Gannon University

Macro Mouse

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I certify that the design and engineering of the Macro Mouse has been significant and equivalent to what could be a senior design project.

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Table of Contents

1. INTRODUCTION

The IEEE student club is a student organization within the College of Engineering and Business of Gannon University. One of the functions of the IEEE student club is to run and support three robotics competition teams, the micro-mouse team, the sumobot team, and the macro mouse team. This year is the first time of the macro mouse team to enter into the 27th annual Intelligent Ground Vehicle Competition (IGVC). The macro mouse is a 170 lb robot, consisting of a wheelchair base, a motor controller, an electrical compartment, and a sensory system. The macro mouse was built on top of Jazzy Select wheelchair base with two batteries included. The sensory system consists of the Inertial Measurement Unit (IMU), Global Positioning System (GPS), a camera, and Light Detection and Ranging (LiDAR). The electrical compartment includes the motor controller, a safety light control, and a wireless E-Stop.

1.1 Team Organization

The macro mouse team is led by one Electrical Engineering senior student. The other four group members are from three different majors as shown in the following table.

Team members	**Major**
Tenger Batjargal (Captain)	Electrical Engineering
Niklas Bitters	Computer Engineering
Peter Caulfield	Mechanical Engineering
Steven Rowland	Computer Science
Timothy Jackson	Mechanical Engineering

1.2 Design Assumptions and Design Process

Two members of the macro mouse team have just successfully completed their senior design project, the autonomous snow removal robot, as shown in Figure 1. It consists of a powerful wheelchair base for the powertrain, installed encoders for the speed feedback, sensors for autonomous action, as well as the precise GPS navigation system. Many of the features and design of the autonomous snow removal robot have been adopted for the development of the macro mouse. Although it seems the design process of the macro mouse has not started until a couple of months ago, part of its design has actually been undergone several rounds of revision through the autonomous snow removal robot. The main design tasks have been completed for the macro mouse in the past months are:

- Selection of the onboard laptop
- Selection and the installation of the LIDAR
- Mechanical frame of the robot
- Selection and the installation of the camera

- Software for the navigation system

Figure 1. Autonomous snow removal robot

2. EFFECTIVE INNOVATIONS

2.1. Adopting and hacking the wheelchair power train

The idea of adopting or "hacking" the wheelchair was developed by those two members from the autonomous snow removal robot when they started designing their robot. The advantages of using the wheelchair base was that it had already mechanical structures such as a frame, wheels, motors, and batteries in place. Those structure enabled team members to implement and design a control method, other electrical and electronics pieces much faster since there was a test platform. In addition, since the wheelchair is manufactured from a company, the team members did not need to worry about the alignment of wheels and suspension system of the robot which saved tons of time.

2.2. Other innovative technology applied

Control system

The control system for the macro mouse utilizes Sabertooth 2x32 as its electric drive to control two 24V DC motors. The Sabertooth 2x32 provides many different control methods such as PWM signal, analog signal, and serial packets. In the macro mouse development we have decided to use serial packet control via USB port since our main processing unit is a laptop.

Object Detection System

For detecting objects purpose, in our case the cones in the competition, we have chosen to use RPLidar A2 sensor, which provides 360 degrees of scanning in 12m radius. The sampling rate can be adjusted by controlling its rotating speed and amount of samples per second.

Processing Unit

On the previous autonomous robot developments such as the micromouse and the autonomous snow removal robot, our team have used development board such Raspberry Pi and Arduino microcontrollers to accomplish the tasks. Even though, our processing capability was enough for certain tasks, it was not enough for macro mouse implementation where we had to process all the input signals from camera, LIDAR, GPS, and IMUs simultaneously in real-time to control the motors properly. Therefore, we have researched to get a powerful processing unit that can serve our purposes. There was a debate between choosing from a mini-PC and a laptop, but we have decided to pursue with laptop because of its built-in keyboard, display, and power system. If we were to move forward with a mini-PC, we would have to have separate keyboard, display, and mouse to develop the software, and more importantly an additional power distribution system to power up the mini-PC during the operation.

Camera

There was not much of decision making in process of choosing the camera. Our team had a camera with USB output from a previous project, so we have decided to utilize it for the macro mouse development.

Xbox Kinect

An additional RGBD camera - from an Xbox Kinect - will be utilized to normalize, build, and improve upon the close reference frame points within the point cloud to remove stray points that do not accurately represent the environment and may throw off the path planning algorithm. A simple approach is used to remove and mitigate these points using the RGB data and depth data, each point in space contains a reliability value which will degrade each update if the point exists within the cameras theoretical frame of view and if no points exist in close proximity within the vector space to the point in question.

3. MECHANICAL DESIGN

3.1. Overview

The macro mouse's mechanical system is designed to have solid and enduring structure, stable, and lightweight. As shown in figure 2, the robot base is adopted from a Jazzy Select wheelchair. The metal frames were added to form different compartments for variable functions. The vertical pole is to hold the cameras at certain height. The solid base frame is to hold the onboard laptop, the LiDAR, and the electronics tray. A second vertical pole was added to place the emergency stop button at a comfortable height. An additional front frame is added for anticipation to have external payload. The length of the robot is 37 inches, width of 25 inches, and height of 5.5 ft which are in the required size amounts. The turning radius of the robot is 22.5 inches. One of the things we have added in the robot was to change the wheel size. The Jazzy Select wheelchair had wheels with 10 inches of diameter, which did not provide enough ground clearance. Therefore, we have changed the wheels with 14 inches of diameter to increase to the ground clearance of the robot.

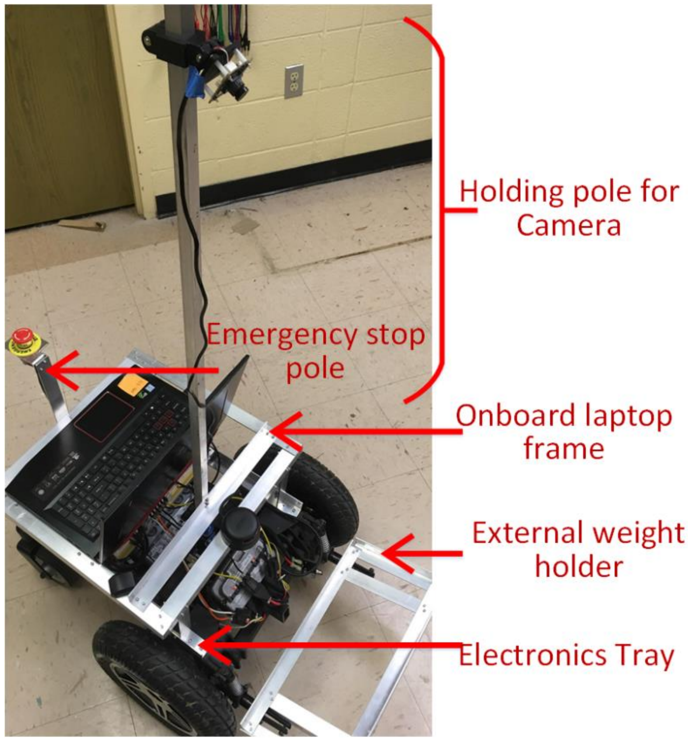

Figure 2. Overview of the mechanical structure of the macro mouse

3.2. Structure design

The structure design was implemented simply to support the processing unit along with sensors and electrical devices on the robot. The main material was an aluminum angle brackets.

3.3. Suspension

The wheelchair base has Active-Trac® built-in, and it can handle up to 300 lbs of load on top of it. This weight limit excludes the wheelchair parts such the batteries, and the chair. Therefore, we have more than enough room regarding the payload capacity of the robot.

4. ELECTRICAL DESIGN

4.1. Overview

The Jazzy Select wheelchair has two 12V batteries. The main electric drive using the Sabertooth H-Bridge can also supply output of 5VDC at 1Amp. There are three different levels of power such as 5V, 12V, and 24V in the system.

4.2. Power distribution system

The motors are controlled with 24VDC level from the batteries through the motor driver. As mentioned above, the Sabertooth can convert the 24VDC to 5VDC at 1 amp to supply power to microcontroller for E-Stop and IMUs. A buck-convertor is stepping down 24VDC to 12VDC for the Safety light. The LIDAR, GPS, and camera are being powered by the laptop since it has its own built-in battery.

4.3. Control system

Processing Unit
Acer Predator Helios 300 is a laptop that has 16GB memory, Inter Core i7, and NVIDIA GeForce GTX 1060 graphics processing unit. The processing unit will be handling all the sensor information and controlling the motors except the E-Stop signal which needs to be handled by a microcontroller.

Motor Driver
Sabertooth 2x32 Dual Motor H-Bridge has many different features, and one of which is that it can support a mechanical E-Stop. When E-Stop engages, Sabertooth would not kill the power of the system, but it would simple disable the motors.

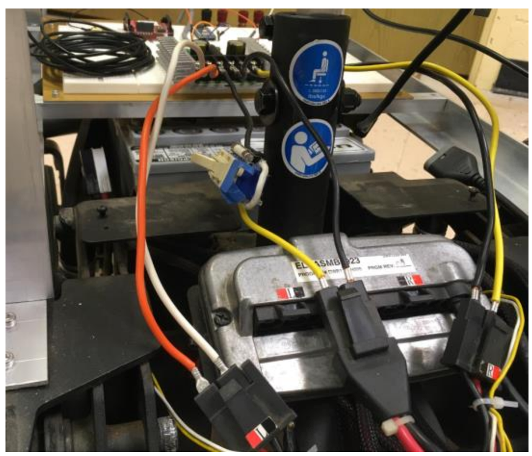

Figure 3. H-bridge to motor connections during testing

4.4. Sensor system

Camera
1080p USB Camera to detect the lines in the course.

GPS
SparkFun GPS-RTK2 Board - ZED-F9P (Qwiic). This GPS can allow the robot to have 10 mm or 1 cm resolution when it comes to positioning with RTK according to the datasheet.

Moreover, the board itself support USB serial, I2C, SPI, and UART interfaces which gave us lot flexibility to communicate with it.

Light Detection and Ranging (LiDAR)

RPLidar A2 is manufactured from SLAMTEC, and it can provide ranging information within 12m radius for 360 degrees.

Gyroscope and accelerometer

GY-521 MPU-6050 IMU is relatively cheap and widely used sensor for robotics development. Our team is looking forward to utilize this sensor to relative turning displacement of the robot.

Compass

Wingoneer GY-273 QMC5883L is being used to provide the macro mouse absolute heading direction to support the GPS waypoint navigation.

4.5. Safety devices

E-Stop

nRF2401 2.4 GHz modules are being used to actuate the Wireless E-Stop. The ranging of the module can be around 400 ft at maximum. The mechanical E-Stop in located on back of the robot.

Light

Alert beacon LED that runs at 12VDC is being used for the safety light. The LED blinks normally, but we have managed to make it controllable to switch between solid light and blinking light.

5. SOFTWARE STRATEGY AND MAPPING TECHNIQUES

5.1. Overview

The primary software strategy relies on four main data sources: the GPS modules positional data, the LIDARs two dimensional environment map for obstacle avoidance, the fusion of the IMUs magnetometer and accelerometer information for absolute rotation, and the RGB camera to generate a 3D point cloud for path planning. A full estimation of the state of the system can be generated from this data along with a relative map of the environment.

5.2. Obstacle detection and path planning

Object detection is primarily handled with the point cloud estimation generated with the data from the camera with ORB SLAM. A mesh is created from this point cloud to give an estimate of object shape and size. The ground plane is first detected and then a parallel process was implemented to test multiple scenarios simultaneously to find the best path to the target coordinate around obstacles; the shortest path with highest probability of success is constantly updated to generate a new trajectory. The point cloud is constantly updated, if a path with a high success probability fails then new paths are tested.

5.3. Software strategy

The main codebase will be developed in C++ for high reliability, high efficiency, ease of use within either a linux or windows environment, and for ease of library use with existing software. Software standards will be based on clear/consistent coding style, maximum utilization of self-documenting code, use of modular and polymorphic structures - no code duplication, proper data encapsulation, commenting where necessary, and concise methods.

5.4. Map generation

The primary navigational map is generated with ORB SLAM as a point cloud converted to a polygonal mesh. However, a secondary map is maintained with information from the PRLidar. This secondary map is purely a backup obstacle avoidance in the case of failure of the primary navigational map, a similar method for avoidance is used with the PRLidar as with the ORB SLAM method except only in two dimensions.

5.5. Goal selection

The target goal of for navigation will be defined as a precise latitude and longitude value as the positional reference frame is defined by the GPS module. Once the goal is set, path generation can begin based on the current environmental map.

6. FAILURE AND RESOLUTIONS

The mechanical frame was made with aluminum angle brackets to provide different compartments to house the computer, electronics, and sensors. The mechanical vibrations may disrupt the camera image and lead to loose bolts and nuts. To resolution is to sufficiently secure the camera and to introduce fast image processing technique. The lock nuts and washers are used to prevent the loosening items from the vibrations.

All electrical and electronics devises in the system are properly connected with fuses to prevent the damaging overcurrent. Current limitation mechanism will also be implemented for certain part of the circuity to prevent it from overheating.

The common failures of software, such as communication error, algorithm runoff, and inaccurate data, are handled by providing larger margin of storage and fast computation capacity with onboard computer. The fast data processing feature also provides minimum time delay for real-time navigation. We have planned for multiple check safety features, but due to the short duration of the project, they are not implemented at this stage of the design.

7. CONCLUSIONS AND FUTURE WORK

The Macro mouse is our first attempt of the IGV project. Due to the time limit, we designed it to meet at least the qualification requirements of the competition. When we select the onboard computer, the sensors and most of the devices, we left large margin and capacity for further improvement. The algorithm and the software can be improved to provide faster and more accurate response and decision making. We see the IGV and plan it as a multiyear project and would like to enter the competition year after year with improvement.