CALIFORNIA STATE UNIVERSITY, NORTHRIDGE
1958

SCORPION

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Faculty Advisor Statement

I certify that the engineering design of the vehicle described in this report, SCORPION, has been significant and equivalent to each team member earning four semester hours of senior design credit for their work on this project.

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1.0 Introduction

California State University, Northridge's (CSUN) Intelligent Ground Vehicle team has designed and engineered an entirely new platform for the 2013 IGVC. SCORPION is a differential driven vehicle with a lower center of gravity compared to its predecessors. The entire process from design, to fabrication and integration of sensors and new algorithms was completed in the 2012-2013 academic year. Some of the new innovations in this platform include a simplified decoupler, new path planning algorithm, and a fully adjustable suspension system.

1.1 Team Organization

CSUN's IGV team is broken into five sub-groups: Mechanical, Electrical/Power, Cognition, Vision, and Navigation/JAUS. Each subgroup has a specified leader not only to maintain organization of the group, but also to maintain communication with other sub-group leaders, ensuring proper integration and flow from one task to another. There are also three team leaders appointed in the following positions: Project Manager, Treasurer, and Club President. These three leaders are responsible for overall organization of the team and team meetings as well as fund raising, registration, and finances. The overall team organization can be seen in Figure 1.1

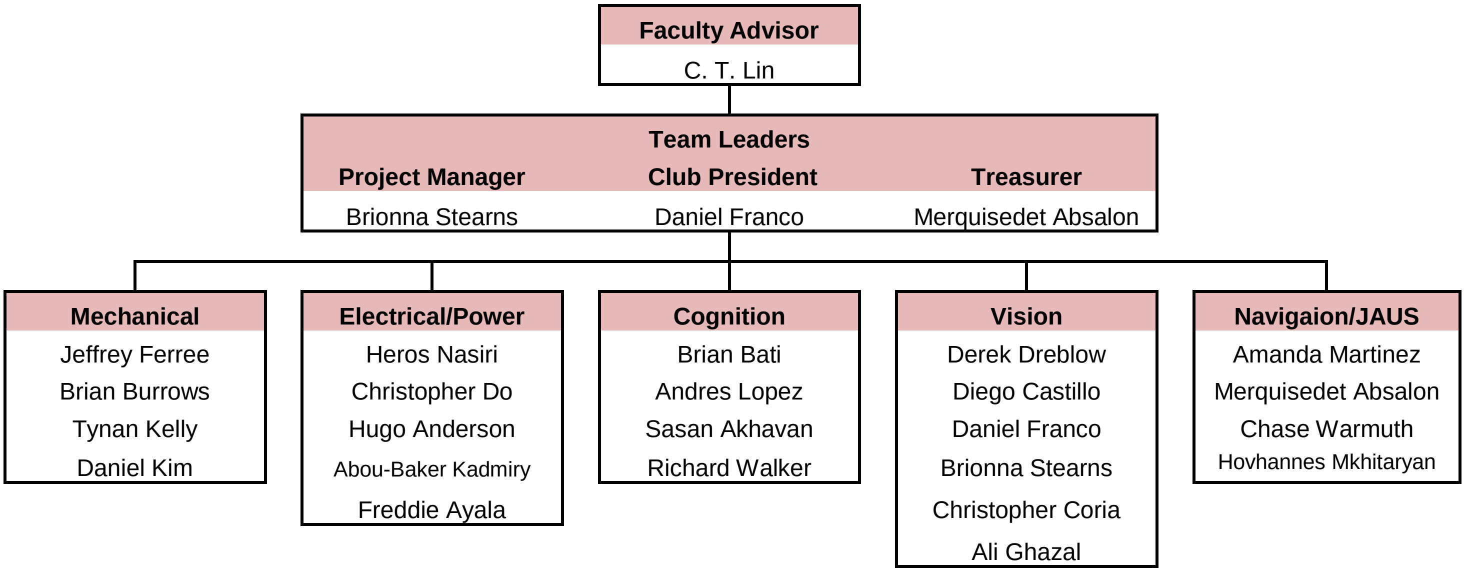


Figure 1.1 Team Organization

1.2 Innovation

SCORPION's initial design was based on the concept of having all four tire contact patches fall within a single unifying circle. This idea dictated the overall shape of the frame. The frame is supported by an air spring system, allowing the axel to move vertically while eliminating rotation and lateral movement. Unlike its predecessors, the component cage of SCORPION is made from fiberglass and PVC perforated shelves, minimizing the overall weight. This year's decoupler has been simplified significantly. No tools are required to engage and disengage the drive wheels; a simple turn of the cap operates the system. One of the biggest improvements made to the new platform is the ability to swap out the batteries without powering down the system. The hot swap system saves time as SCORPION does not have to restart and reinitialize all the programs and sensors.

SCORPION's vision system is entirely new this year: camera, lens, and algorithms. Allied Vision Technology's Prosilica GT 1290 is coupled with Theia's SY110A lens. The camera houses auto white balance and auto exposure, while the lens operates with a DC auto-iris. The two combined create a system that outputs consistent imagery, regardless of changing conditions. This year's vision algorithm includes flag detection, dead grass detection, and has been written to operate with the new camera system. Additionally, an Arduino Uno and light sensor combination have been incorporated into the system to alert cognition if the lux value being read by the camera exceeds that of its operating range. This blind flag is simply a true/false output.

SCORPION's navigation algorithm utilizes both intermediate waypoints and timed waypoints. Intermediate waypoints were put in place due to encouragement of course mapping. The timed waypoint algorithm eliminates the vehicle from indefinitely circling a waypoint in the event it cannot check it off. SCORPOIN's navigation system also utilizes a new compass, the TRAX AHRS (attitude and heading reference system).

1.3 Systems Integration

In order to acquire and process information from the immediate surroundings, SCORPION utilizes a range of sensory equipment. A camera, Global Positioning System (GPS), compass, and Laser Range Finders (LRF) gather information from the environment around SCORPION and, after processing the input, send the data to cognition. This data is then evaluated and placed into path planning. Once cognition has determined the path of motion, this data is sent to power (motion control). From here the required velocity and acceleration can be determined and executed allowing SCORPION to maneuver through the course.

2.0 Mechanical Design

The responsibility of the Mechanical Team is to design and fabricate the chassis of the robot, equipping it with the necessary mobility technologies and designing the optimal component layout to carry the equipment to power, navigate and drive the robot. Various features were implemented to carry out that criterion such as; a circular foot print, active suspension, alternative lightweight materials and new component design innovations.

2.1 Frame Chassis Design

The base of the SCORPION platform is comprised of rectangular aluminum tubing. The 6061-T6 alloy was chosen for its ease of welding, light weight, and strength. The shape of the frame was based on the overall concept of having the tire contact patches for the drive wheels and the base of the casters form a unifying circle that would meet the minimum rule requirements for length. In combination with independent differential drive motors, this system allows for a zero turning radius as shown in Figure 2.1.

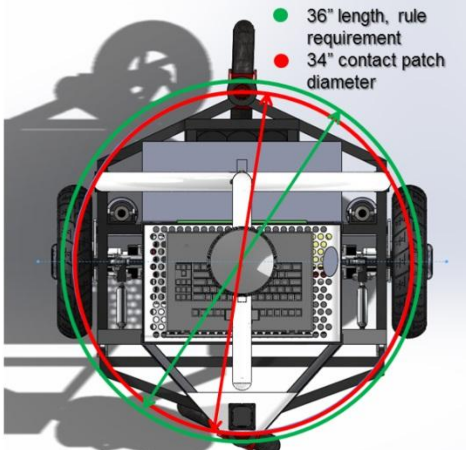


Figure 2.1: Single Contact Diameter

2.2 Multi-Link Suspension

The suspension design consists of an equal length, parallel arm multi-link system. This allows for vertical movement of the axle due to ground inputs while virtually eliminating axle rotation and lateral movement (Figure 2.2). In addition to the drive suspension, the front caster is mounted to a swing arm connected to the main chassis. Each of the moving components is suspended by adjustable pressure air springs. This allows for adjustment to varying terrain and fine tuning of the system for its operating environment.

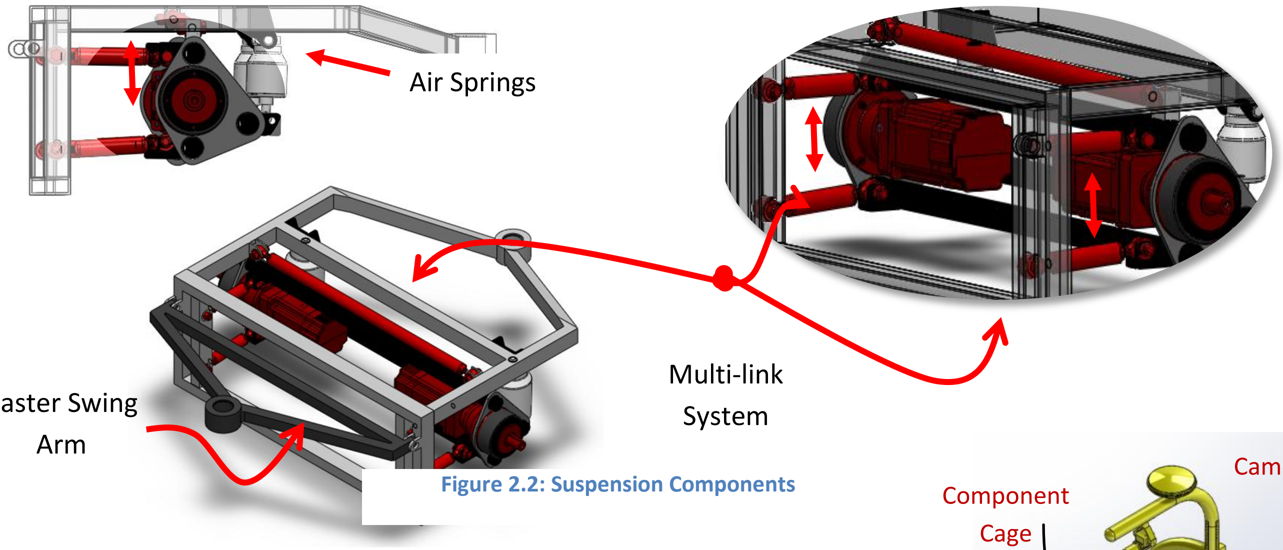


Figure 2.2: Suspension Components

2.3 Composite Component Frame System

The chassis consists of four elements, each color coded and labeled in Figure 2.3. One of SCORPION's innovations was the utilization of several materials, which in combination created a complete platform. Aluminum was utilized to create the lower frame and suspension (blue / red), adding strength and rigidity while minimizing weight. The component cage (green) was made from fiberglass with PVC perforated shelves, minimizing overall weight and lowering the center of gravity. The camera boom (yellow) was made from hollow ABS tubing, which was much lighter than an aluminum boom and provided the height needed to obtain an optimal field of view for the camera.

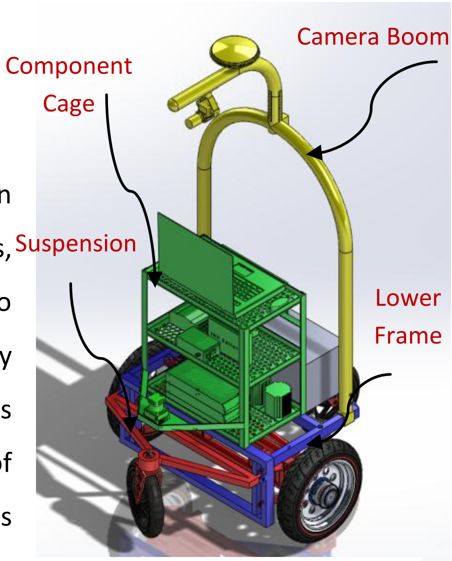


Figure 2.3: Component Frame System

2.4 Gearbox/Motor Configuration

A straight gearbox configuration is ideal for SCORPION's layout; this allows the motors and gearboxes to be mounted within the beam axle. A force analysis was performed to get an optimal gear ratio for operating conditions the robot will experience. Our goal was to decrease the gearhead ratio from

Model	QCI-A34HC-2
Max Speed	1500 RPM
Torque at Optimal Speed	2.03 lb-ft
Continuous Stall Torque	6.77 lb-ft

Table 2.1: Motor Specifications

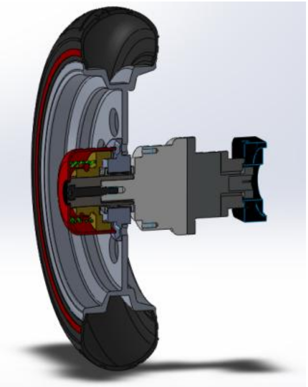


Figure 2.4: Gearbox Section

20:1 (last Year's platform) to 15:1. Based on the analysis, the Apex Dynamics AE-090 -15 15:1 gearboxes were chosen for the drive train. Quicksilver motors were coupled to the gearboxes. Motor specifications are presented in Table 2.1.

2.5 De-coupling Mechanism

An important feature for any IGV is its capability to be transported while powered down. The solution is to decouple the drive train from the wheels allowing the wheels to roll freely while SCORPION is powered down. The unique design of this year's decoupler is the ease of operation. The innovative design of the new configuration bolts directly to the rim's original bolt-hole pattern. The core of the decoupler is the drive shaft, which connects directly to the gearhead by a through bolt. The splines at the outer end of the drive shaft mate to splines cut into the engaging hub. These splines allow the hub to slide freely back and forth across the drive shaft maintaining a direct drive between the shaft and the hub as shown in Figures 2.4 & 2.5. A two-piece inner hub consists of six interlocking cogs locking the drive wheel and the drive train. The two hubs engage and disengage by a cam feature between the engaging hub and the cap (Figure 2.6). A large spring (Figure 2.6, green) was employed between the engaging hub (yellow) and the outer cap (red) to create a positive load on the hub preventing any recoil of the hub due to vibrations. The shaft and gearhead connection consists of a standard keyway configuration. The main benefit of this year's design simplifies operation by users; 1/3 of a rotation of the outer cap decouples or engages the wheels.

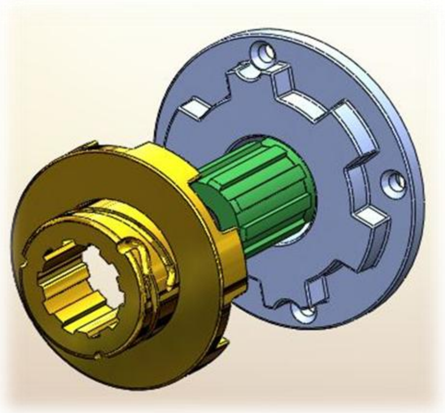


Figure 2.5: Decoupler Components

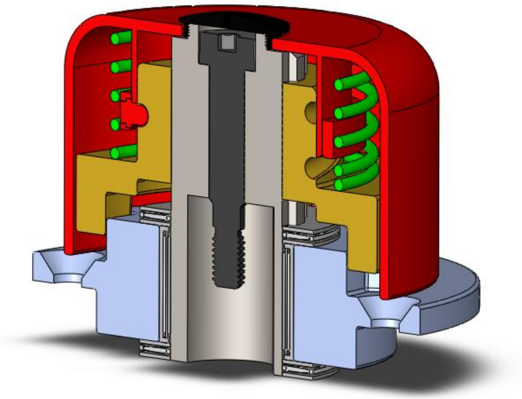


Figure 2.6: Decoupling Mechanism

3.0 Power (Motion Control)

The heart of the power system is a PCB which takes the input from the batteries and, through the use of 3 DC/DC converters and a voltage regulator, outputs 48V, 24V, 12V and 5V, as needed by the components. The addition of the LIDAR unit was being considered for future improvement in obstacle detection. For this reason the team went about revising the previous board's design to accommodate this necessity.

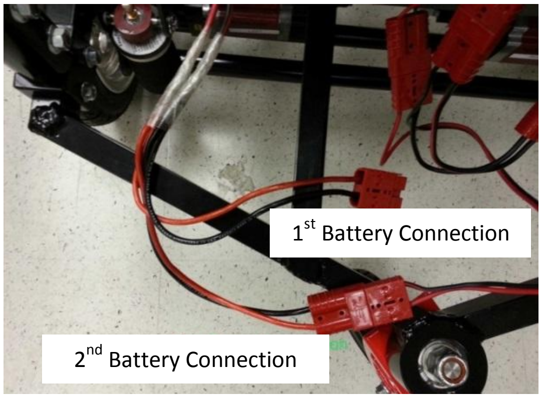


Figure 3.1: Hot Swap Mechanism

3.1 Battery Configuration

The current power configuration and settings have an average lifetime of 3-5 hours depending on the load used by the robot. Lithium Polymer Batteries (LiPo) are being utilized in this configuration. The advantages of this type of battery are high energy density and light weight.

3.2 Hot Swap

The hot swap system is a new improvement added this semester. During testing and competition it has been an issue in the past that when the batteries were running low the entire system needed to be turned off to swap out the batteries. This causes delay in testing and operation while all of the different software modules and components are being initialized again. The solution to this problem was to add hot swap capability for the batteries. The cable, seen in Figure 3.1, makes it possible to connect the new set of batteries before removing the old ones, allowing the robot to stay operational even during the swap if necessary.

3.3 Autonomous Safety light

In order to satisfy the requirement of an active safety light with a solid “on” when the intelligent ground vehicle is in manual mode and flashing “on” when the vehicle is in autonomous mode, an approach was chosen that utilized available parts that allow the lights to interface with the already implemented 12v connectors on the robot’s power distribution board. It was decided that the approach would utilize TTL, as the gates used are common and the method for creating the logical switch was well understood by the group.

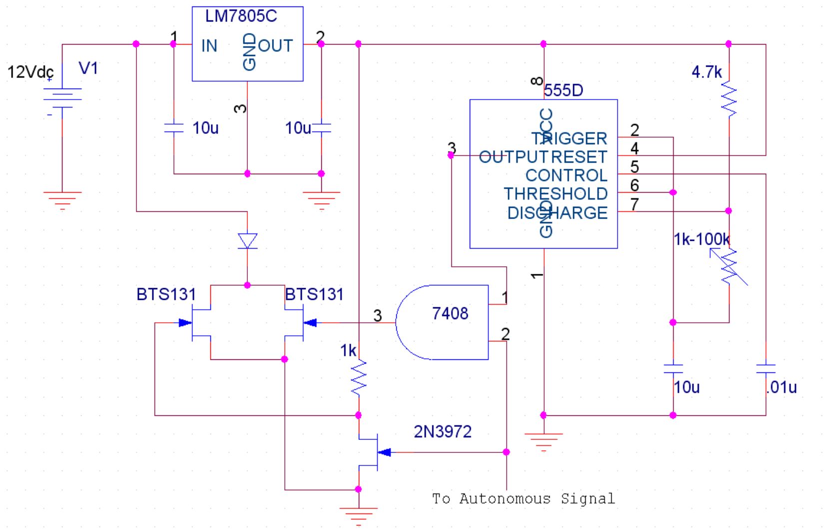


Figure 3.2: Autonomous Safety Light

The first step was to determine how to use a signal dedicated to declaring the state of SCORPION’s autonomy to maintain a solid or flashing signal. It was decided that the logical not of the autonomous state should trigger the solid “on” for the LED array, which was achieved by running the non-autonomous signal to the gate of a power MOSFET such that it would operate as a switch. This switching arrangement accommodates the 12v needed in order to switch the LED strip on. The same route is taken in order to switch the lights to flashing mode, except the logical true of the autonomous state was ANDed with a pulsing signal. The source of the signal was chosen to be the 555 timer, as the output operates at TTL levels when supplied with 5v. Resistor and capacitor values were chosen such that each flash occurs at a .5 second frequency. The completed circuit diagram can be viewed in Figure 3.2.

4.0 Vision

The purpose of vision is to find important obstacles when other sensors cannot. The main objective is to find white line boundaries and small colored flags all in real time. The camera is mounted at the highest position possible in order to get the best perspective and to be able to see as many obstacles as possible, so cognition can make the best planned path.

4.1 Camera Hardware


Figure 4.1: AVT Camera and Theia Lens

The camera of choice is a combination of AVT Prosilica GT 1290 machine camera and Theia SY110 lens with DC auto iris. In the top portion of Figure 4.1 is the Prosilica GT 1290. It communicates with a computer system via IEEE 802.3 1000baseT Ethernet. The GT 1290 has a resolution of 1280 x 960 and the senor is a Sony ICX445 CCD Progressive. The max frame rate is 33.3 fps at full resolution. The truly import attributes that the GT 1290 offers is its ability to have auto exposure, auto white balance and auto DC iris. As SCORPION travels around the course, the machine will experience different perspectives. The results are glares from the sun reflecting off of barrels or shadows being casted. This gives the Prosilica GT 1290 the ability to adapt to the situation. In the bottom portion of Figure 4.1 is the Theia SY110 with auto iris. The lens has a 94^{o} vertical by 109^{o} horizontal field of view with less than one percent distortion. SCORPION's field of view yields the advantage of planning its path with the least amount of time and work. The iris is controlled by the GT 1290's built in algorithms, alleviating resources that the computer system needs.

4.2 Vision Software

In order to detect the blue and red flags, two different filters are required. The first step to creating the color filter is to extract a color plane from the initial RGB (Red, Green, and Blue) image. For the red flags, the blue color plane is extracted; and for the blue flags, the red color plane is extracted. After extraction, the image type changes from RGB to a grayscale image, based on the selected color plane. A second color plane extraction must occur to isolate the red or blue flags. This second color plane to be extracted is the value color plane. Once both color planes have been extracted, the two different images are subtracted from one another, resulting in either the blue or red flags being isolated in the grayscale image.

A threshold is applied to the final grayscale image to convert it to a binary image. In the binary image, the grayscale pixel values are either one or zero and represented by the colors red and black. Following the conversion to a binary image, the pixels must now be grouped together to make the shape of the flag more prominent (Figure 4.2). This is accomplished by utilizing a morphological transformation, making the flag more distinguishable. The final step is producing a histogram for each flag before sending the data to cognition.

Figure 4.2: Red and Blue Flags Detected in a Video Feed

Line detection utilizes an RGB color plane extraction to isolate white lines on the course under dynamic lighting conditions. The resulting image after this process is a grayscale that contains the line data. One major problem faced during this transitional step is that LabVIEW picks up erroneous data from dead grass and shadows being cast from barrels. To correct this problem, filters have been created to isolate dead grass and shadows. These errors are then subtracted to produce a clean image which contains only white lines. After getting a clean grayscale image, a threshold is applied to find white pixels in binary. A particle filter is used in the later stages of processing to remove unwanted noise and further define the white lines. The images, which are distorted through the perspective of the camera, are corrected and converted into a histogram. The line data is then sent to Cognition for path planning.

The dead grass filter starts off with a vision acquisition sub .vi that hosts a video feed from the camera. The color plane chosen in this filter is luminance. Once the color plane has been extracted a threshold filter then converts the image from a grayscale image to binary. The threshold filter controls the values of luminance in the image. The image is then sent through a particle filter which removes unwanted and small scattered pixels. The data is then processed through a fill hole sub .vi which joins the patches of dead grass together and produces the red and black image shown in Figure 4.3.

Figure 4.3: Dead Grass in Video Feed

5.0 Navigation

New to the navigation program this year are intermediate waypoints and timed waypoints. Due to the encouragement of mapping the course by the competition rules, and, in order to prevent dead grass patches on white lines that may cause our vehicle to veer off course, data from successful runs will be used to add waypoints with larger tolerances. Also, in order to prevent our vehicle from circling a waypoint indefinitely, in the instance it is unable to check off a waypoint within in its program, an algorithm was created to time the waypoint search. If after a certain amount of time the waypoint hasn't been checked off, the vehicle will internally check off the waypoint and move on to the next one.

5.1 Navigation Hardware

SCORPION uses a NovAtel SPAN (Synchronized Position Attitude Navigation) system for navigation. This system includes a GPS-702L antenna (Figure 5.1), a LN200 IMU (Inertial Measurement Unit, Figure 5.2) and a ProPak-V3 receiver (Figure 5.3). OMNISTAR has donated an HP differential GPS (DGPS) service, which will increase the accuracy of the SPAN system to 0.1 meters. The IMU provides position data when the GPS data is unavailable, as well as increases the refresh rate by up to 200 Hz. The ProPak receiver takes the GPS and IMU data and combines it in order to provide latitude, longitude and velocity to SCORPION. The ProPak receiver is connected to the computer running SCORPION via an RS232 serial connection at 460800 baud rate while updating at 40 Hz.

Another addition to improve our Navigation for SCORPION is the implementation of a TRAX AHRS or attitude and heading reference system. This sensor incorporates magnetic sensors with gyros and accelerometers. The Trax employs a proprietary Kalman filtering algorithm that intelligently fuses PNI's patented Reference Magnetic Sensors with a 3-axis gyroscope and 3-axis accelerometer. What is unique about this module is the fact that it is immune to distortion and magnetic interference like rebar or magnetic interferences. This allows for a heading device that can be attached to any type of robotics application and allow for high resolution of accuracy when traversing through obstacles.

Figure 5.1 – GPS-702L

Figure 5.2 – LN200 IMU

Figure 5.3 – ProPak-V3 Receiver

Figure 5.4 -TRAX Compass

5.2 Navigation Software

For the Autonomous/Navigation challenge, the software will accept a list of waypoints and will choose the sequence that the vehicle will visit the points that will have the shortest path. This is especially helpful for a large number of waypoints because it will generate a path that requires the least amount of time. Once the waypoint sequence is created, the vehicle will use the first waypoint as its initial goal.

The Navigation program continuously calculates the bearing and distance between the vehicle's current position and its current goal waypoint. This is achieved through the Haversine and Great Circle formulas. The vehicle's compass heading is compared to the bearing in order to find the approximate direction to the goal; this is the "goal angle". The distance from the goal, "goal distance," is monitored, and when it becomes half the radius given in the IGVC rules (2 meters), the current waypoint is checked off and the vehicle moves onto the next waypoint. This process repeats until all waypoints have been checked off. The "goal angle" and "goal distance" are provided to cognition where they are used for path planning. JAUS is provided with yaw, yaw rate, latitude, x & y position and velocity data.

6.0 Joint Architecture for Unmanned Systems (JAUS)

The JAUS set of standards was developed to enable systems interoperability for unmanned vehicles. For the purposes of the JAUS Challenge, the current platform, Scorpion, was programmed in order to execute remote communication between it and a Common Operating Picture (COP). While the Discovery, Capabilities, and System Management, set of commands used in the current algorithm make use the Core Service Set, the Velocity State, Position and Orientation, and Waypoint are based on the Mobility Service Set. Considering the complexity and recurring nature, these commands are modularized and then combined into the main program in both case structures and sequential structures, depending on the application. This strategy, as seen in Figure 6.1, eases the management and debugging of recurring, non-linear processes.

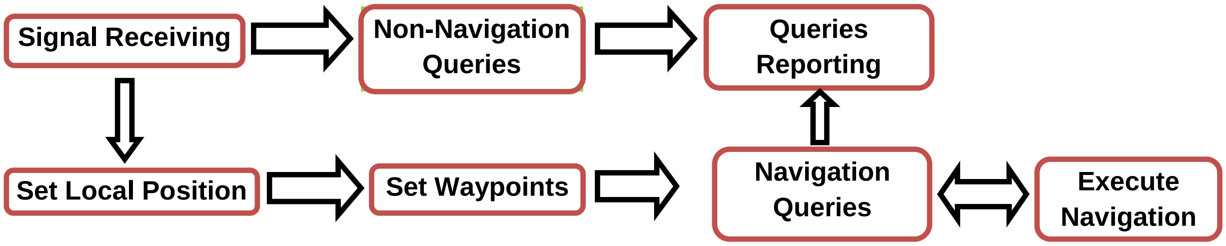


Figure 6.1: JAUS Flowchart

7.0 Cognition

The purpose of the cognition team is to produce an optimal path planning and motion control algorithm for a mobile robot. This obstacle avoidance algorithm provides motor control to the robot through an instantaneous turning radius and velocity. The new innovative algorithm being implemented on SCORPION this year is called Midpoint Polar Histogram (MPH). By analyzing acquired data from a Laser Range Finder (LRF) and a camera, these sensors produce an overlaid histogram to determine all possible path openings. Along with a navigational heading, the robot is able to autonomously navigate through an obstacle filled course and check off various GPS waypoints.

7.1 LRF

The LRF used on the robot is the Hokuyo UTM-30LX as shown in Figure 7.1. The laser range finder continuously scans in a counter clockwise direction for a range of 270^{o}in a planar field. SCORPION only needs 180^{o}, anything more is unnecessary for algorithmic purposes. The LRF executes an 8m range and performs at a refresh rate of 25-milliseconds. The connection to the laptop is direct via a USB 2.0 port. The placement of the LRF is critical for path planning; it has been mounted front and center at an 18-inch elevation with 0^{o} tilt.

Figure 7.1 LRF

Figure 7.2 represents the data acquisition process for the LRF. The left image is a true image of three barrels in front of SCORPION, at different distances. The middle image, showing raw LRF data distances and widths of obstacles, is converted into a histogram plot. The right image is the final 3D rendered feed of the true image situation. The 3D rendered feed creates a virtual local map useful for algorithmic tests.

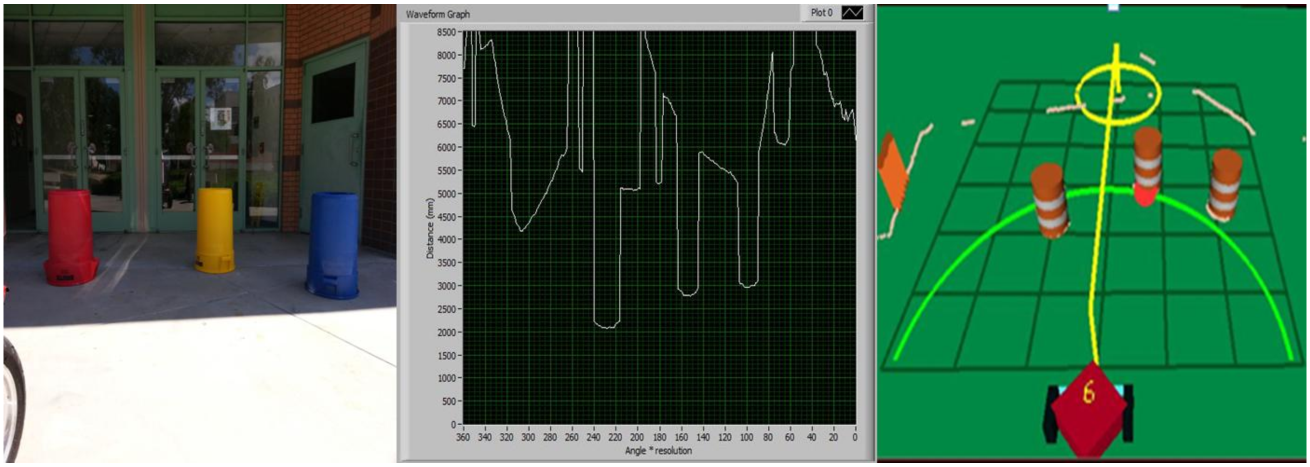


Figure 7.2: Data Acquisition Process

7.2 Map Generation and System Cooperation

Generation of an accurate local map of Scorpion's environment is vital to an optimal path planned algorithm. To achieve this, onboard sensors such as a camera, horizontal and vertical LRFs are integrated together in a checks and balances system (Figure 7.3). The sensor from the horizontal LRF acquires data to detect full bodied obstacles such as barrels. The orientation of this LRF, however, is incapable of detecting a ramp and sawhorse obstacle. To detect ramps and sawhorses, an additional LRF, oriented in the vertical direction, has been implemented into the system. White lines, dead grass, and colored flags are addressed through camera data. Each of these sensor devices acquire raw data which is then converted into a histogram. These individual histograms are superimposed onto a master histogram and create an instantaneous local map stored in short-term memory.

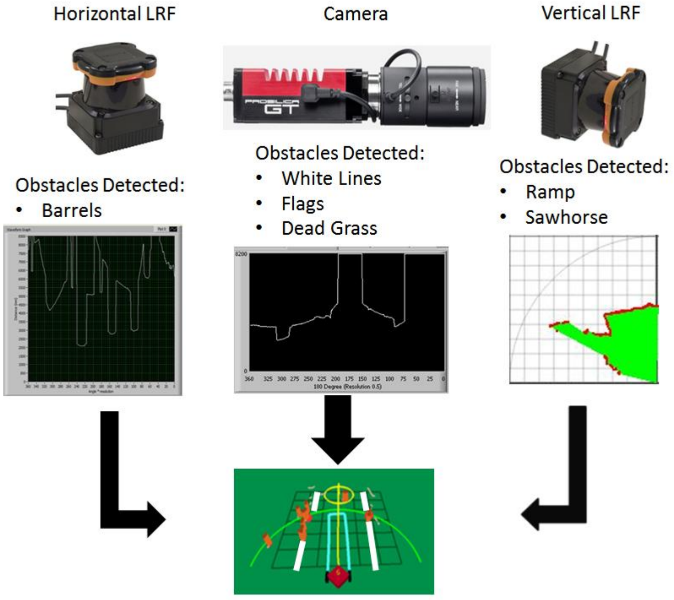


Figure 7.3: Sensory Input

7.3 Path Planning

The new obstacle avoidance algorithm MPH focuses on the edges of a chosen opening to calculate a midpoint. The algorithm uses this midpoint to calculate a turning radius through the midpoint and simultaneously controls the speed of two separate motors. The flow chart below (Figures 7.4 – 7.8) displays the steps that the algorithm takes in order to determine the turning radius of the robot.

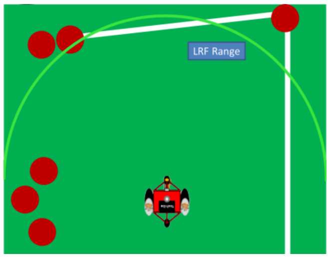


Figure 7.4: First, the robot will approach obstacles and find an opening based on the LRF Range

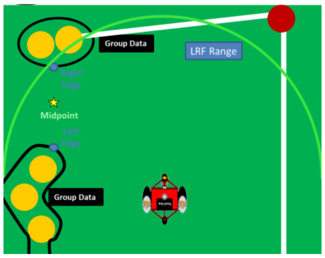


Figure 7.5: Next, obstacles are grouped and the midpoint of the

Figure 7.3: Sensor Input/Output Diagram

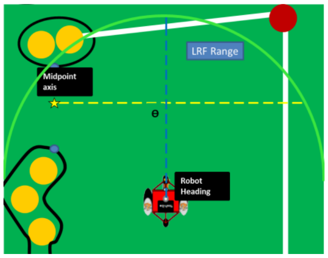


Figure 7.6: Afterwards, Scorpion's heading and midpoint axis are crossed to calculate an angle ɵ

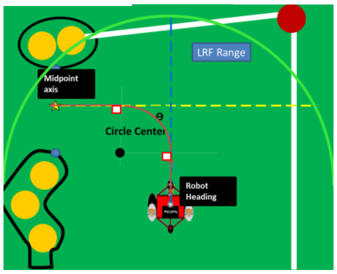


Figure 7.7: Based on the angle ɵ, a turning radius is calculated from the circle center

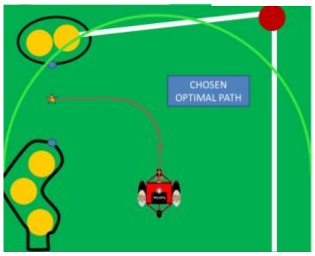


Figure 7.8: Scorpion will then take the chosen optimal path based on these conditions

7.4 System Integration

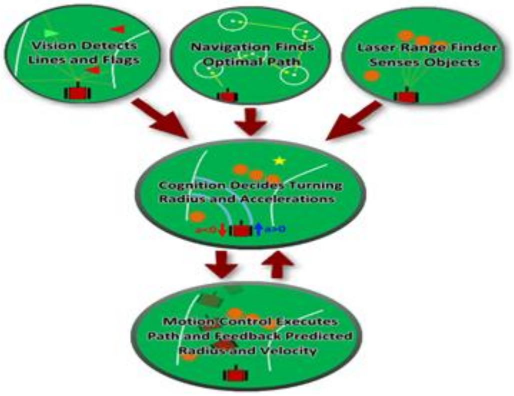


Figure 7.9: System Integration

Figure 7.9 shows the process that SCORPTION uses to complete full integration of all systems onboard. The robot gathers position and heading information through the onboard GPS, which detects instantaneous locations of the robot and waypoint coordinates. The camera and two LRF sensors are used for the obstacle avoidance algorithm, which scans for objects and line boundaries in the robot's environment. Paired with the GPS, a local map is created from these sensors. The local map aids in evaluating open blocks in a selected area to determine a desired radius which is then sent to motion control for execution. The motion control continuously updates SCORPION's predicted turning radius and velocity to determine ideal motor acceleration for each wheel. This instantaneous motion control optimizes smoothness for motion. After this cycle is complete, the sensors rescan the environment and re-iterate the process.

7.5 Blind Flag

Other innovations this year in cognition include a blind camera indicator and ramp detection algorithm. The blind camera indicator algorithm utilizes a light sensor to detect if the camera is blind and therefore unable to produce accurate live feed. This algorithm checks measures the luminance value of the light entering the camera lens; if the value exceeds that of the camera's maximum tolerance, a blind flag is sent. If this case occurs during the robot's course, then the velocity of the robot will be reduced to a minimum until the blind flag is lifted.

7.6 Ramp Detection

In order to deal with a potential ramp on a course, a Ramp Detection Algorithm has been made to allow SCORPION to navigate over a ramp rather than treat it as obstacle avoidance. Depending on the LRF height position, detection of ramp can be very difficult as a horizontally mounted LRF cannot detect terrain inclines, speed bumps or terrain drop-offs. To identify these potential terrain inconsistencies, another LRF sensor is utilized and mounted in a vertical orientation. The purpose of this vertically positioned LRF sensor is to identify slope inconsistencies by comparing ideal distance and height dimensions with the real time data collection of the LRF detected measurements. Mathematical models derived by the change in terrain, and critical parameters of the LRF sensor are used in order to create the algorithm for ramp detection. This algorithm computes the changing heights from the LRF to the ground depending on its scanning range angle and measured distance. An output tabulation of all of the critical data components is necessary for motor control and MPH integration. The plot in Figure 7.7 displays the comparison between terrain without inconsistencies and terrain with slope inclination.

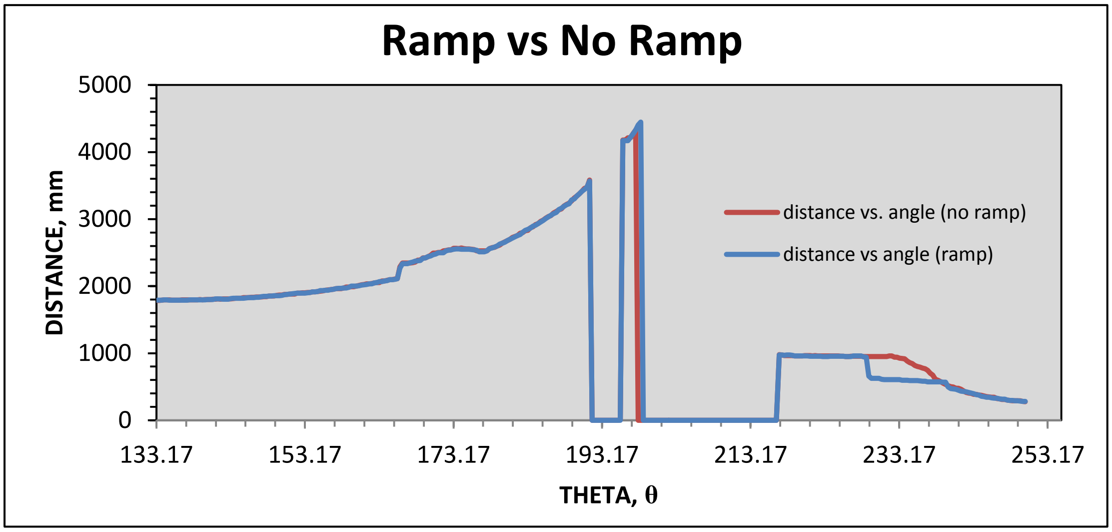


Figure 7.7: Plot depicts LRF sensor data along a plane with and without a ramp detected.

8.0 System Performance

SCORPION has been designed and programmed for efficiency. The result is a highly maneuverable vehicle which operates at high speeds through precision path planning and obstacle avoidance. The performance breakdown can be seen in Figure 8.1. The light weight chassis design allows SCORPION to boast a top speed of 8mph, and the low center of gravity coupled with the multl-link suspension allows SCORPION to climb ramps of up to 35^{o}. By cleaning up previous years' algorithms and replacing parts with streamlined programming, the reaction time has been reduced to 75ms.

Performance	
Top Speed	8.0
Reaction Time	75ms
Ramp Climbing	35^{o}
Battery Life	3-6 hrs
Obstacle Detection	8m
Waypoint Accuracy	10cm

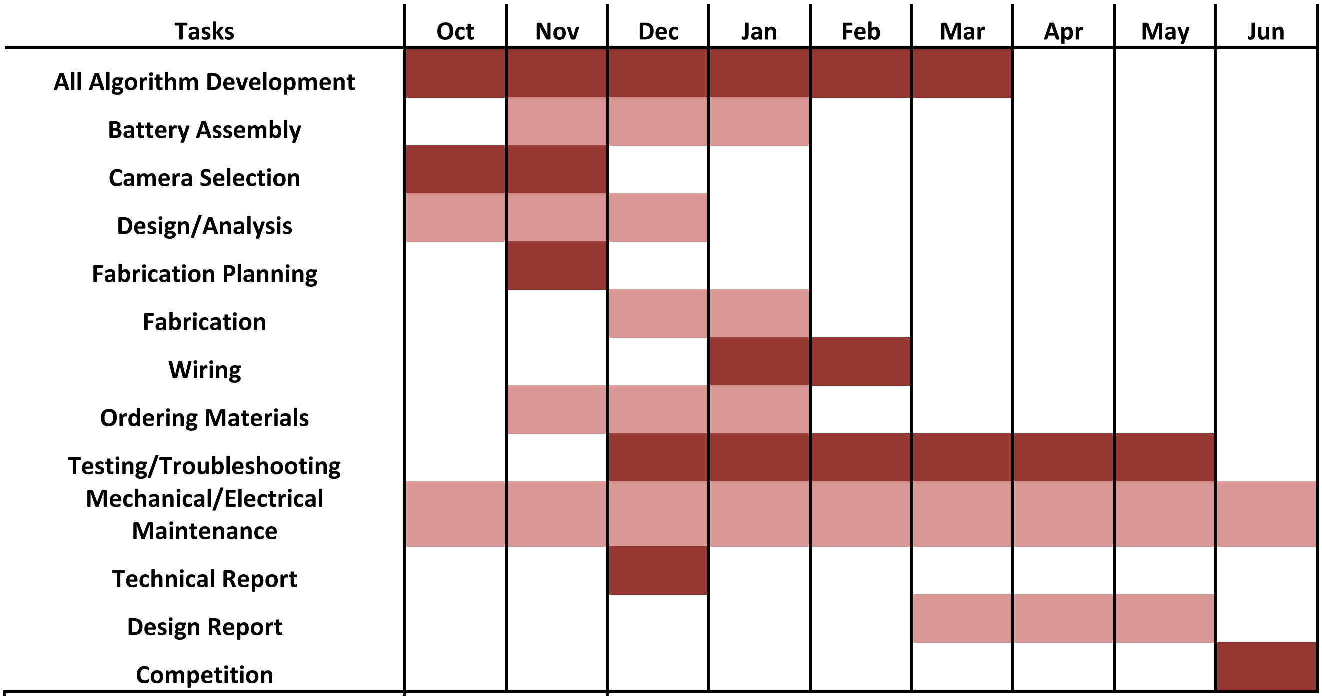
Figure 8.1: Performance

9.0 Appendix

Figures 9.1 & 9.2 represent the total cost and time utilized in building SCORPION from the initial design phase to completion.

Group	Description	Qty	Unit	Cost/Unit	Total Cost	Sub Total
Mechanical Group	Chassis Materials	n/a	Each	$364.50	$364.50	
	Component Cage	n/a	Each	$65.00	$65.00	
	Camera Boom	1	Each	$25.00	$25.00	
	Skin Materials	1	Each	$130.00	$130.00	
	Decoupler	n/s	Each	$55.00	$55.00	
	Linear Bearings	2	Each	$8.00	$16.00	
	Caster Bearings	4	Each	$13.50	$54.00	
	Rod Ends	10	Each	$6.50	$65.00	
	Air Springs	2	Each	$55.00	$110.00	
	Gearboxes	2	Each	$397.00	$794.00	
	Drive Rims	2	Each	$75.00	$150.00	
	Caster Rims	2	Each	Donated	Donated	
	Caster Tires	2	Each	$150.00	$300.00	$2,128.50
Electrical Group	Custom PCB	2	Each	$350.00	Donated	
	PCMs	3	Each	$34.25	$102.75	
	PCB Fuse Holders	48	Each	$0.88	$42.24	
	Hot Swap Switches	2	Each	$54.95	$109.90	
	Digit LCD Panel	2	Each	$14.95	$29.90	
	Anderson PCB Adapters	24	Each	$4.42	$106.08	
	Battery Cells (LiPo 3.7V0	16	Each	$34.99	$559.84	$950.71
Vision Group	AVT Prosilica GT 1290	1	Each	$800.00	$800.00	
	Thea SY110A Lens	1	Each	$400.00	$400.00	$1,200.00
Cognitition Group	Hokuyo UTM-30LX	1	Each	$5,327.90	Donated	$0.00
Navigation/JAUS	TRAX AHRS Module	1	Each	$1,295.00	Donated	
	GPS Receiver/Antenna/IMU	1	Each	$$$	Donated	$0.00
					Grand Total	$4,279.21

Figure 9.1: Budget



Tasks	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
All Algorithm Development	■	■	■	■	■	■			
Battery Assembly		▨	▨	▨					
Camera Selection	■	■							
Design/Analysis	▨	▨	▨						
Fabrication Planning		■							
Fabrication			▨	▨					
Wiring				■	■				
Ordering Materials		▨	▨	▨					
Testing/Troubleshooting			■	■	■	■	■	■	
Mechanical/Electrical Maintenance	▨	▨	▨	▨	▨	▨	▨	▨	▨
Technical Report			■						
Design Report						▨	▨	▨	
Competition									■

In Class Hours	12/week
Out of Class Hours	12/week
Total Hours	984 Hours*

*September was utilized to famaliarize the team with the IGVC and previous platforms

Figure 9.2: Total Hours Input