INTRODUCTION, ORGANIZATION, DESIGN PROCESS AND SYSTEM OVERVIEW

Introduction

The Professional Autonomous Vehicle Engineering (PAVE) team from Ohio University (OU) has designed and developed the autonomous ground vehicle, dubbed Pathfinder, to join the 25th Annual Intelligent Ground Vehicle Competition (IGVC) at Oakland University in Rochester, Michigan. Our team members include undergraduate and graduate students in the School of Electrical Engineering and Computer Science (EECS) under the guidance of Professor J. Jim Zhu, and with consultations to other faculty, technical staff and students in the Russ College of Engineering and Technology of OU. The Pathfinder is a modified toy car equipped with a novel autonomous control system comprises a patent-pending motion control sub-system for autonomous driving and steering, and a novel cognitive control system for lane detection, obstacle avoidance, and trajectory planning. This report details the design process, technical approach, test results to date, and plan for the remaining days before the completion to complete of the yet unfinished system integration and integrated testing. It is noted that this is our first time to compete in IGVC or anywhere else.

Organization

The OU-PAVE is a newly founded student organization consists of mechanical, industrial, electrical and computer engineering, as well as computer science students. The Pathfinder competetion team structure and team members are shown in Figure 1 and Table 1, respectively. Under the guidance of our Faculty Advisor, the System Engineering Group is responsible for designing the overall autonomous control architecture, identifying all supporting engineering tasks, maintaining the interfaces of the subsystems, and managing day-to-day operation of the project. The Guidance and Control Group develops the motion control system and the finite-state cognitive control system. The Navigation Group integrates all motion sensors and environmental sensors to provide reliable motion states and obstacle information. The Mechanical Engineering Group focuses modifying the drive and the steering system to meet the competition qualification requirements. The Electrical and Computer Engineering Group is responsible for designing electrical and electronic circuits, integration of the various microprocessors, and distribution of power to the various components. In particular, this group designs the safety subsystem comprising power system protection, the e-stop system, and the operation status lights. The Software Engineering Group is in charge of developing software strategies and coding the image and sensor data processing, lane and obstacles detection, mapping, localization, guidance, and controller algorithms. Each group is responsible for identifying failure points and modes, along with mitigation strategies, and the System Engineering Group will document and coordinate these strategies.

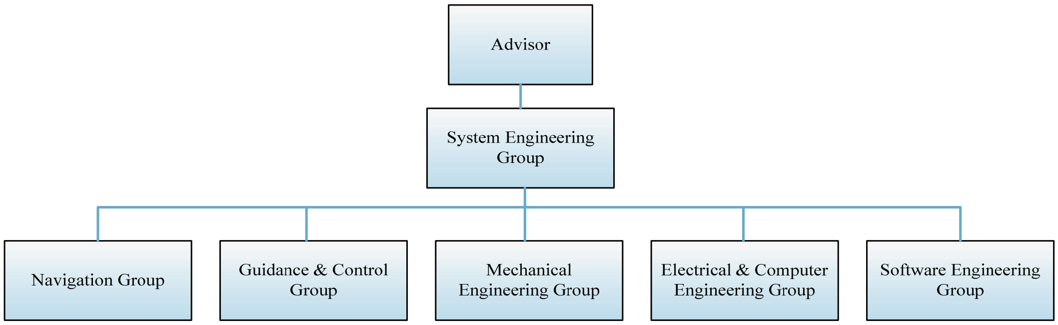

Figure 1. Organization Structure.

Table 1. Team Members.

Advisor: Dr. Jim Zhu (zhuj@ohio.edu)

Name	Level	Major	Email	Task
Yuanyan (Amy) Chen	G-PhD	EE	yc187911@ohio.edu	System engineering/Control
Letian Lin	G-PhD	EE	ll728811@ohio.edu	System engineering/Guidance/Safety
Yang Liu	G-MS	EE	yl011014@ohio.edu	System engineering/Navigation
Miguel Sosa Sempertegui	G-PhD	EE	ms070613@ohio.edu	Mechanical
Stuart Randle	G-MS	CpE	sr231609@ohio.edu	Computer Engineering/Safety
David Wisniewski	UG-Sp	EE	dw269715@ohio.edu	Electrical and Power
Jonathan Waters	UG-Jr	EE	jw039215@ohio.edu	Electrical and Power/Mechanical
Krerkkiat Chusap	UG-Jr	CpE	kc555014@ohio.edu	Software
Matchima Buddhanoy	UG-Jr	EE	mb664814@ohio.edu	Software/Logistics
Logan Wilkovich	UG-Jr	CS	lw072215@ohio.edu	Control
Yichao Li	G-PhD	CS	yl079811@ohio.edu	Software
Yingnan Zhang	G-PhD	CS	yz209517@ohio.edu	Software

Design Assumptions and Design Process

The team carried out the design in the following 6 steps: (1) System requirement analysis and concept of operation development, (2) Planning: work breakdown, scheduling, team structure, budgeting, technical approach selection, (3) Hardware, software and algorithm design, (4) Hardware and software implementation, (5) Simulation, (6) Hardware and software testing and performance assessment. First, the team members examined the competition rules carefully and formulated the specific tasks that should be accomplished accordingly. Second, the team members were organized into groups. The tasks were properly broken down and assigned to each group. The detailed schedule and budgets were made. Third, according to the functionality and performance requirements for each task, the team designed the hardware and software, and selected or developed the algorithms to be used. Fourth, the hardware components were either fabricated or purchased, and the algorithms were coded into the software system as designed. Next, simulations were carried out to verify the validity and effectiveness of the design. Finally, the hardware and software testing were conducted under the conditions similar to the competition. The performance of the test results were assessed to guide further improvement.

In the design, the following operational assumptions were made specifically for the IGVC

- The vehicle must meet all qualification requirements set forth in the completion rules in size, weight, payload, propulsion, speeds, and safety devices.
- The vehicle will drive on a dry or wet grassy area under normal weather conditions or with light rain.
- The course will be either a marked winding passage no less than 5 feet wide or a free roaming area, with exit and entry points of the passage defined by a special marker object and GPS coordinates.

- In the course, there will be only static obstacles to avoid. The obstacles will be either drawn on the ground or solid objects with colors distinctive from the grass.
- There will be no strong wireless interference on the course.
- Maximum operation time will be no more than 10 minutes per competition run.

System Design

The overall system design is shown in Figure 2. The top view of Pathfinder is shown in Figure 3. The system consists of 4 sub-systems: cognitive system, motion control system, power system and safety system. They are responsible for environmental cognition/navigation, guidance/motion control, power supply/electrical distribution and emergency stop, respectively.

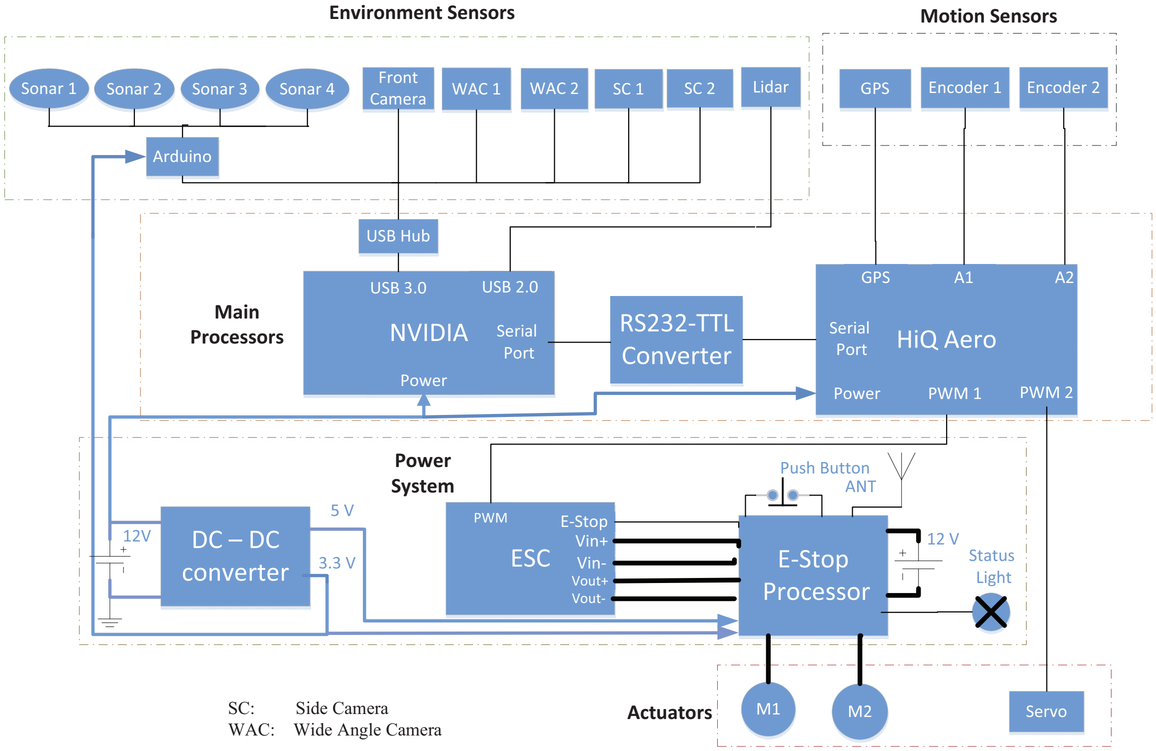

Figure 2. System Structure Diagram.

INNOVATION

The design of Pathfinder includes the following innovations

- Magnetic dampers are used in the suspension system.
- Image processing is used to facilitate the measurement of ground velocity.
- A 3DOF Trajectory Linearization Controller is implemented for simultaneous and precise drive and steering control [2] [4] and it has been filed an international patent application under the PCT.
- The mission trajectory planning system is constructed by using a line-of-sight pure pursuit guidance trajectory generator [1] and a switching control based path planner [3]. A PCT patent application has been filed for the former, and a US provisional patent application has been filed for the latter.

- A novel bio-psychically inspired cognitive autonomous control architecture [5] [6] [7].

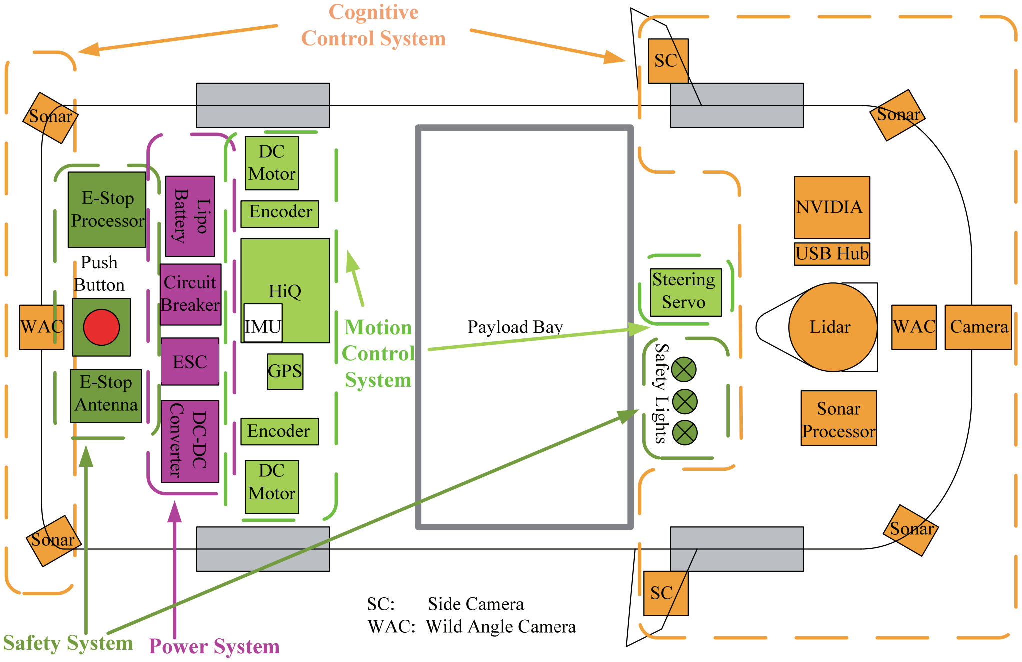

Figure 3. Top View of Pathfinder.

MECHANICAL DESIGN

Overview

The Pathfinder's mechanical design was to adapt a four-wheel toddler sit-in toy vehicle to the performance requirements set forth by the competition rules. The original vehicle had basic driving and steering functionalities, and satisfied the size, weight, payload and propulsion requirements. It also came with a lighting system that could be readily adapted to satisfy the safety light requirement. However, it had a number of critical performance deficiencies: (i) its was capable of achieving a maximum speed of only 2.3 mph; (ii) its tires did not provide efficient traction force and were too stiff; (iii) its suspension system consisted of only springs that were too hard, and its ride on a grass field was too bouncy; (iv) its steering mechanism was functional but poorly fitted and actuated; (v) minor structural modifications were also needed to accommodate the electrical and electronic components, as well as the required cinder block payload. Thus, the following redesigns were carried out to correct these deficiencies.

To correct (i), the original driving mechanism, comprising two DC motors with gearboxes have been replaced by a pair of off-the-shelf product capable of achieving a maximum speed closer to the maximum allowed for the competition. For (ii) and (iii), pneumatic rubber tires have been adapted to the existing driving mechanism. A coupling connector had to be costume made so the driving motor-gear mechanism could drive the pneumatic tires. To further improve (iii) under the limited time and resources, a simple, yet innovative and effective solution was chosen. The original front and rear springs were replaced with new ones with a proper stiffness of 21 lb/in. Additionally, two magnetic dampers were implemented using permanent magnets that are fixed on the chassis and copper tubings connected to the real axle to generate a viscous friction force by means of the induced eddy current to damp the vibrations. The viscous friction between the steering shaft and its bushing bearings were relied on for damping. Together with the new pneumatic tires, initial testing showed much improved and acceptable performance. Significant redesign of the suspension system has been planned for next year's competition.

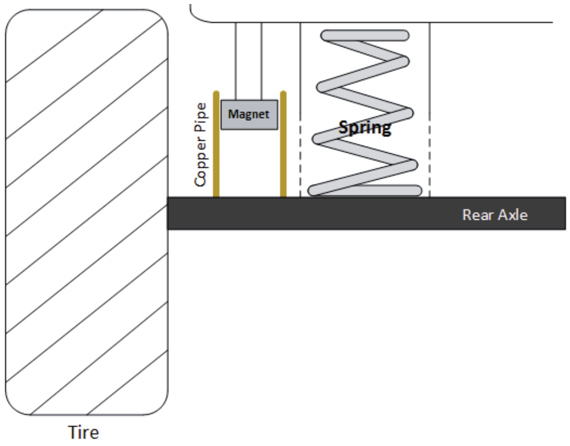

Figure 4. Rear Suspension.

The additional traction provided by the pneumatic tires also had a side effect of increasing the amount of torque needed to steer the vehicle. Because of this, the steering mechanism was upgraded to use high-torque servo motor and a gearbox with a torque-ratio of approximately 1.6. To correct (iv), nylon washers were fitted in the original steering shift bushing bearing to improve precision.

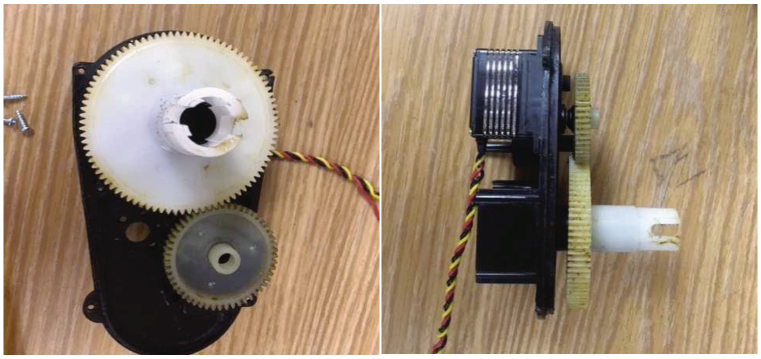

Figure 5. Steering Servo.

Since the required payload length exceeds the size of the vehicle's inner compartment, an aluminum/wood structure had to be constructed to securely hold the payload vertically inside the vehicle. Weather-proofing structures for housing the instrumentation per Figure 3 had also been constructed. These addressed Deficiency (v).

ELECTRONIC AND POWER DESIGN

Overview

The overall electronic and power system design is illustrated in Figure 2. The main components of the electrical and electronic subsystems are shown in Table 2.

Table 2. Electrical Components Specifications.

Components	Functionalities	Power	Specification
JETSON TK1	Processor	12VDC	NVIDIA Tegra K1 Mobile Processor Quad-core, 4-Plus-1™

		500mA	ARM® Cortex –A15 MPCore™ processor, Low-power NVIDIA Kepler™-based GeForce® graphics processor with 192 CUDA cores, USB 3.0, RS232 serial port
HIQ Aero	Processor Motion sensor	12VDC 400mA	Processor Marvell PXA270 @600MHz, IMU(3-axis accelerometer, 3-axis gyroscope), 6 channel 12-bits analog input, 10 PWM output, TTL serial GPS input, 2 GP TTL serial ports
Motor Driver	Actuators	12VDC 60A	ION RoboClaw, 2x30A, PWM input
Encoder	Motion sensor	5VDC 100mA	Incremental 30 PPR magnetic encoder, Trinket M0 processor, Magnet sensor 2SS52M
GPS	Motion sensor Environment Sensor	3.3 VDC 20mA	3D Robotics GPS Module, 5Hz, Ublox Lea-6H GPS chip
LIDAR	Environment Sensor	5VDC 500mA	RPLIDAR A1, 2D LIDAR, USB port, range 12m, 10Hz
Camera	Environment Sensor	5VDC 150mA	1080P High Speed No distortion Lens, 2MP Full HD, Mini USB 2.0, 100 degrees view angle, 60fps @ 720P
Sonar	Environment Sensor	3.3VDC 2mA	LV-MaxSonar-EZ, 6-254 inch range with 1 inch resolution, analog voltage output, RS232 output

Sensor

Accelerometers, gyroscopes, encoders, GPS, LIDAR, cameras, and sonar are employed to obtain the motion states and determine a feasible path. For motion states, data from the HiQ Aero built-in inertial measurement unit (IMU) block, GPS, and wheel encoders are fused together with a loosely-coupled Kalman Filter. The IMU block includes a 3-axis accelerometer (with resolution of 3.33 mg/LSB) and a 3-axis gyroscope (range ±75 deg/s with resolution of 0.0125 deg/s/LSB) with a data rate greater than 100Hz. The GPS module provides position (latitude and longitude), velocity, and true heading angle at a rate of 5Hz. The shaft encoder has a resolution of 3053 pulses per revolution of the wheel shaft at a data rate 50Hz. According to the gear ratio and sampling time, it can detect the minimum speed at 0.0346m/s with a bandwidth of 4 rad/s. Since the onboard accelerometer and gyroscope have uncertain biases which , the GPS was used to correct their outputs. The encoders were also utilized to correct the motion state measurements especially under the constant speed situations when the outputs of the encoders are more accurate than the inertial sensors. A Kalman Filter was applied to the fusion of motion sensors. The output of Kalman Filter was sent to the trajectory tracking controller to achieve precise feedback control.

For environmental detection, a Lidar and cameras are used. The Lidar can perform 360° scan within 6m range with resolution of 1mm and data rate of 1980Hz. The cameras have a frame rate 60 frame/s at a resolution 720p. The Lidar was used to obtain distance data of solid obstacles. The cameras were used to see the boundary lines/potholes and also help to detect the solid obstacles. The Solid obstacles were detected by fusing the image data and the distance data and can be mapped by further fusing the motion data. The Pathfinder then used the map to conduct mission trajectory planning. Sonars were mounted around vehicle to avoid collision.

Encoder. Magnetic encoders were custom designed and installed in the rear wheel gear boxes. Two Honeywell magnetic sensors 2SS52M were used as the pulse reader to implement a quadrature encoder for forward and reverse speed sensing. The data were moving-averaged and converted to an analog signals with an Adafruit Trinket M0. The analog speed signal was passed through an anti-aliasing filter and transmit to an analog input port of the HiQ. There are 30 magnets on the encoder.

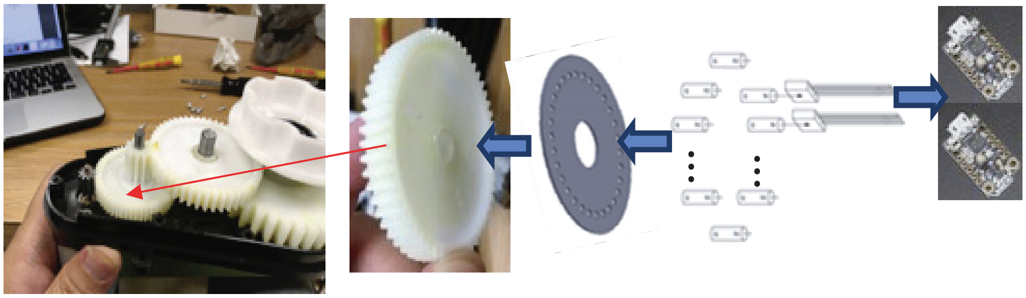

Figure 6. Encoder Installation Diagram.

Lidar. A RPLIDAR A1 360 Lidar has been mounted on the front hood of the vehicle to detect the obstacles in the course. Its outputs are the distances of the solid obstacles in the different orientations around the Lidar. The scanning results can be draw as a map as following

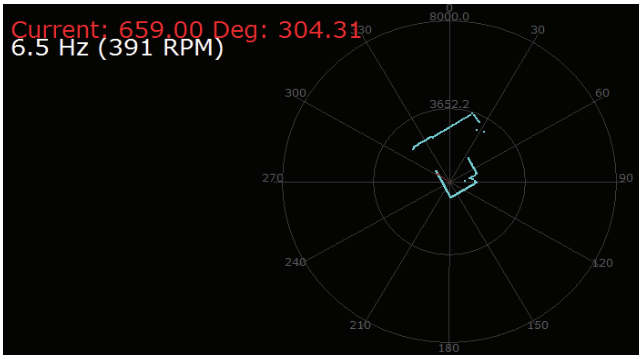

Figure 7. The Map Obtained by the Lidar Scanning.

The installation of the Lidar is shown in Figure 8.

Camera. The front camera were mounted on the front bumper as shown in the figure. The camera view angle can be adjust as need.

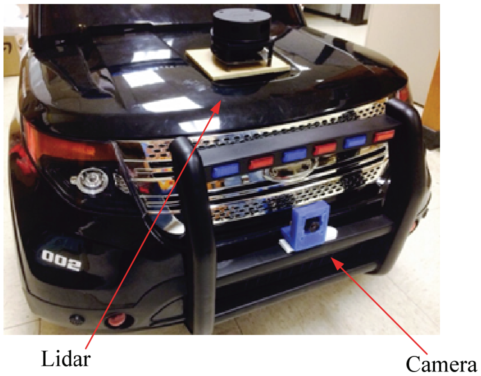

Figure 8. Front Camera and Lidar.

Figure 9. Sonar Installation.

Sonar. Four sonars were mounted at four corners of the vehicle. Because of the wide beam, which cannot resolve relatively small objects in the distance, the sonar signal is susceptible to interference. Therefore, when the distance is far, these four sonars are only used to avoid close-range collisions.

GPS. In this project, we used the 3DR GPS with compass module. The updating rate is 5 Hz. The built-in Ublox LEA-6H GPS receiver can reach up to 15 ns timing accuracy with 2.5 m position error.

IMU (Inertial Measurement Unite). The HiQ aero was equipped with a 9DOF inertial sensors: 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer.

E-Stop System

The E-Stop system is designed to stop the vehicle promptly in case of system malfunctions to protect the people and property around the vehicle. It can be activated wirelessly or manually. The E-Stop design diagram is shown in Figure 10, where the power breaker system is built to protect the onboard systems in case of a power system malfunction. In the normal cases, the sonars can report the possible collisions and the vehicle can be stopped by the controller. However, if the stop is necessitated due to a system malfunction, then the wireless or mechanical E-Stop button will be pressed. If the RF receiver receives a wireless E-Stop signal or the push button is pressed, the control board would first attempt to activate the E-Stop function of the ESC with regenerative braking. If it does work, the control board would cut off the power of the ESC and the motor. Then, the motor will be stopped with regenerative braking. There are two motors on the Pathfinder, thus we need one SPDT relay, bidirectional diode and current sensor for each motor.

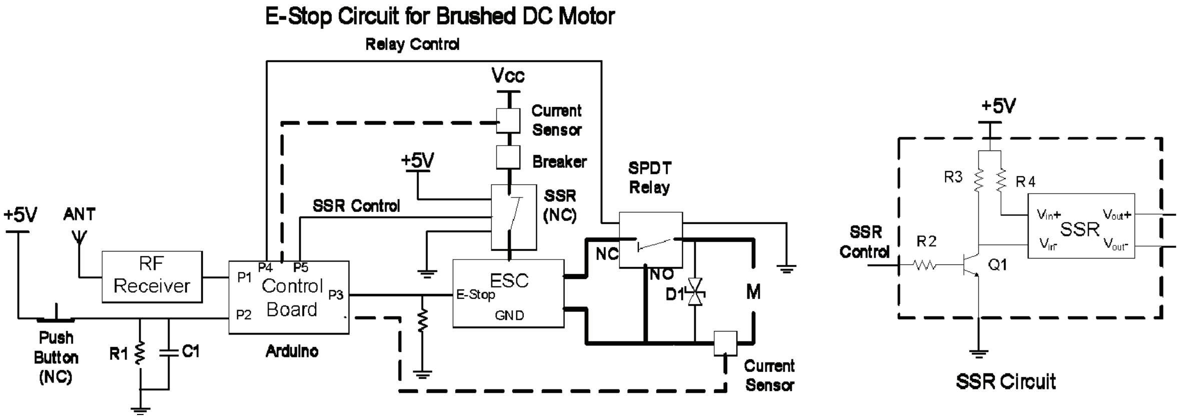

Figure 10. E-Stop Design Diagram.

The wireless link is handled by a pair of RFM69 packet radios operating at 915 MHz. These radios support encryption and multiple networks in the same frequency band so if they are being used by another team they should be able to operate concurrently. The transmission distances of 500+ feet line of sight has been achieved, which is adequate for IGVC competition.

The design for the wireless link for the E-Stop system uses the Arduino Pro Mini microcontroller and consists of two main components, the remote controller and the receiver. The remote controller allows the user to put the system into the ready, warning, and e-stop states. The status of the system can be shown by the lights on the case. The receiving Arduino takes the command signal and passes it to the controller which interfaces with the physical e-stop button to start and stop the vehicle.

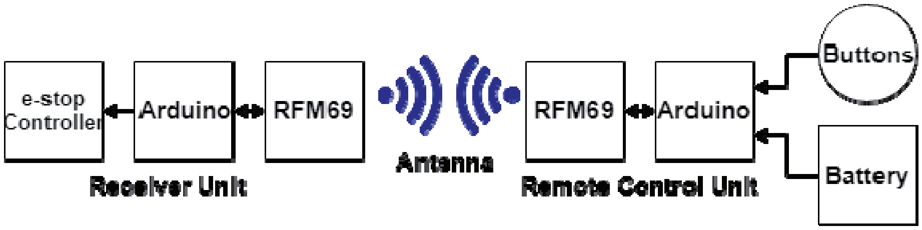

Figure 11. Wireless Link of the E-Stop System.

SOFTWARE STRATEGY AND MAPPING TECHNIQUES

Overview

A cognitive controller and a motion controller are designed for the Pathfinder. The overall control system is shown in Figure 12. By using the environment data from the environmental sensors and the motion states from the motion sensors, the cognitive controller is able to aware the situations round the vehicle, make the decisions properly and generate feasible trajectories for the vehicle. The motion controller is used to drive the vehicle to tracking the trajectories obtained by the cognitive controller. The details of each part in the control system are discussed as below.

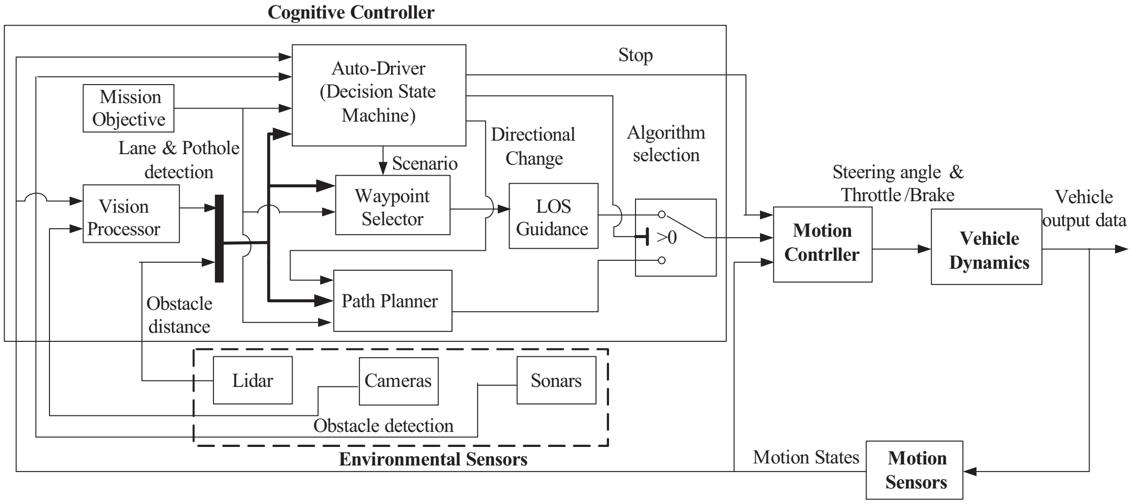

Figure 12. Control System Diagram.

Vision System

The main responsibility of the vision system is to process the image frame from the camera to find the center point of the white lane at a certain view distance. The center point signal is then sent to calculate the line of sight angle α between the frame center line with the center point itself. The line of sight angle is passed to the LOS PPG guidance subsystem [1] to generate a feasible trajectory for the vehicle to track. The vision system is running on the NVIDIA Jetson board.

The vision system took one frame of image at a time from a video camera. To determine the edge from the grass, the following methods were used instead of the edge detection in normal lane detection. The frame is cut into small region of interest to reduce the dimension of the frame. The color space transformation is performed on the fame as well, so the range of white color can be selected in the next step. The median filter is used on the frame along with adaptive threshold, and followed by, again, median filter to reduce the noise in the image. The processed frame is then used to determine the position of clustered white area. The result from that is fit by the polynomial curve fitting to find the equation for the curve. The lane equations are then used to find the center point of the lane. The image processing result is shown in Figure 13.

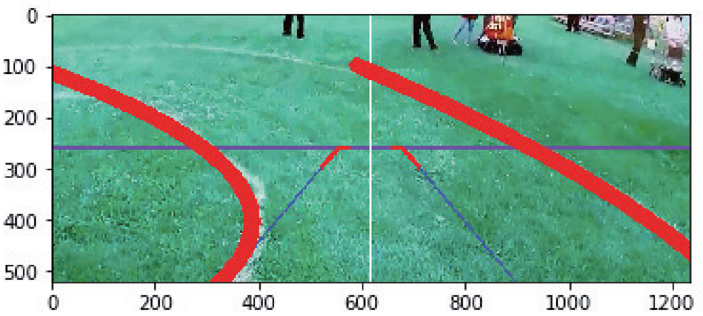

Figure 13. Image Processing Result.

Localization

The Motion Sensor System includes GPS/INS and velocity encoder data processing. In practice, the onboard inertial sensors, like gyroscopes and accelerometers will have some bias. If these signals are used directly to calculate the orientation and position by integration, the results would drift because of the bias. Comparing to inertial sensors, GPS is much more accurate over time, but the data update frequency is lower than inertial sensors. The quadrature motor shaft encoder can be erroneous when vehicle is in dynamic motion due to wheel slipping and skidding, but provides relatively accurate velocity data when the vehicle is running at constant velocity. Accordingly, a bias removal function is applied to the inertial sensors, and a Kalman filter algorithm is employed for sensor data fusion. For outdoor tests, the GPS, inertial and encoder data are fused by using the Kalman filter.

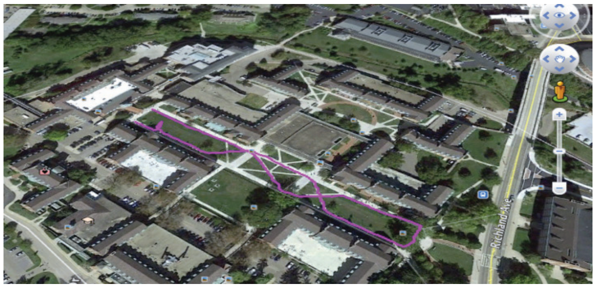

Figure 14. Kalman Filter Result Shown in Google Map.

Mission Trajectory Planning

The mission trajectory planning system is responsible for generating a feasible, collision free nominal trajectory that leads the vehicle to the target. In the competition, the vehicle has two different mission modes: lane traveling and open area traveling. In the lane traveling mode, the vehicle is confined to the lane between the two boundary lines and 4 different driving scenarios may happen. In the open area traveling mode, the vehicle drives towards a goal point (GPS waypoint) and 2 different driving scenarios may happen. The scenarios are shown in Figure 15.

In the lane traveling mode, scenario 1 represents the case when both of the boundary lines can be seen by the camera without obstacle or pothole in the lane. If there is an obstacle or pothole in the lane, we have scenario 2. Scenario 3 represents the case when only one line can be seen. If the sight of the car is completely blocked by the obstacles, we have scenario 4. In the open area traveling mode, scenario 5 shows the case when the car drives through the obstacles to the goal point without boundary line. Scenario 6 shows the case when a boundary line can be seen.

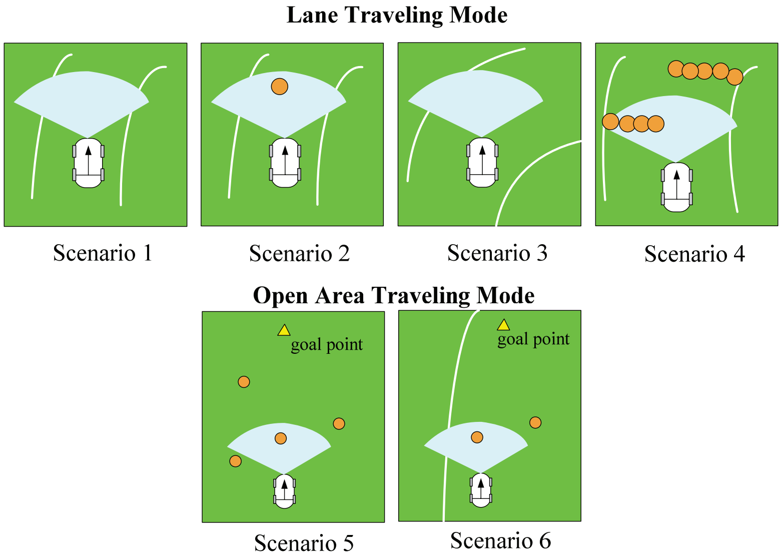

Figure 15. Traveling Scenarios.

In Scenario 1,2,3,5 and 6, the environment is sufficiently wide for the vehicle to drive without needing backups. So a fast line-of-sight pure pursuit guidance (LOS PPG) [1] is adapted to conduct the trajectory tracking guidance in these scenarios. In Scenario 4, to drive through the obstacles, the vehicle may need several directional changes and backups. In this situation, we use a switching control based path planning algorithm [3] to generate a desirable path. The mission trajectory planning logic is shown by the finite-state machine shown in Figure 16.

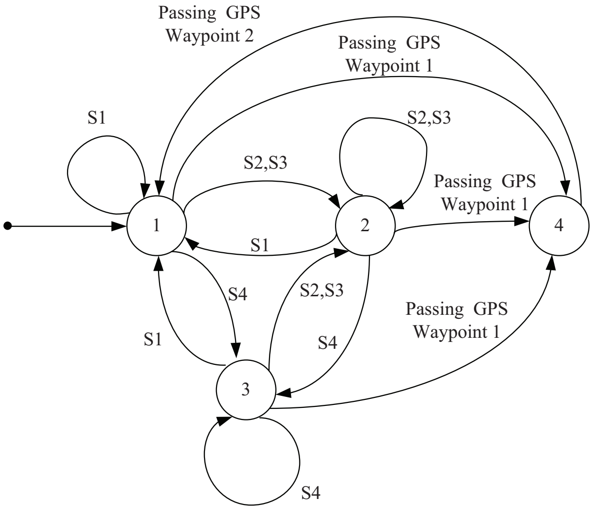

Figure 16. Finite-state Machine for Mission Trajectory Planning.

In Figure 16, S1, S2, S3, S4 denote scenario 1, 2, 3, 4 respectively. In State 1, the way points would be selected along the middle line of the lane and the LOS guidance would be conducted. In State 2, the way points would be selected to avoid the obstacles and potholes and then the LOS guidance would be applied. In State 3, the switching control based path planning would be carried out. In State 4, the vehicle is driving in the open area traveling mode, so the waypoints would be selected to avoid the obstacles and potholes as well as lead the vehicle to the next GPS waypoint. LOS guidance would be conducted in State 4.

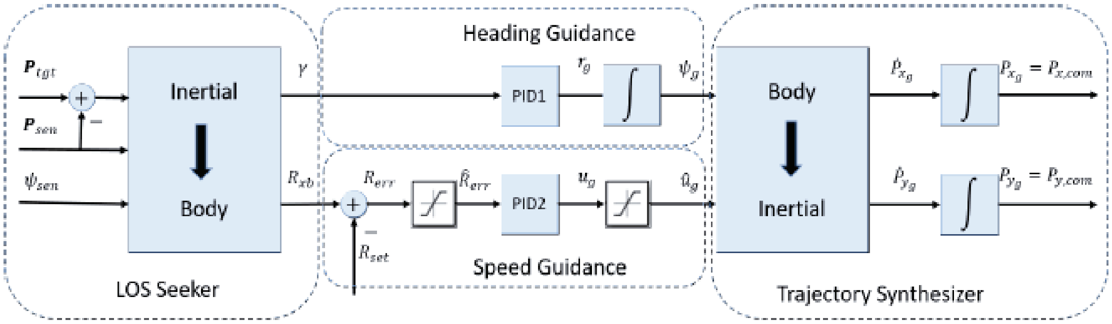

Figure 17. LOS PPG Trajectory Generator Architecture.

LOS Guidance. LOS PPG has been used in aircraft guidance design. By taking into account the nonholonomic constraint, we modified LOS PPG to generate a feasible trajectory for car-like ground vehicles. The LOS PPG trajectory generator consists of four subsystems, including target seeker, heading guidance, speed guidance and trajectory synthesizer, as shown in Figure 17.

Switching control based path planning. The path planning algorithm is comprised of 4 steps. First, the map of the environment around the vehicle is discretized. Safety buffer zones are padded around the obstacles and result in a discrete collision-free space. Next, a path that connects the start point and the goal point in the discrete collision-free space is obtained by using the well-developed A* algorithm. Then, the A* path is optimized to a shortest path in the continuous collision-free space. Finally, by using a switching control law to drive a virtual vehicle from the start point to the goal point along the shortest path, we can obtain a feasible, collision-free path. The simulation result is as shown in Figure 18.

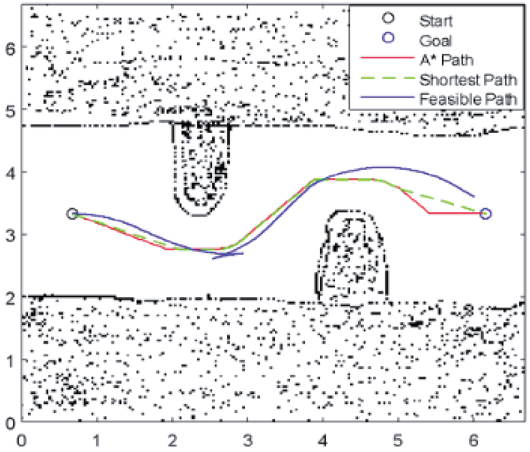

Figure 18. Path Planning in Scenario 4.

Controller

For an under-actuated car like ground vehicle trajectory tracking control, we consider the 3 degree-of-freedom nonlinear vehicle rigid-body dynamics with nonlinear tire tracking force, nonlinear drag force and actuator dynamics [1]. The uphill and downhill affection will be treated as load disturbances and will be overcome by closed-loop driving control. The control algorithm employs Trajectory Linearization Control (TLC) based on singular perturbation theory. The controller considers the nonlinear kinematics with the dynamics of a car-like ground vehicle. TLC consists of an open-loop nominal controller with a closed-loop tracking error regulator, as shown in Figure 19.

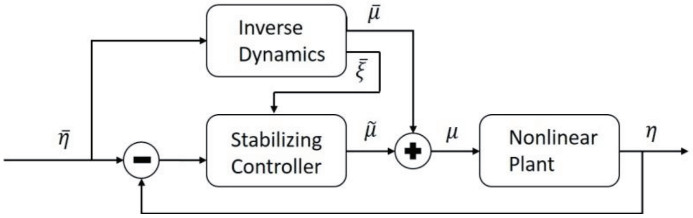

Figure 19. TLC Structure.

The overall closed-loop system consists of 4 loops as shown in Figure 20, which are the guidance outer and inner loop, and steering outer and inner loop. Each loop employs the TLC structure as shown in Figure 19.

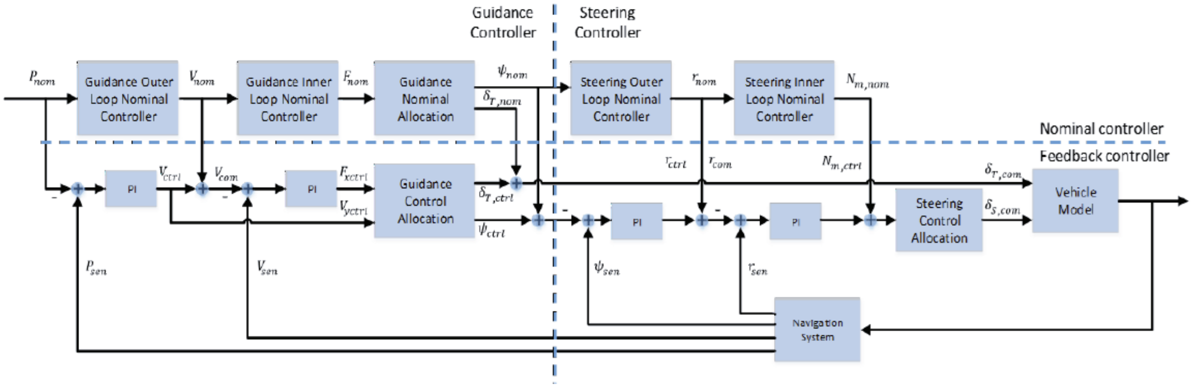

Figure 20. 3DOF Trajectory Linearization Controller Block Diagram.

FAILURE MODES, FAILURE POINTS AND RESOLUTIONS

Failure mode/points	**Resolutions**
Electronic	
Encoder, GPS, LIDAR and sonars not working	Reinserting connector cables, changing related components
Electrical	
The ESC (RoboClaw) may be damaged in the high load situation.	Replace it with an ESC from other manufactures or prepare backup ESCs. Fast replacement is possible
Car may lose control when it is outside the range of the E-stop transmitter.	The E-stop system is designed to stop if it goes out of range of the transmitter.
Mechanical	
the rear wheel coupler may break under heavy torsional loading	Change wheel coupler
Servo-motor overheating	Control algorithm design to avoid steering car at zero speed
Guidance (software)	
The sensors misidentify obstacles.	Introduce fault-tolerance to the output of the sensors, e-stop as needed
Tracking error is too large when the vehicle is too far from the planned path.	Introduce path re-planning logic to the mission trajectory planning system

SIMULATIONS

Simulations were carried out to verify the design. In MATLAB/SIMULINK, the LOS PPG trajectory generator together with the TLC controller were implemented on the vehicle dynamics to simulate the trajectory generation and trajectory tracking. The simulation results are shown in the following figures.

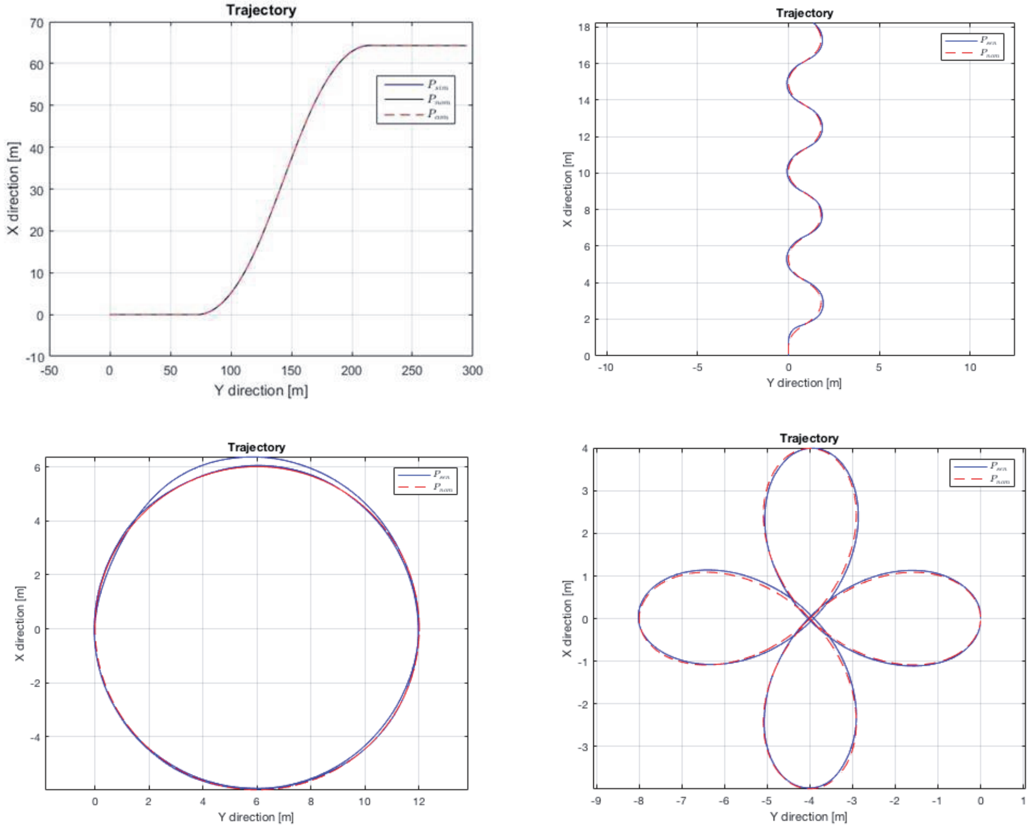

Figure 21. Simulation Results of Pathfinder.

PERFORMANCE TESTING

To ensure on-time integration of all subsystems and successful integrated hardware testing, subsystem and component, tests have been conducted on the Pathfinder and a small prototype of Pathfinder. All the hardware tested on the prototype of Pathfinder can be directly integrated on the Pathfinder.

Mechanical System

The redesigned suspension system, steering system, propulsion system and the new tires have been tested on an open grassy area. By driving the vehicle at a speed about 2m/s, we manually steered the car to turn with the minimum turning radius. The video of the test can be found at the following link:

https://www.youtube.com/watch?v=VYLKhZcLyAE

Navigation System

The navigation system includes environmental sensors and motion sensors. Motion sensors includes GPS and encoder, and have been hardware tested in the loop and can be viewed from the controller video. The controller video also contains some clips of vision system. The environmental sensors have been tested individually, and an integrated test is yet to be completed.

Guidance and Control System

The guidance and control system was tested on the prototype of Pathfinder. Straight line, circle, slalom curve tracking were carried out. The last test is chasing a target car. The video can be found in the following link:

https://www.youtube.com/watch?v=KOCQIMT2N9A

PERFORMANCE ASSESSMENTS

Assess the performance against the qualification test requirements:

- **Length**: (over the minimum of three feet long and under the maximum of seven feet long): YES
- **Width** (over the minimum of two feet wide and under the maximum of four feet wide): YES
- **Height** (not to exceed six feet high): YES
- **Mechanical E-stop**: YES
- **Wireless E-Stop:** YES
- **Safety Light**: need to be improved
- **Speed (**the minimum of 1 mile/h and not exceed the maximum speed of 5 miles/h): YES
- **Lane Following:** YES
- **Obstacle Avoidance:** YES
- **Waypoint Navigation:** YES

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5. Zhu, J. Jim, and Xudan Xu. “Biopsychically inspired cognitive control for autonomous agents based on motivated learning.” Methods and Models in Automation and Robotics (MMAR), 2012 17th International Conference on. IEEE, 2012.
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