Team Maverick Machine

The University of Texas at Arlington

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

Signature	Signature
Dr. Chris McMurrough	Dr. Christopher Conly

1 Introduction

The purpose of this project is to provide a showcase of the Computer Science and Engineering Department at the University of Texas at Arlington during the Intelligent Ground Vehicle Competition. This would exhibit the technical skills, teamwork, and project management of the students working on this project. Additionally, displaying the final product at UTA would encourage incoming freshman students to pursue the academic programs of Computer Science, Computer Engineering, or Software Engineering. Designed for the 2023 Intelligent Ground Vehicle Competition, the Maverick Machine is a vehicular robot that must autonomously navigate through a course. By utilizing sensors and a computer, the robot will safely avoid obstacles, take turns, and traverse a ramp. Key requirements to accomplish this includes sensors (to navigate the local environment safely), controllers, and movement (to physically navigate the robot through the course). Currently, the vehicle is only to be used by the team and academic faculty member for the competition.

1.1 Organization

The development team includes Shreya Bhatta, Brian Quintero, Ethan Jobe, and Caleb Rivera. Altogether, the team will collaborate by performing software developer activities and redesigning the entire rover which include the wiring. Activities such as analyzing our projects requirements, designing and coding based on those requirements, testing, and maintaining our code base. Additionally, the University of Texas at Arlington is a sponsor, in which hardware, funding, and lab space are provided, in exchange for the team to represent the school at the competition. Dr. McMurrough is also involved with our project as a stakeholder, since he may provide advice and experience to the project, with the intention to help evolve the project into one that is successful and competitive.

1.2 Design Assumptions and Design Process

To address the problem statement our team will construct an intelligent ground vehicle that is able to compete in the Intelligent Ground Vehicle Competition. The Maverick Machine purpose is to maneuver through a course while avoiding obstacles all by itself. Therefore, the team has decided to use an electric wheelchair as the base of the Maverick Machine. Then the team will add features to the vehicle which include a camera, LiDAR and other object detection sensors if needed. Additionally, a computer is also needed to be added to the vehicle to compute all the inputs from the sensors and to move the motors of the electric wheelchair. Thus, software development is needed to tie everything together and make the Maverick Machine capable of navigating through the course during the competition. As a result, it will allow our team to exhibit our skills and provide an overview of the Computer Science and Engineering Department at the University of Texas at Arlington.

2 Effective innovations

2.1 Innovative Concepts

For innovative design concepts we used aluminum for the main structure because we have seen it used in buildings and provides a strong structure. Also with proper design files it can be sent to a factory to laser cut for a precise design. Next aluminum extrusion is used for the skeleton as it is very adaptable for a lot of projects. The T-slots along the edges provide countless ways to attach and connect pieces to the design.

Figure 1: Old Design

2.2 Innovative Technology

As innovative technology applied, we used Mission Planner Software that is primarily designed for Drone usage. Additionally, our RC transmitter was originally intended for drone control. As a result, we needed to be observant and ensure that we carefully distinguished between the documentation meant for rovers versus drones. We also decided to use Mission Planner instead of ROS which is what is commonly used robotics. While ROS offers extensive capabilities and flexibility for robotics applications. The decision to use Mission Planner reasons was to take full advantage of the algorithms that is already incorporated into Mission Planner, the way-point based-navigation and the mission planning. All these reasons align with the requirements of the competition.

3 Description of Mechanical Design

3.1 Overview

Our vehicle is a converted electric mobility wheelchair, without the seat attached. It features two 12V lead-acid batteries connected in series to produce 24V, which is encased in a lower level housing, away from all electronics. In place of where the seat was, is a new structure. It contains iron housing along the walls and sides, with electronics and breakers inside it. For support, 80/20 aluminum T-slot extrusions can be found along the sides for structural support. Since an electric wheelchair base was used, suspension, motors, and wheels were already attached.

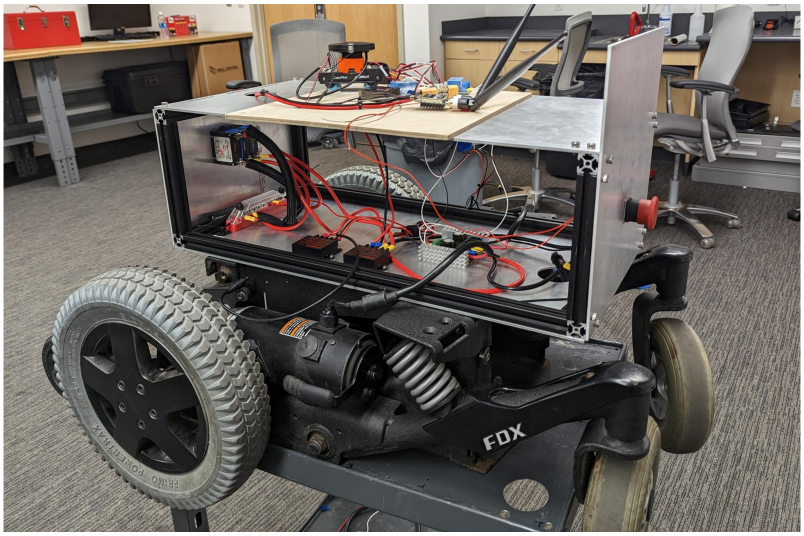

Figure 2: Side profile

3.2 Decision on Frame Structure, Housing, Structure Design

For the design of the Maverick Machine, we decided for a standard box structure for the simplicity of the design as well as the ability to easily carry a payload on the roof. The vehicle housing is made from aluminum attached to aluminum extrusion. Since aluminum is very durable and stable. The overall design was the have all major components inside the box design, with holes on the roof and floor for wires to connect to outside the box. A mandatory addition was to include holes to connect the wires from the motors to in motor controller inside, though instead of a hole, we used an arch cut so that the side walls could be removed. The roof has 3 walls extended up to provide a housing for the cargo.

4 Description of Electronic and Power Design

4.1 Overview

Our rover is designed to be powered by two 12 volt lead-acid batteries that are connected in a series circuit. This setup allows us to to power our electronics and the electric wheelchair's motors. Based on testing, the batteries can run the rover for around 2-3 hours but also depends on the usage of the motors or speed. With these batteries it allows to charge the vehicle when it is not being used. Furthermore, the Cube Orange serves as the primary component for controlling the vehicle by sending signals to our motor controller called the Sabertooth 2x32. Also in between the Cube Orange and the Motor controller is where we implemented the Mechanical and Wireless E-Stop to provide the safety requirements. Additionally, another major component is our UP Squared which is integrated into our system to enable input of computer vision algorithms, while Lidar and c920 cameras are utilized to detect objects in the surrounding environment.

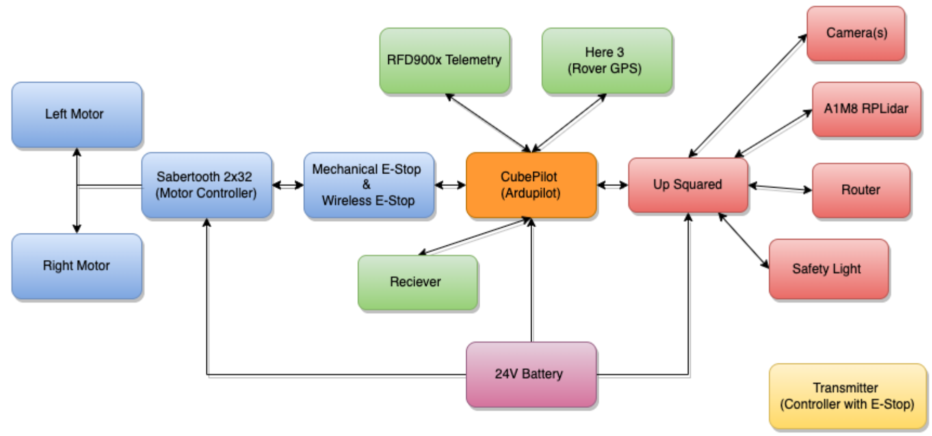

Figure 3: Electrical Design

4.2 Power Distribution System

Power distribution plays a critical role in any electrical system, ensuring that electricity is delivered safely and efficiently to various components. For powering the vehicle's motors and its components uses two 12-volt deep cycle sealed lead acid batteries that are securely positioned at the base of the vehicle. These batteries that are connected in a series can generate 24-volt output that will satisfy the demand of motors and the other components. To safely power ON and OFF the entire system, we added a 50 amp breaker to allow us to flip a switch that is located in front of the vehicle. The system also includes other breakers that are assigned to the Cube Orange (includes components that attached to Cube Orange) and one to the Sabertooth 2x32 Motor Controller. This allows us to power each individually if need be. In order to reach the 24V, we added two bus bars distinguished by their red and black colors. This serves us as bridge to the batteries that power the whole system. Since some components just need 5V instead of 24V (which include UP Squared, the Router and Cube Orange) we added converters that will step down the voltages to power the components safely with their desired input voltage. These converters will output the 5V and are located inside the metal compartment with all the components. The Cube Orange also comes with a battery management system called the Power Brick Mini that will provide the sufficient power to all the devices that are connected to the Cube Orange. Furthermore, 5V is also being provided to the A22 push button switch (Red Button E-Stop) this will cut source of the power when the button is pressed, cutting all signals to the motor controller and stopping the vehicle in place. Therefore, based on testing done the batteries can sustain power to the whole vehicle for a duration of approximately 2-3 hours. However, it is important that it can depend on the intensity of motor usage during operation.

4.3 Electronics Suite Description including CPU and Sensors System Integration/Feedback Concepts

4.3.1 UPSquared

The UPSquared is a key component for the robot's navigation system and general processing. This CPU controls sensors data from the navigation sensors and generates motor commands, interfacing with the Cube Orange autopilot. The compact size of the UPSquared makes it an ideal fit for placement inside the robot. The computer features quad-core Intel Atom E3950 processor, 8GB RAM, and 128GB of storage, providing plenty of power for the robot's needs. Additionally, it is interfaced with the router via Ethernet to allow other nearby computers to remote desktop into the computer, useful for setting up software before an autonomous run as the robot features no monitor.

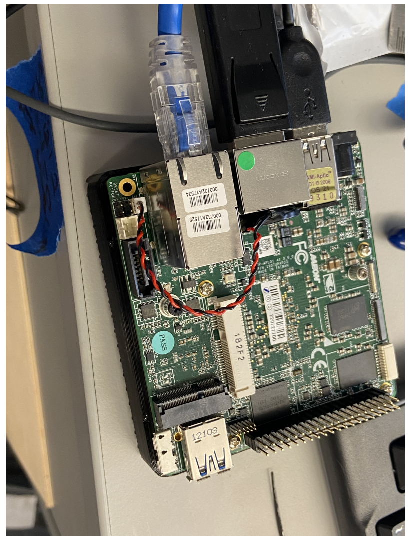

Figure 4: UP Squared

4.3.2 Cube Orange and Here3

The Cube Orange autopilot, together with the Here3 GPS module, provides the robot with precise location and orientation information, enabling it to navigate along a pre-determined path, useful for waypoint navigation. The autopilot communicates with the UP Squared CPU over a serial connection, receiving high-level commands and sending back telemetry data. The Here3 GPS module uses real-time kinematics (RTK) to provide sub-centimeter accuracy, making it suitable for navigating the robot to waypoints.

4.3.3 Sabertooth 2x32 Brushed Motor

The Rover runs on a Sabertooth32x2 motor controller that provides incredible performance and easy interfacing. This motor controller can be reprogrammed using the DEScribe software. Currently the DEScribe software is used for near immediate motor shut down when signal is lost. The motor controller is set up for independent control of the left and right motors, and it is controlled through the use of PWM servo signals. The basic concept involves generating motor commands through navigation software on the UPSquared computer, transmit to the Cube Orange autopilot, and finally sent to the Sabertooth through PWM signals.

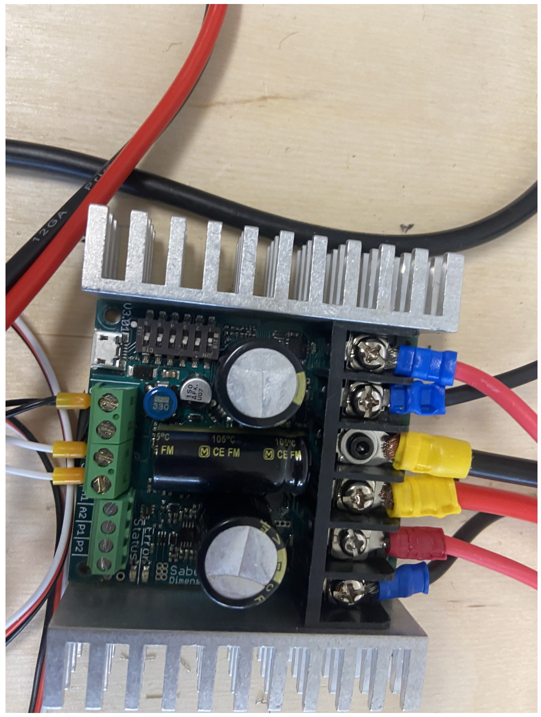

Figure 5: Sabertooth 2x32 Brushed Motor Controller

4.3.4 Navigation Sensors

The robot's navigation system includes an RPLidar A1M8 and two c920 webcam cameras. The Lidar is useful for object detection, while cameras can be utilized for lane detection. Our small, yet powerful UP Squared is perfectly capable of processing Lidar information and two camera modules to justify it's motor commands to the CubePilot. Overall, the Lidar measures a 2D plane of objects, obtaining angle and its corresponding distance. Meanwhile, the cameras have a Hough Transform algorithm overlaid to detect, track, and avoid lanes on the course.

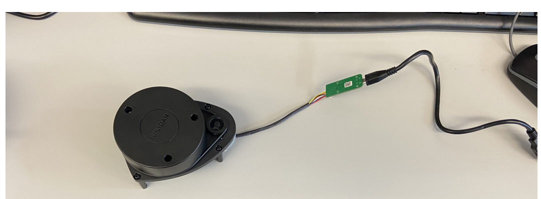

Figure 6: RPLidar A1M8

4.3.5 Router and Telemetry Radios

To interface with the UP Squared computer on board, a router provides the infrastructure to allow computers to wirelessly connect and remote desktop into the computer. This is useful for teammates, since anyone can access and monitor the robot in real time.

Additionally, RFD900x-US telemetry radios is provided as a secondary way to interface directly with the CubePilot. This way we can access the CubePilot's firmware and signals on another computer, completely detached from the UPSquared. This freedom has proven to be useful during developmental stages as we did not have to solely rely on the UPSquared for communication during testing and troubleshooting.

4.3.6 Receiver and Transmitter

To manually control the robot, or wirelessly e-stop the robot, a R12DDS receiver is connected to one of the Cube Orange's servo channel. Connected to that receiver is a RadioLink AT10II RC transmitter. The transmitter is able to control the channels on the Cube Orange. Manually controlling the robot has been useful for fine-tuning the robot's control and behavior, as well as testing e-stop functionality.

Figure 7: RC Transmitter

4.4 Safety Devices and Integration into the System

The Safety Subsystems are to ensure the safety of anyone near the vehicle during operation. This provides the user of the vehicle to have total control over the vehicle during operation. The user can cutoff power with an E-Stop when needed if any malfunction occurs. Therefore, keeping the people around the vehicle safe to prevent any accidents of occurring. While the vehicle is in operation a safety light will ensure people to become more aware of their surroundings and to keep a safe distance of the vehicle. These subsystems are important to have in order to safely operate the intelligent ground vehicle.

The Safety Light will allow people to know when the vehicle is in operation and when it is operating in autonomous mode. The Safety Light (LUBAN LED SIGNAL TOWER STACK LIGHT) requires a program to switch between ON,FLASHING, and OFF.

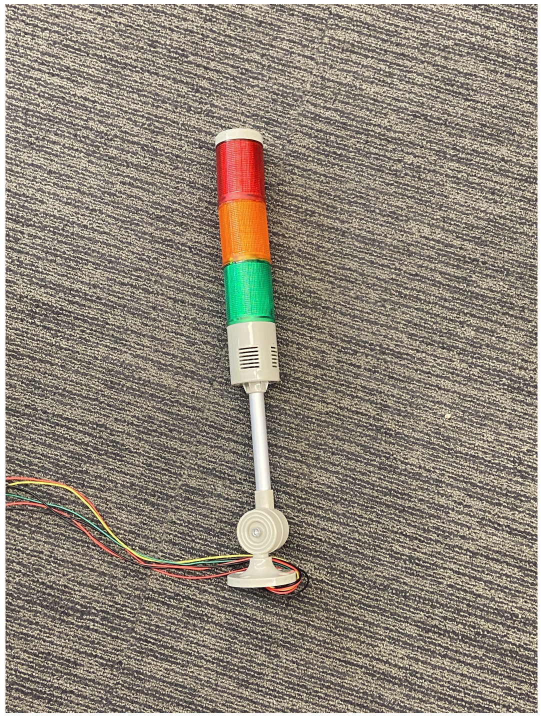

Figure 8: Safety Light

The E-Stops will provide the user control over the vehicle by having the ability to completely cut off the signal to the vehicle's motors during any moment. This ensures the vehicle to safely operate and turn off when needed if any malfunction occurs. Both of the E-Stops will be hardware and not software due to the rules of the competition. The mechanical E-Stop (A22 pushbutton switch) will have power run through the switch and once pushed it will cut off the signal to motor controller stopping both motors. The Wireless E-Stop will have RC relay switch providing an option to cut off the signal to stop both motors from a distance. The RC Transmitter will have switch to communicate to the RC relays making them switch ON and OFF. Labels will be found on the RC Transmitter to clearly locate the switch that will work for the Wireless E-Stop.

5 Software Strategy and Mapping Techniques

5.1 Overview

The robot uses potential fields and RTK for navigation and obstacle avoidance while generating 2D mapping of the world around it using real-time readings from the RPLidar A1M8. By using two cameras, Hough Transform is utilized for lane and pothole detection.

5.2 General Path Planning and Obstacle Avoidance Strategy

We utilize Real-time Kinematic Position, or RTK, for accurate positioning of waypoints. The robot is programmed to use potential fields to navigate to the designated No Man's land, follow the generated waypoint, and then proceed to the final goal, which also has its coordinates marked due to RTK. By utilizing cameras and RPLidar technology, the robot can identify and follow valid, open paths while avoiding invalid ones. The stream of data from the cameras and RPLidar are essential components as it processes the information to make informed decision about the robot's path. The following sub sections represent each component's role for path generation in a more detailed manner.

5.2.1 Hough Transform

Hough Transform is a popular technique for lane detection, as it can be programmed to capture geometric shapes of a designated color. For the sake of the competition, this includes detecting white lines and circles, for lanes and potholes, in a camera's feed. By utilizing two cameras, we are able to obtain a wide viewing angle. As the camera's stream gets captured, techniques like Gaussian blur and Canny edge detection are used to help pre-process the image by getting rid of noise and enhance edges. Next, Region of Interest (ROI) is applied to the stream of frames, as its used to encapsulate the area we want to only detect. This is useful, since white straight lines and circles can only be detected within the ROI, and other straight white lines (or circles) in the feed, like clouds in the sky, are ignored. By applying the ROI as a trapezoid, which takes the bottom 1/3 of the image, the Hough Transform can be applied here. This is accomplished in Python with HoughLinesP (and HoughCircles), as well as an upper and lower threshold of white colors. As seen in the Figure below, a test image with lane detection is clearly marked. The basic idea for the robot is to determine the steering angle to move away from the white lines. As long as the detected lines are treated as objects, the potential field algorithm described in the next subsection will help determine this for us.

Figure 9: Test Image with Hough Transform

5.2.2 Potential Fields

Potential fields navigation is a method that can be used to navigate a robot through obstacles and towards a goal. By obtaining lanes and potholes from the cameras, and objects from the RPLidar, potential fields can be generated to repel from said obstacles and attract toward the goal. The attractive forces are created by setting up virtual potentials at the goal location, which pulls the robot towards it. This is made possible through RTK, since it gives accurate coordinates for the robot to pull towards. The repulsive forces are created by setting up virtual potentials around the obstacle, which push the robot away from it. The combination of attractive and repulsive potentials creates a vector field that directs the robot towards the goal while avoiding obstacles. Essentially, the idea is to continuously update the vector field based on the robot's current location and the detected obstacles, then the robot can navigate towards the goal while avoiding obstacles in real-time.

5.3 Map Generation

Real-time readings from the RPLidar A1M8 are utilized to generate 2D mapping of the world around the robot. This map is consulted to make informed decisions about its path planning and obstacle avoidance.

Figure 10: Distance Map From RPLidar A1M8

6 Description of Failure Modes, Failure Points and Resolutions

6.1 Vehicle Failure Modes and Resolutions

One failure mode was the way-point based navigation. Our configuration for controlling the vehicle was set to one motor to throttle left and the other motor to throttle right. The problem comes when we map it to the RC transmitter on the two joysticks.For the left joystick it will be for going forward and backwards and for the right joystick it was for turning left and right. This configuration caused a problem when the vehicle was navigating based on way-point making it spin in circles. When it marginally wanted to move left or right it caused it to spin out since it stopped moving forward. What we needed it to do was keep moving forward and at the same time turn left or right. To resolve this issue we mapped the servo outputs on the RC transmitter to one joystick fixing the way-point navigation.

6.2 Vehicle Failure Points and Resolutions

One failure point we encountered was testing the vehicle indoor or nearby tall buildings. This caused the GPS coordinates of the vehicle to be off or not even get a GPS lock. To resolve this we had to find a location (large open parking lot) that will be clear of any tall buildings in order to test the vehicle properly. Another failure point we encountered was when we initially received the vehicle from anther team's project. We invested significant amount of time on the learning about the wiring of the old vehicle but found out that it was best to redo the whole wiring again. This was also needed since the old vehicle was not able to carry a payload and a new redesign was required.

6.3 All Failure Prevention Strategy

The Maverick Machine is built to last and will have the ability to withstand any certain circumstances. From the wiring to the build design itself, time was spent to make sure these components of the system was robust. Also time was spent of making sure the safety measures was carefully added to the robot.

6.4 Testing

On testing not a lot time was spent moving the vehicle outside due to issues that needed to be resolve while also focusing more on safety. The weather conditions also had a notable impact on our testing the vehicle outdoors. More time spent testing inside was done to the vehicle to enhance the safety of the vehicle.

6.5 Vehicle Safety Design Concepts

The overall safety design concept of the vehicle involves using a Safety light so the vehicle is more noticeable, wireless E-stop that is found on the RC transmitter, and the mechanical E-stop (Red Push button) found at the back of the vehicle. These safety design concepts prioritize the well-being of individuals and enable users to take swift action in the event of malfunctions or potential hazards, ensuring the secure and controlled operation of the intelligent ground vehicle.

7 Simulations Employed

7.1 Simulations in Virtual Environment

For a lot of development, Mission Planner has been utilized. As for simulation, Ardupilot Mission Planner can be used as a powerful simulation tool which takes Cube Orange auto pilot configurations and parameters to perform in various waypoint and autonomous scenarios. By running scripts to enable this, we can observe its behavior to navigate between waypoints, and change the robots heading based on the input data given to it, such as obstacles. By utilizing this simulation, we can refine performance to navigate properly. The main objective in using the simulator has been for algorithmic development, such as potential fields. Overall, Mission Planner is an excellent way to optimize an algorithm for waypoint navigation since it does not require physical limitations in early developmental stages.

Figure 11: Mission Planner Simulation

8 Performance Testing

Performance testing is critical to ensure the robot can effectively navigate. Accuracy and speed testing is still under evaluation. Utilizing RTK we predict to have sub-centimeter coordinate points, but without RTK we have gotten waypoint accuracy within a parking space. In addition this, manually controlling the robot has been fine tuned via PID, and it is assumed that auto navigation will be able to use these same PID configurations. As for the Hough Transformation, it is accurate enough for realistic lane avoidance, when using a human observer to verify the detection in real-time.

9 Initial Performance Assessments

The newly redesigned electrical system for our robot is a remarkable achievement. It boasts a clear, easily repairable, and modular design that is future-proof for upcoming iterations. Moreover, the electrical system is encased in a new robust, factory-grade metal box that can withstand heavy payloads. The development of the waypoint navigation, manual control, and autonomous navigation features is progressing as intended. With a new custom-built vehicle, we aim to achieve success in competing and qualifying for this upcoming competition!