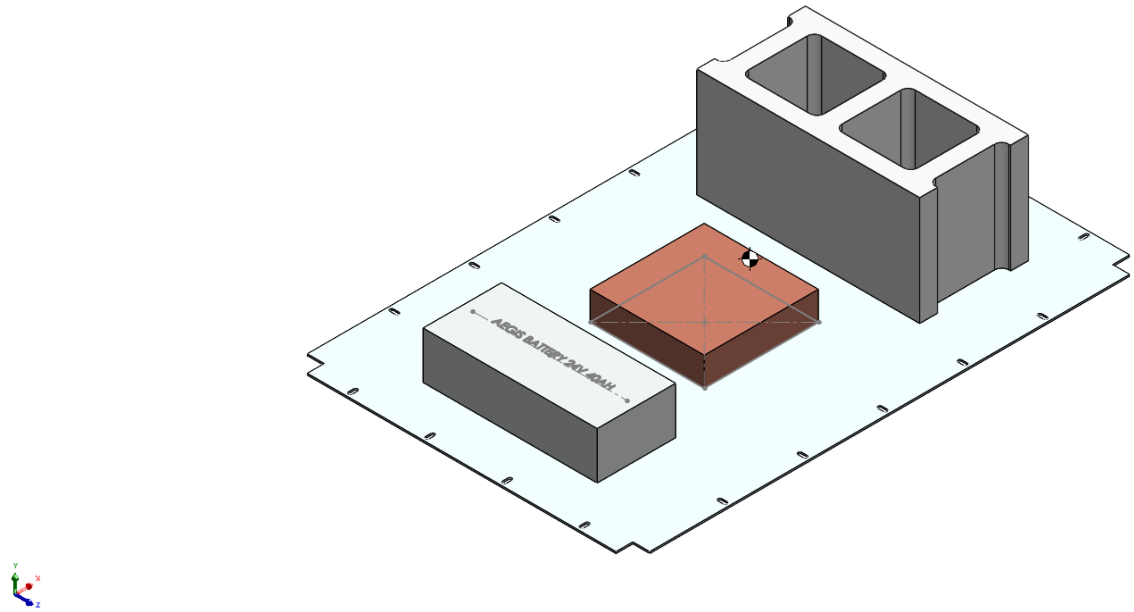


FIGURE A.3: Final hub assembly

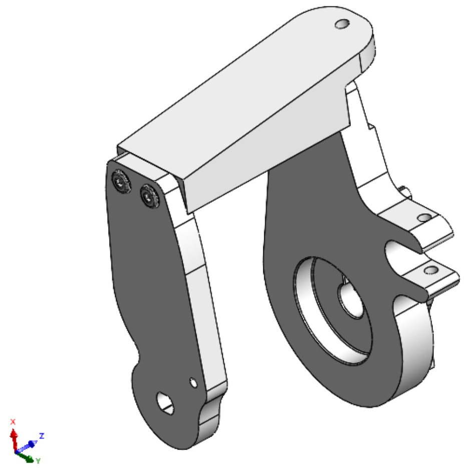


FIGURE A.4: Wishbone new design and legacy

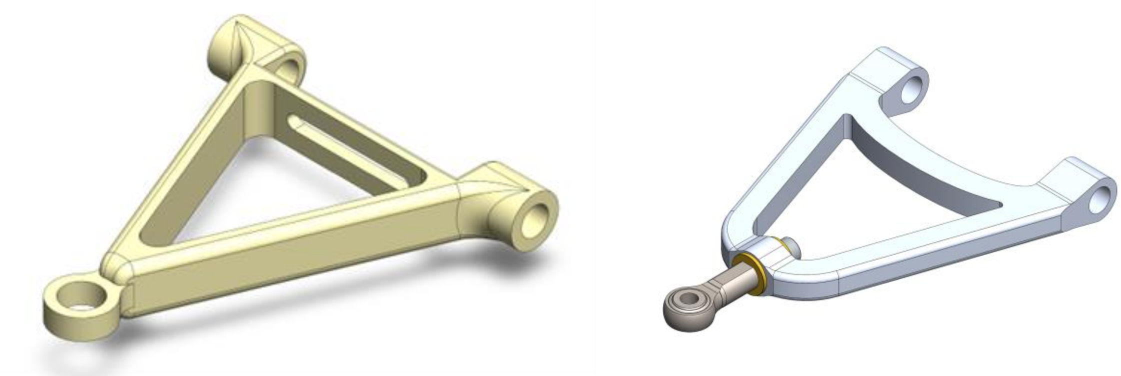


FIGURE A.5: Wishbone and hub assembly

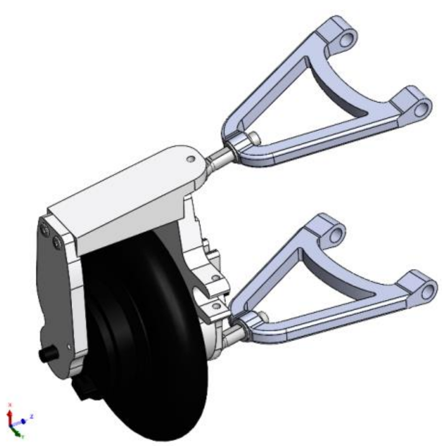


FIGURE A.6: Chassis

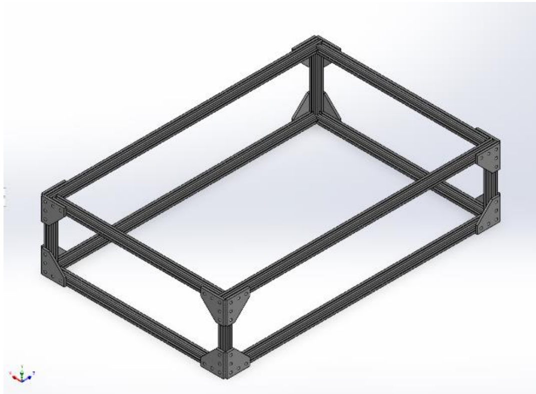


FIGURE A.7: Electronics path diagram showing the hierarchy of control from the ROSII commands to the CAN bus hub down to the motors

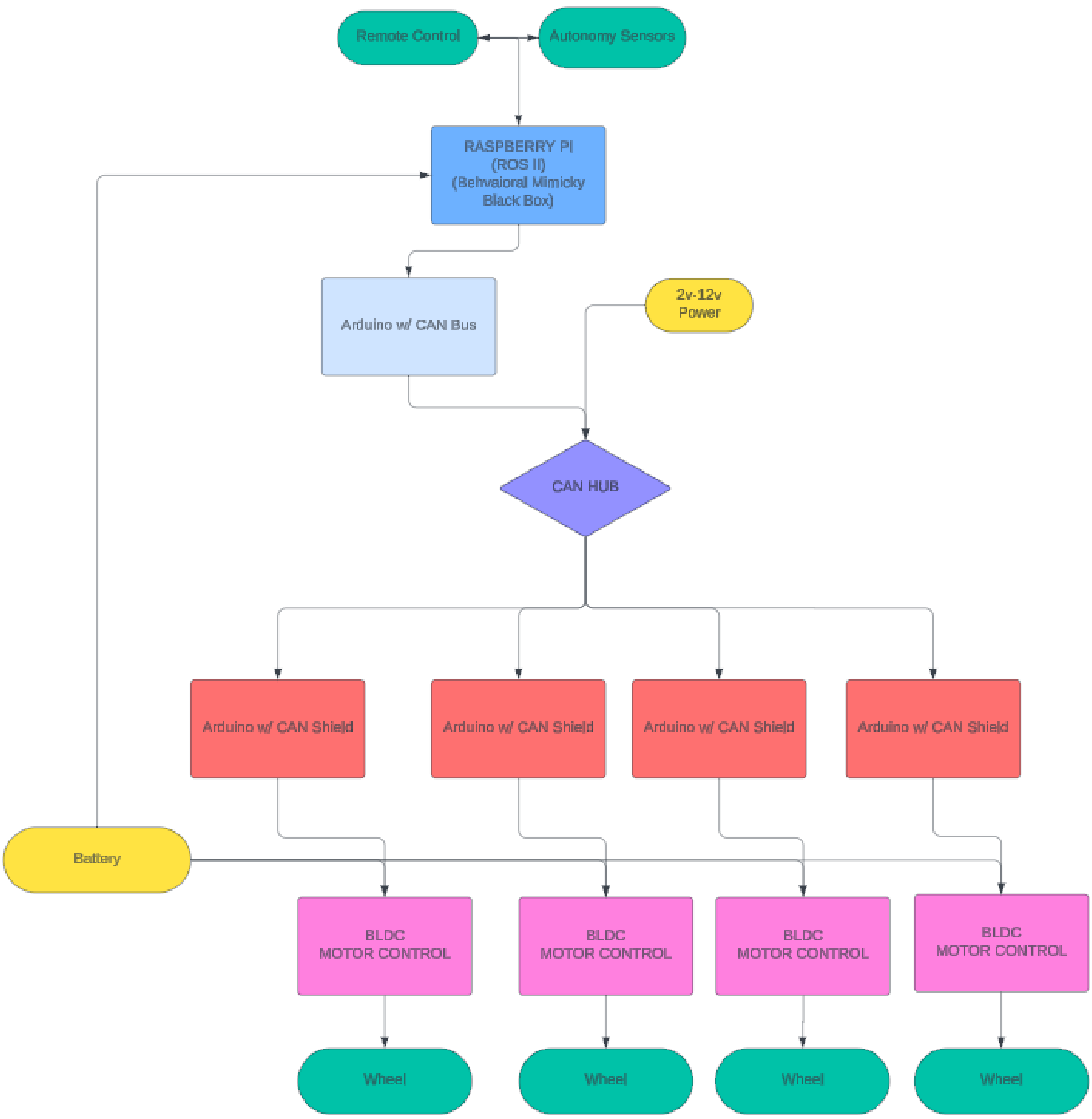


FIGURE A.8: Block diagram outlining the single motor tabletop system

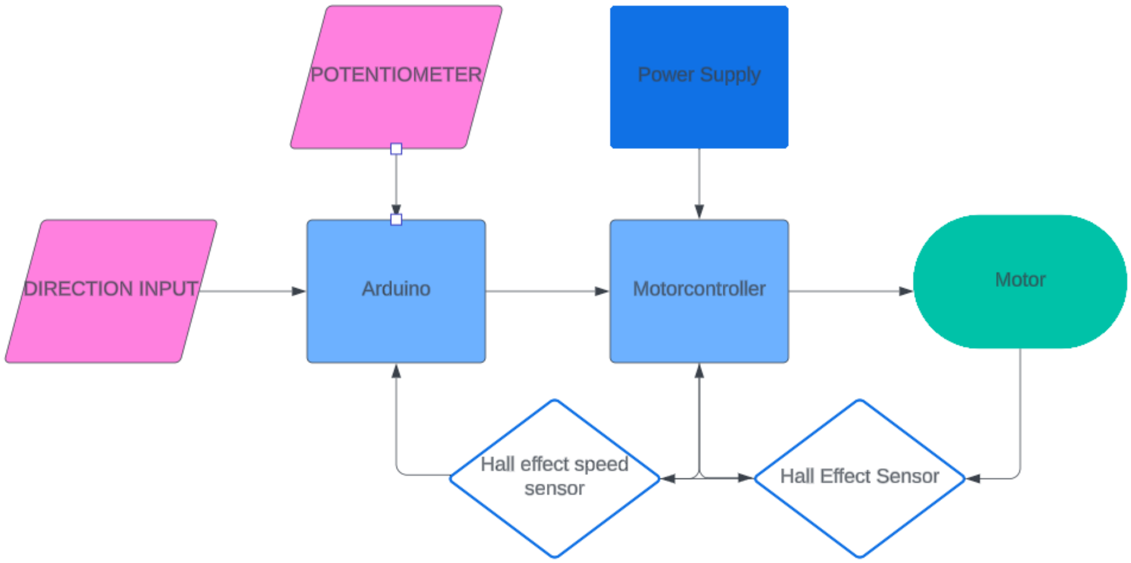


FIGURE A.9: Arduino Codebase

```
const int hallSensorPin = 2; // Hall effect sensor connected to digital pin 2
volatile unsigned int count = 0; // Variable to store the number of sensor pulses
volatile unsigned long lastTime = 0; // Variable to store the last time a pulse was detected
volatile unsigned long period = 0; // Variable to store the time period between pulses

int potPin = A0; // Analog pin for potentiometer
int speedValue; // Variable to store the speed value read from potentiometer

int motorState = 0; // 0: Stop, 2: Backward, 5: Power off, 8: Forward, 9: Brake

void setup()
{
  pinMode(13, OUTPUT);
  pinMode(12, OUTPUT); //Direction
  pinMode(11, OUTPUT);

  Serial.begin(9600);
  while (!Serial);

  attachInterrupt(digitalPinToInterrupt(hallSensorPin), hallSensorISR, RISING); // Attach interrupt to hall sensor pin
}

void loop()
{
  // Calculate RPM
  if (millis() - lastTime > 1000) { // Calculate RPM every second
    period = millis() - lastTime;
    float rpm = 2*(600.0 / period)*count; // Calculate RPM using count and period
    int tire_D = 8; //inches
    float mph =  rpm*tire_D*3.14159*60/ 63360;
    Serial.print("MPH: ");
    Serial.println(mph);
    count = 0; // Reset count
    lastTime = millis(); // Update lastTime
  }

  while (Serial.available())
  {
    speedValue = analogRead(potPin); // Read the potentiometer value
    speedValue = map(speedValue, 0, 1023, 0, 180); // Map the value to the range used by the ESC (0-180)

    Serial.print("Speed: ");
    Serial.println(speedValue); // Print the speed value to the Serial Monitor

```

```
    delay(1); // Small delay to stabilize the reading
    int state = Serial.parseInt();

    Serial.println(state);

    if (state == 2)
    {
      motorState = 2;
      Serial.println("Wheel Backward");
    }
    else if (state == 5)
    {
      motorState = 5;
      Serial.println("Wheel PWR OFF");
    }
    else if (state == 8)
    {
      motorState = 8;
      Serial.println("Wheel Forward");
    }
    else if (state == 9)
    {
      motorState = 9;
      Serial.println("BRAKE ENGAGE");
    }
  }

  // Control the motor based on the motorState
  if (motorState == 2)
  {
    digitalWrite(11, LOW);
    delay(10);
    digitalWrite(12, LOW);
    digitalWrite(13, HIGH);
  }
  else if (motorState == 5)
  {
    digitalWrite(11, LOW);
    digitalWrite(13, LOW);
  }
  else if (motorState == 8)
  {
    digitalWrite(11, LOW);
    delay(10);
    digitalWrite(12, HIGH);
    digitalWrite(13, speedValue);
  }
  else if (motorState == 9)
  {
    digitalWrite(13, LOW);
    delay(10);
    digitalWrite(11, HIGH);
  }
}

// Interrupt service routine for hall effect sensor
void hallSensorISR()
{
  count++; // Increment count when a pulse is detected
}
```

Budget

Summer 2024 Rapid Prototyping

1	Part name	QTY	P/n	Price per unit	Units	Source	Link	Total
2	Hub Screws(pack of 5)	30	93615A456	8.91	6	McMaster-CAR	https://www.mcmaster.com/93615	53.46
3	10lb Shock	2	STS40-010-C	21.52	2	Guden	https://www.guden.com/Item/Stan	43.04
4	20lb Shock	2	GGN42-020-C	10.97	2	Guden	https://www.guden.com/Item/Stan	21.94
5	Resin	1	ELEGOO Upgr	24.99	1	Amazon	https://www.amazon.com/ELEGO	24.99
6	PLA	1	Polymaker Matt	19.99	1	amazon	https://www.amazon.com/Polymal	19.99
7								0
8								0
9								
10	Grand Total	163.42						
11								

Fall 2024 MAE 435

1	Part Name	QTY	P/N	Price per unit	Units	Source	Hyper Link	Total
2	Aluminum blocks for Wishbones (6061,8"x8",3/8 thick)	8	9246K41	48.6	8	McMaster-CARR	https://www.mcmaster.com/products/metals	388.8
3	Frame Fastner Nuts (4 Pack)	20	47065T147	6.12	5	McMaster-CARR	https://www.mcmaster.com/products/80%2	30.6
4	T-Slotted Framing Structural Bracket	15	47065T278	12.1	3	McMaster-CARR	https://www.mcmaster.com/products/80%2	36.3
5	Top Whishbone ball joint to frame	6	60645k51	7.83	6	McMaster-CARR	https://www.mcmaster.com/catalog/130/12	46.98
6	Bolts For Ball Joint	1	92196A318	29.73	1	McMaster-CARR	https://www.mcmaster.com/catalog/130/35	29.73
7	Washer For Ball Joint	50	92916A395	22.86	1	McMaster-CARR	https://www.mcmaster.com/catalog/130/36	22.86
8	Single Frame Fastener Button Head screw (1")	80	47065T142	3.3	20	McMaster-CARR	https://www.mcmaster.com/products/80%2	66
9	Resin	1	ELEGOO Upgra	24.99	1	Amazon	https://www.amazon.com/ELEGOO-Washa	24.99
10	PLA	1	Polymaker Matte	19.99	1	amazon	https://www.amazon.com/Polymaker-PolyT	19.99
11								0
12								0
13								0
14								0
15	Emergency Funds	1	0	300	1	n/a		300
16								
17								
18								
19	Grand Total	966.25						
20								

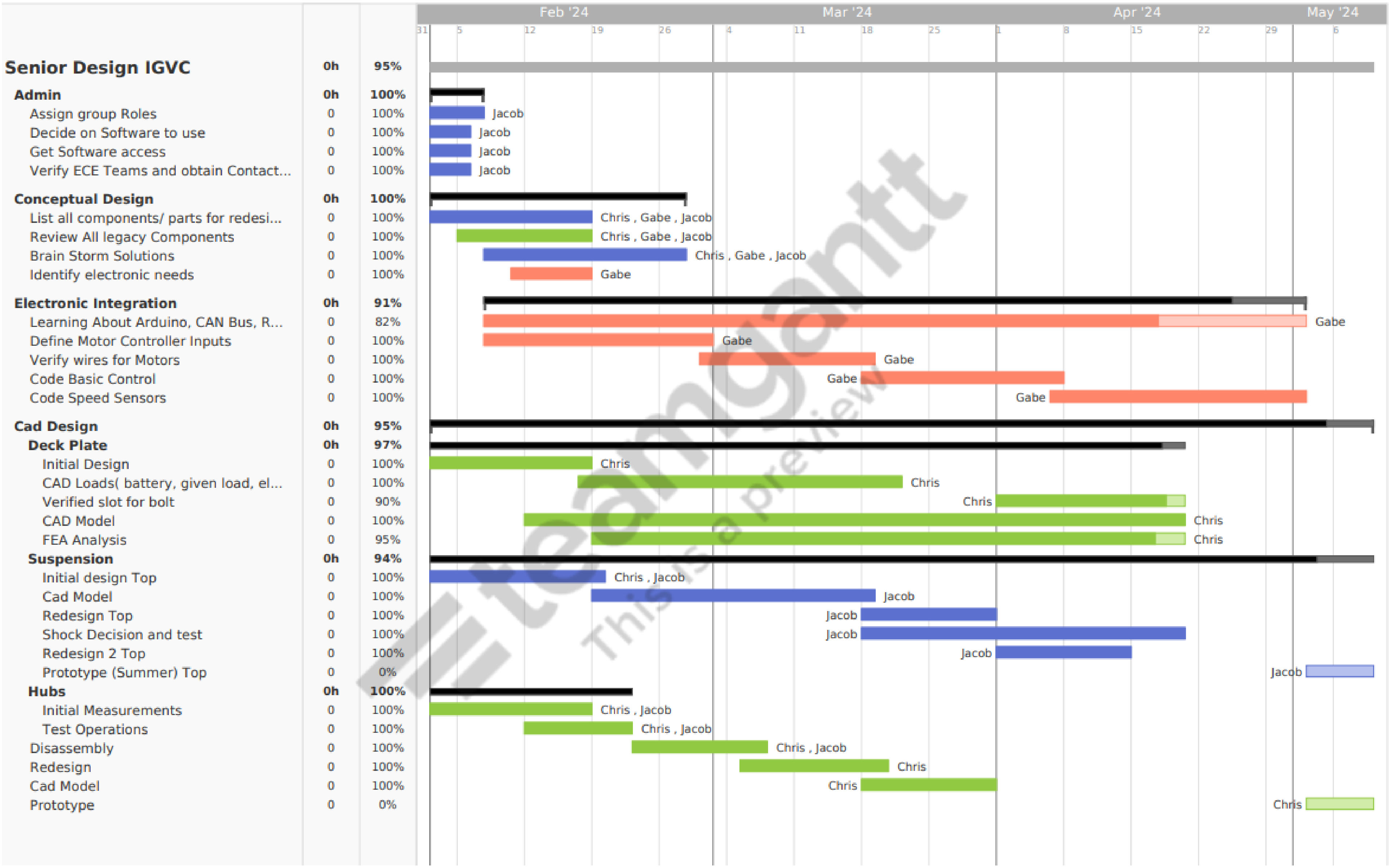
Man Hours

1	Name	Pay Rate ($ per hour)	434W(Hours)	Summer (Hours)	435 (Hours)	Total
2	Gabe	25	60	40	200	7500
3	Aj	25	40	30	135	5125
4	Jared	25	38	15	110	4075
5	Reece	25	40	25	120	4625
6	Chris	25	38	40	160	5950
7	Jacob	25	60	40	200	7500
9	ODU Supplied					
10	Lars (Machinist)	100	0.5	24	80	10450
11						
12						
13						
14						
15						
16	Grand Total	45225				

Electronic Integration (Naval Surface Warfare Center Dahlgren Division (NSWCDD)

Part Name	DESCRIPTION	Qty	Unit Price	Total Price	Link	Shipping Company		
Rasberri Pi	Raspberry Pi	2	55	110	https://www.canakit.com/raspberry-pi-4-4gb.html	Canakit		
Arduino CANBus sheild	CAN Integration Sheilds For Arduino	6	27	162	https://www.mouser.com/ProductDetail/Seeed-Studio	Mouser		
5052-H32 Aluminum Sheet	24" X 36" X .125"	1	150	150	****Dahlgren Order Source**** ideally out of scrap bin	***		
CAN BUS HUB	CANBUS hub for controlling four CAN systems with a High and Low CAN input	2	27.59	55.18	https://holybro.com/products/can-hub	holybro		
DC power supply 3005PM - Power supply	it would be nice not to steal Andy's power supply.	1	135.2	135.2	https://wifixusa.com/en/products/power-supply-dc-sugon-3005pm?gad_source=4&gclid=Cj0KCQjwk6SwBhDPARIsAJ59GwcG_fMGFGBO1oXnBluUVah0WgKiejkEd6tcZNE3LxI98-FG788tEKsaAuN6EALw_wcB	Wifix.usa		
RioRand 350W 6-60V PWM DC Brushless Electric Motor Speed Controller with Hall	BLDC Hall motor controller	6	17.99	107.94	https://www.vlidscrom.com/product-page/dc-6-60v-400w-bldc-3-phase-dc-brushless-motor-controller-pwm-hall-motor-e95?utm_source=google&utm_medium=wix_google_feed&utm_campaign=freelistings			
7-Port USB Hub for Raspberry Pi	Raspberry Pi USB hub	1	26.36	26.36	https://www.robotshop.com/products/7-port-usb-hub-raspberry-pi	robotshop		
RioRand 350W 6-60V PWM DC Brushless Electric Motor Speed Controller with Hall	BLDC Hall motor controller	6	17.99	107.94	https://www.vlidscrom.com/product-page/dc-6-60v-400w-bldc-3-phase-dc-brushless-motor-controller-pwm-hall-motor-e95?utm_source=google&utm_medium=wix_google_feed&utm_campaign=freelistings			
7-Port USB Hub for Raspberry Pi	Raspberry Pi USB hub	1	26.36	26.36	https://www.robotshop.com/products/7-port-usb-hub-raspberry-pi	robotshop		
Arduino uno R3	standard arduino board	6	26.3	157.8	https://store-usa.arduino.cc/products/arduino-uno-rev3-smd?queryID=undefined&selectedStore=us	Arduino		
				0				
XT30 Power Connectors (5 Pair)	CANBus hub power connector 5 pack	1	4.99	4.99	https://www.getfpv.com/xt30-power-connectors-5-pair.html?utm_source=google&utm_medium=cpc&utm_campaign=DM+-+NB+-+PMax+-+Shop+-+SM+-+ALL+%7C+Full+Funnel&utm_content=pmax_x&utm_keyword=&utm_matchtype=&campaign_id=17881616054&network=x&device=c&gc_id=17881616054&gad_source=1&gclid=Cj0KCQjwk6SwBhDPARIsAJ59GwcIIXFfzbuEiR9hs1f9tVKgelNpXcbB1QS31LqlrL8eUzqJgbfyF-EaAqybEALw_wcB	gettpv.com		
SHR-04V-S-B	Connectors to the CANBUS hub	20	0.123	2.46	https://www.digikey.com/en/products/detail/jst-sales-america-inc/SHR-04V-S-B/759868?_gl=1*ge2duy*_up*MQ..&gclid=Cj0KCQjwk6SwBhDPARIsAJ59GwcCl6Py27B2YB0JfFz0BRnbqyEUdiLVS8G0Yy0PDYqhl3mDtGeJLK0aAsl0EALw_wcB	digikey		
A04SR04SR30K	CANBUS connector jumper	10	1.27	12.7	https://www.digikey.com/en/products/detail/jst-sales-america-inc/A04SR04SR30K152B/6009390?_gl=1*ge2duy*_up*MQ..&gclid=Cj0KCQjwk6SwBhDPARIsAJ59GwcCl6Py27B2YB0JfFz0BRnbqyEUdiLVS8G0Yy0PDYqhl3mDtGeJLK0aAsl0EALw_wcB	digikey		
TOTALS			Price	924.63				

Gantt Chart


Feb '24
Mar '24
Apr '24
May '24
31 5 12 19 26 4 11 18 25 1 8 15 22 29 6
Senior Design IGVC 0h 95%
Admin 0h 100%
Assign group Roles 0 100% Jacob
Decide on Software to use 0 100% Jacob
Get Software access 0 100% Jacob
Verify ECE Teams and obtain Contact... 0 100% Jacob
Conceptual Design 0h 100%
List all components/ parts for redesi... 0 100% Chris , Gabe , Jacob
Review All legacy Components 0 100% Chris , Gabe , Jacob
Brain Storm Solutions 0 100% Chris , Gabe , Jacob
Identify electronic needs 0 100% Gabe
Electronic Integration 0h 91%
Learning About Arduino, CAN Bus, R... 0 82% Gabe
Define Motor Controller Inputs 0 100% Gabe
Verify wires for Motors 0 100% Gabe
Code Basic Control 0 100% Gabe
Code Speed Sensors 0 100% Gabe
Cad Design 0h 95%
Deck Plate 0h 97%
Initial Design 0 100% Chris
CAD Loads(battery, given load, el... 0 100% Chris
Verified slot for bolt 0 90% Chris
CAD Model 0 100% Chris
FEA Analysis 0 95% Chris
Suspension 0h 94%
Initial design Top 0 100% Chris , Jacob
Cad Model 0 100% Jacob
Redesign Top 0 100% Jacob
Shock Decision and test 0 100% Jacob
Redesign 2 Top 0 100% Jacob
Prototype (Summer) Top 0 0% Jacob
Hubs 0h 100%
Initial Measurements 0 100% Chris , Jacob
Test Operations 0 100% Chris , Jacob
Disassembly 0 100% Chris , Jacob
Redesign 0 100% Chris
Cad Model 0 100% Chris
Prototype 0 0% Chris

REFERENCES

[1] “The 30th Annual intelligent ground vehicle competition,” The Purpose of IGVC, http://www.igvc.org/objective.htm (accessed Feb. 14, 2024).

[2] D. Berenson, P. Abbeel and K. Goldberg, "A robot path planning framework that learns from experience," *2012 IEEE International Conference on Robotics and Automation*, Saint Paul, MN, USA, 2012, pp. 3671-3678, doi: 10.1109/ICRA.2012.6224742.
keywords: {Libraries;Robots;Maintenance engineering;Planning;Lightning;Path planning;Surgery},

[3] Shiwei Wang, A. C. Panzica and T. Padir, "Motion control for intelligent ground vehicles based on the selection of paths using fuzzy inference," *2013 IEEE Conference on Technologies for Practical Robot Applications (TePRA)*, Woburn, MA, 2013, pp. 1-6, doi: 10.1109/TePRA.2013.6556354.
keywords: {Niobium;Robots;Manganese;Path planning;motion control;fuzzy inference;unmanned ground vehicle;robot operating system},

[4] N. A. Rawashdeh, L. M. Alkurdi, and H. T. Jasim, "Development of a low-cost differential drive Intelligent Ground Vehicle," *2012 8th International Symposium on Mechatronics and its Applications*, Sharjah, United Arab Emirates, 2012, pp. 1-5, doi: 10.1109/ISMA.2012.6215184.
keywords: {Global Positioning System;Wheels;Sensors;Land vehicles;Cameras},

[5] Bernard L. Theisen "The 21st annual intelligent ground vehicle competition: robotists for the future", Proc. SPIE 9025, Intelligent Robots and Computer Vision XXXI: Algorithms and Techniques, 902504 (3 February 2014); https://doi.org/10.1117/12.2044468

[6] CSS Electronics. “Can Bus Explained - a Simple Intro [2023].” *CSS Electronics*, 1 Nov. 2021, www.csselectronics.com/pages/can-bus-simple-intro-tutorial.

[7] Kenton, Will. “What Is a Black Box Model? Definition, Uses, and Examples.” *Investopedia*, Investopedia, www.investopedia.com/terms/b/blackbox.asp. Accessed 22 Apr. 2024.

[8] Banas, D, Chovanova.H.H, “RESEARCH PAPERS FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA,”2023, Volume 31, Number 52, DOI 10.2478/rput-2023-0007