



UNIVERSITY OF TEXAS AT ARLINGTON
RESEARCH INSTITUTE

MARAUDER

The University of Texas at
Arlington

2013 IGVC Team



Team Members: Chris McMurrough, Bardia Mojra, Fermin Feroshi Arun Joseph, Rommel Alonzo, Adis Kovacevic, Ashley Chase Guy, Michael Smith, Nirmal Kumar Kanagasabapathy, Robert Castillo Jr, Scott Phan, Banuchandar Esakkimuthu, Roochi Mishra, Prabhat Sharma, Kishan Thapa, Shawn Gieser

Faculty Advisor Statement

I certify that the engineering design of the vehicle described in this report, The Marauder, has been significant and equivalent to each team member earning academic credit towards a senior design course in their respective departments.

A handwritten signature in black ink, appearing to be "L. Gieser", written over a white background.

1 Introduction

The Marauder robot at UTA is developed by a multidisciplinary team consisting entirely of student volunteers and a faculty mentor. While UTA has previously competed in past IGVC events, the 2013 team has built their mechanical, electrical, and software systems from the ground up without reusing any existing platforms or code from previous teams. The principal goal of the 2013 team is to develop a UGV platform with design innovations that are truly disruptive to the IGVC community. In this document, we describe Marauder, an intelligent off-road ground vehicle platform that utilizes a novel omni wheel design to achieve holonomic motion. The mechanical, electrical, software, and logistical strategies employed to prepare the platform by the 2013 IGVC team are described in the following sections.

1.1 Team Organization

The Marauder team is organized according to a decentralized organizational model. This was chosen in order to efficiently utilize the combined labor resources of the team members. Since the team is comprised entirely of volunteer members with outside scholastic and professional obligations, it was necessary to use a development model that favors subcontracting of discrete labor tasks. A central planning and design committee was formed by the senior project members, which collectively established the overall development strategy and division of tasks. Each task was broken down into individual specifications and assigned to a subcommittee, which was responsible for the design, fabrication, and testing of the particular component. Figure 1 provides a graphical overview of the Marauder team structure and allocated human resources.

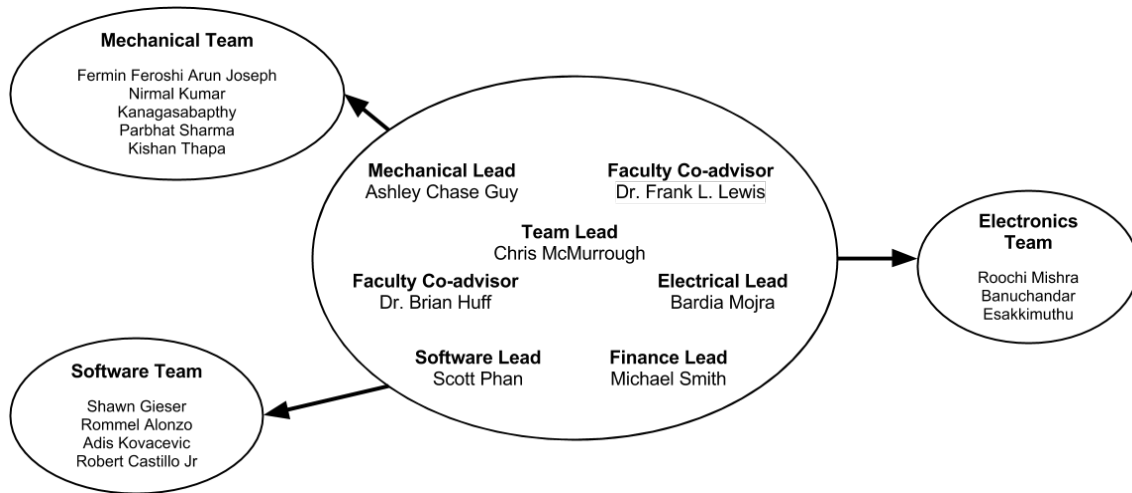


Figure 1: UTA IGVC Team Organizational Structure

1.2 Design Planning Process

The design planning process for the Marauder robot was broken down into 3 strategic implementation areas: mechanical, electrical, and software. During the initial planning phase of the project, the organization assumed a flat structure and collectively decided upon the omni wheel concept. Once the individual committees were formed, overlapping integration areas (such as motor selection for the mechanical and electrical committees) were discussed and finalized. From this point, the individual committees were able to provide added value in a subcontracting manner while avoiding conflicts with other groups.

The platform consists of quad omni wheel platform that uses a laser ranger finder and color camera array for detection of obstacles and ground features. Global navigation is provided using a fusion of GPS and IMU data. Global and local costmaps are used by a planning algorithm to guide the vehicle to waypoints while reporting status updates to a JAUS network.

1.3 System Integration Plan

As each discrete task was completed, system integration responsibilities were shared between the central planning and individual area committees. Unit testing of each module was performed prior to integration by each committee, while overall system testing was performed by the committee head and central planning committee prior to acceptance. The main benefit of this approach is that knowledge of module operation is passed from the individual committees to the central leadership during the integration process, which acts as a built in training mechanism.

1.4 Key Innovations

The Marauder team established high-risk, innovative design as a key priority early in the planning process. Several novel concepts were developed and integrated into the platform. A summary of design innovations is listed below, while details of each item are presented in later sections of the document.

- Design of a low-cost, off-road capable omni wheel
- Fabrication of a quad omni wheel platform with independent wheel suspension
- Utilization of a steadicam gimbal camera mount for vibration mitigation
- Development of modular, open-source software for perception and control

2 Mechanical Design

Traditional vehicle platforms, such as car-like Ackermann steering or tank-like skid-steering, are used in the vast majority of mobile ground robots. These mechanically

simple systems provide a relatively efficient means of forward locomotion, but have limited degrees of motion freedom due to their non-holonomic configuration. Because of this, traditional platforms are typically constrained by a tight coupling between angular and linear motion.

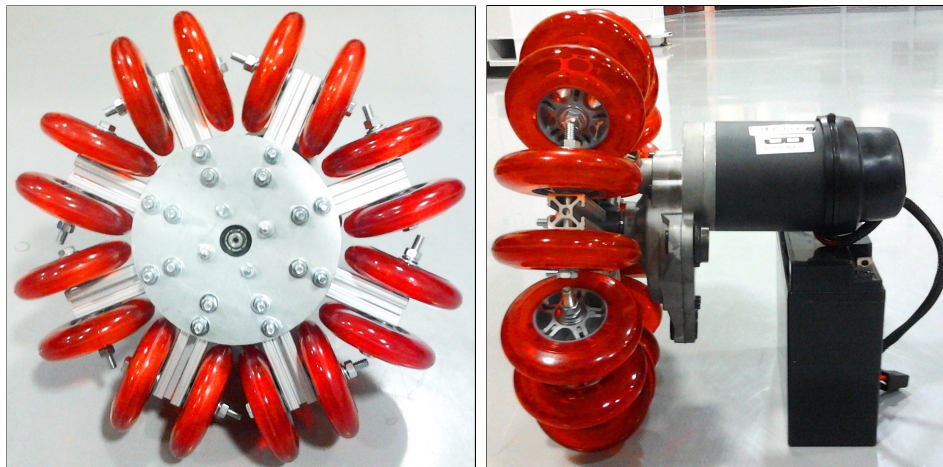
Holonomic platforms, on the other hand, are not limited by these constraints and are able to move in any direction independent of their orientation. These highly mobile platforms, while more mechanically complex, can perform some tasks that are not suitable for non-holonomic platforms. We present an omniwheel design that uses inexpensive, readily available components that is relatively simple to fabricate and assemble.

2.1 Omni Wheel Design

The omniwheel utilized by our platform is designed to provide traction on rough surfaces when moving in the direction of wheel rotation, while providing near frictionless casting in directions along the axis of the drive shaft (i.e., the wheel should freely slide sideways). To facilitate this, we designed an assembly that utilizes commercially available 100 millimeter polyurethane wheels that are commonly found on recreational scooters. These wheels were chosen due to their relatively low-cost, integrated bearings for smooth rotations, and durability in outdoor environments. Each of the 16 wheels are mounted on either side of a piece of aluminum extrusion using a single carriage bolt. The resulting 8 wheel pairs are bolted to a central aluminum disc along with a wheel hub.

The wheel design has an overall diameter of 15.0 inches. This diameter supports the arrangement of 16 wheels such that the gaps between wheels are minimized in order to provide the smoothest operation possible. Other omniwheel designs often

employ barrel shaped orbital wheels in multiple layers to eliminate this gap, though this approach does not work well on rough surfaces and is generally difficult to fabricate. Our design can be fabricated with simple machine shop equipment, such as a hand-held hacksaw and power drill. The fully assembled wheel module is shown in Figure 2. The wheel assembly is driven by brushed DC motors which were salvaged from discarded electric wheelchairs. The maximum speed of the motors measured when no load is applied is 180 RPM. The maximum attainable speed of the vehicle is then calculated to be 8.02 MPH.



(a) Front view of wheel assembly (b) Wheel assembly mounted on motor

Figure 2: Completed wheel module after fabrication

2.2 Structural Assembly and Vehicle Suspension

In order for omniwheel platforms to move successfully, each drive wheel must maintain contact with the ground when actuated. This design consideration is commonly overlooked in most approaches, since it is generally assumed that the surface of the

operating environment is both flat and smooth. Our approach uses an independent vertical suspension system for each drive module. Each motor and wheel pair is allowed to slide upward along a pair of vertical rails against a spring. The spring applies a constant force in the downward direction, such that the drive module is normally pressed against the vehicle chassis when the wheel is on flat ground. When the platform is on rough terrain, the wheel modules will move upward toward the springs, which absorbs the shock and causes the wheel to maintain contact with the ground. Original CAD renderings of the rail and spring drive suspension assembly are shown in Figure 3.

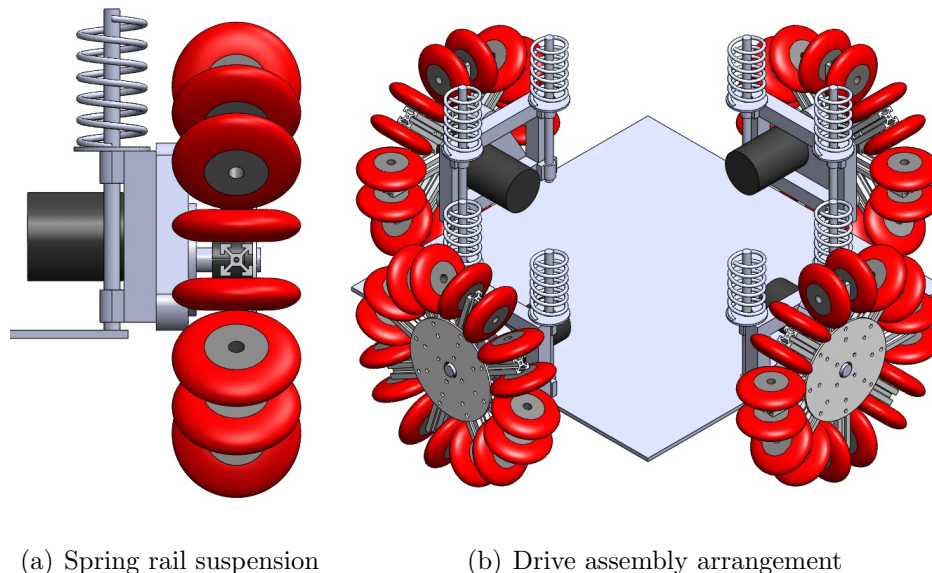
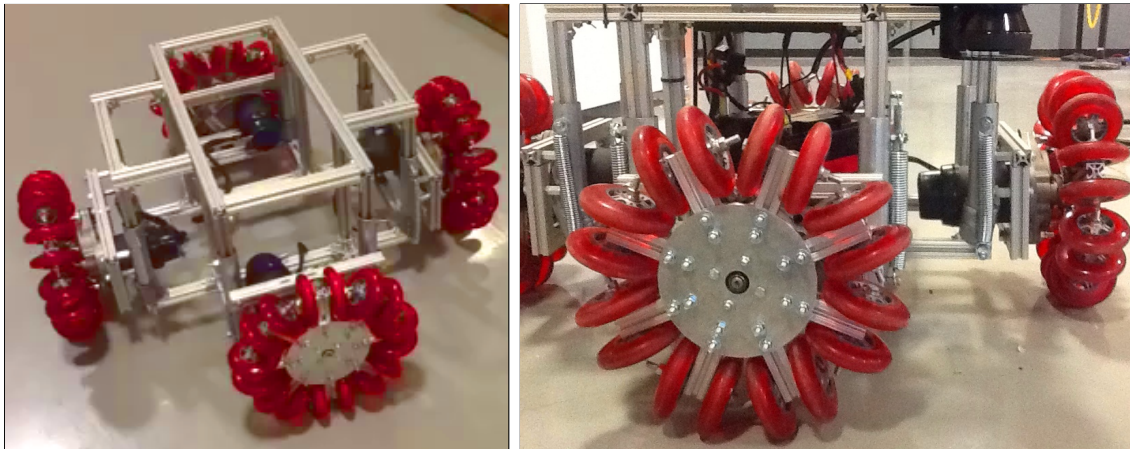


Figure 3: Original platform suspension and motor arrangement design

Our platform is designed to utilize 4 drive modules mounted in a square configuration. Each drive module is positioned on one side of a chassis base with a 90 degree offset from the adjacent motors. When mounted on a 24.0 inch square chassis base, the resulting platform is 37.0 inches in length and width. The arrangement

of the drive assemblies and suspension rails on the chassis base is shown in Figure 3(b). The fully assembled mechanical platform is shown in Figure 4. The 4.5 inches of vertical wheel travel allows the vehicle to negotiate significant bumps and ramps. A 30 degree ramp was successfully negotiated during testing.



(a) Vehicle chassis

(b) Assembled platform

Figure 4: Assembled mechanical platform

2.3 Modularity and Maintenance

The Marauder platform is assembled from primarily 8020 aluminum extrusion and standard fasteners available at most hardware stores. Similarly, the suspension system is made from standard conduit tubing and extension springs which are also commercially available. Each motor module and suspension assembly can be removed from the chassis for maintenance by removing only 4 bolts. The suspension springs can be easily changed by removing only two nuts based on the weight of the cargo. The platform structure contains a cargo area where a payload can be both easily accessible and securely stored, while an enclosure mounted toward the top

of the frame protects the system electronics while providing convenient access and expandability.

2.4 Steadicam Gimbal Assembly

In order to maximize image stability, a steadicam gimbal system was designed. The 2 axis gimbal minimizes vibration by absorbing motion in the pitch and roll directions. The camera array is mounted on the top of the gimbal assembly, and is held parallel to the gravity vector by a counterweight attached to the bottom of the gimbal arm. This approach results in stable video images even during top speed conditions.

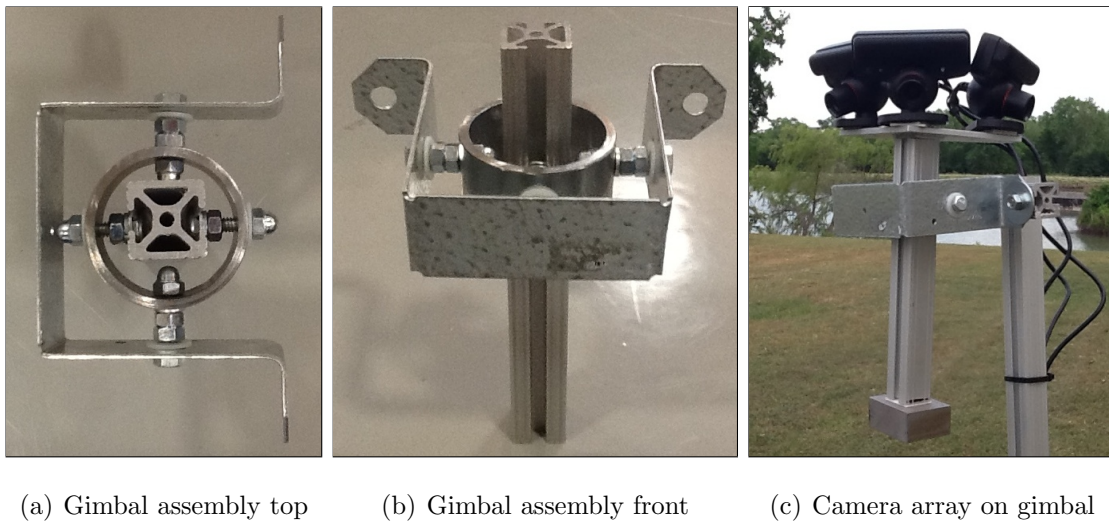


Figure 5: Steadicam gimbal equipped with camera array

3 Electrical Systems

Electrical components for the Marauder platform were chosen based on tradeoffs between cost and performance. While high-end GPS, IMU, and imaging components

would provide optimal performance, appropriate substitutes were selected to remain within budget constraints. An overview of the hardware components present on the Marauder is shown in Figure 6. Safety is provided by a wireless E-stop, mechanical E-stop, and automatic motor controller deactivation after 0.5 seconds of communication timeout.

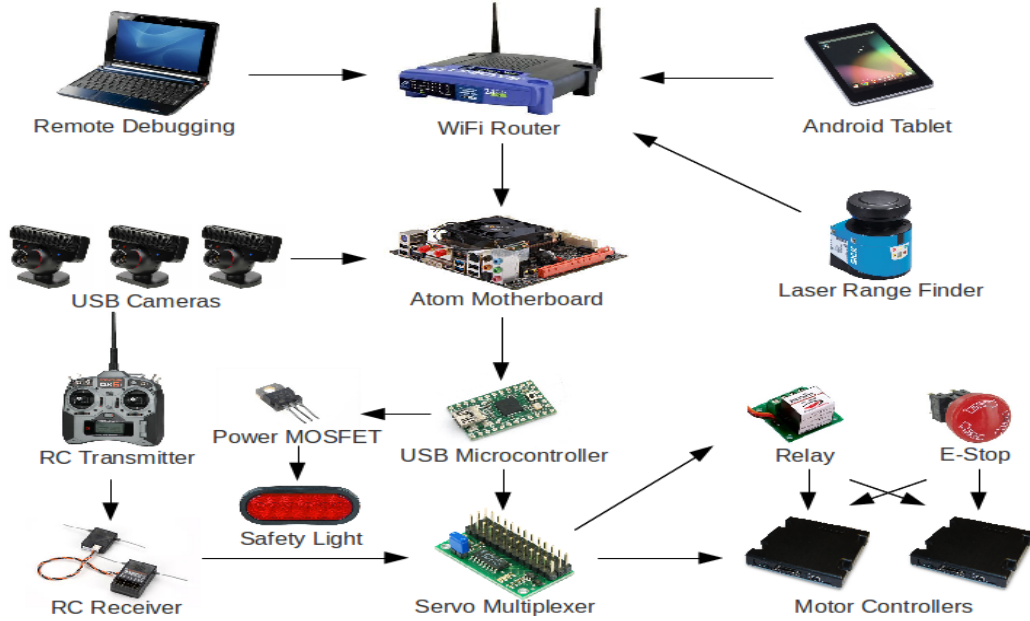


Figure 6: Marauder sensing and control comonents

3.1 Power System

Power for the Marauder platform is provided by a pair of 12 volt 20 Amp hour batteries connected in series. The resulting 24 volts supplies power directly to the MDC2250C motor controllers, while an automotive M4 ATX power supply regulates power for the computing and sensing components. The series connection between the two batteries is protected by a 30 amp fuse, limiting the peak platform power

consumption to 720 Watts. The computing and sensing components were found to draw a maximum of 5 amps at peak, resulting in 120 Watts of power consumption. The motor controllers are each set to provide a maximum of 5.5 amps of power, which results in a total maximum current draw of 27 amps at 24 volts, or 648 Watts of power consumption. The 20 Amp hour batteries provide a theoretical 44.4 minutes of operating time under load, though in practice the system is never run continuously for more than 25 minutes between charging.

3.2 Computing and Control Hardware

A Zotac D2700 mini-ITX motherboard equipped with a dual core Intel Atom processor and integrated NVIDIA GPU provide all of the processing capabilities of the system. This solution is able to process the 3 camera array video streams in real-time (30 fps) while performing other mapping, control, and communication tasks. Network services are provided by a Linksys WRT54G wireless router, which supports the IP based laser range finder and Nexus 7 tablet. Connection to the JAUS network is provided using the integrated WiFi connection on the motherboard such that the external network interface occupies a subnet separate from the internal communication network.

Control of the platform is achieved using a Teensy 2.0 USB microcontroller and servo multiplexer. The USB microcontroller is programmed to generate PPM servo control signals, which are interpreted by the servo multiplexer, and also MOSFET activation signals for the safety light. The multiplexer selects between the USB microcontroller and AR6200 DSM2 6-channel receiver as inputs based on a toggle switch located on the DX6i RC transmitter, while the transmitter provides remote control and E-stop activation via a PPM actuated relay.

3.3 Sensors

Sensing capabilities are provided by a Sick LMS100 laser range finder, an array of 3 Playstation Eye USB cameras, and Nexus 7 Android tablet providing GPS and IMU measurements. The tablet was chosen due to its relatively low cost and acceptable GPS accuracy. The data streams provided by the laser, cameras, and tablet are fused together in order to achieve localization and mapping, which is discussed further in section 4.

4 Software Modules

Our system utilizes the open-source *Robot Operating System* software to facilitate code modularity and reduce development time. Each core software process is implemented as a ROS *node*, which compiles and executes independently and publishes or subscribes to ROS *topics*. The resulting architecture, shown in Figure 7, allows interoperability and rapid prototyping of nodes.

4.1 Environment Scanning

The Sick LMS100 laser is the primary navigation sensor used by the system. The laser measurements acquired by the `lms100` node are processed using hector mapping in the hector mapping node. Hector mapping is a 2D mapping technique that quickly generates accurate occupancy grid maps without the need for odometry. The laser is able to detect obstacles at a range of up to 20 meters.

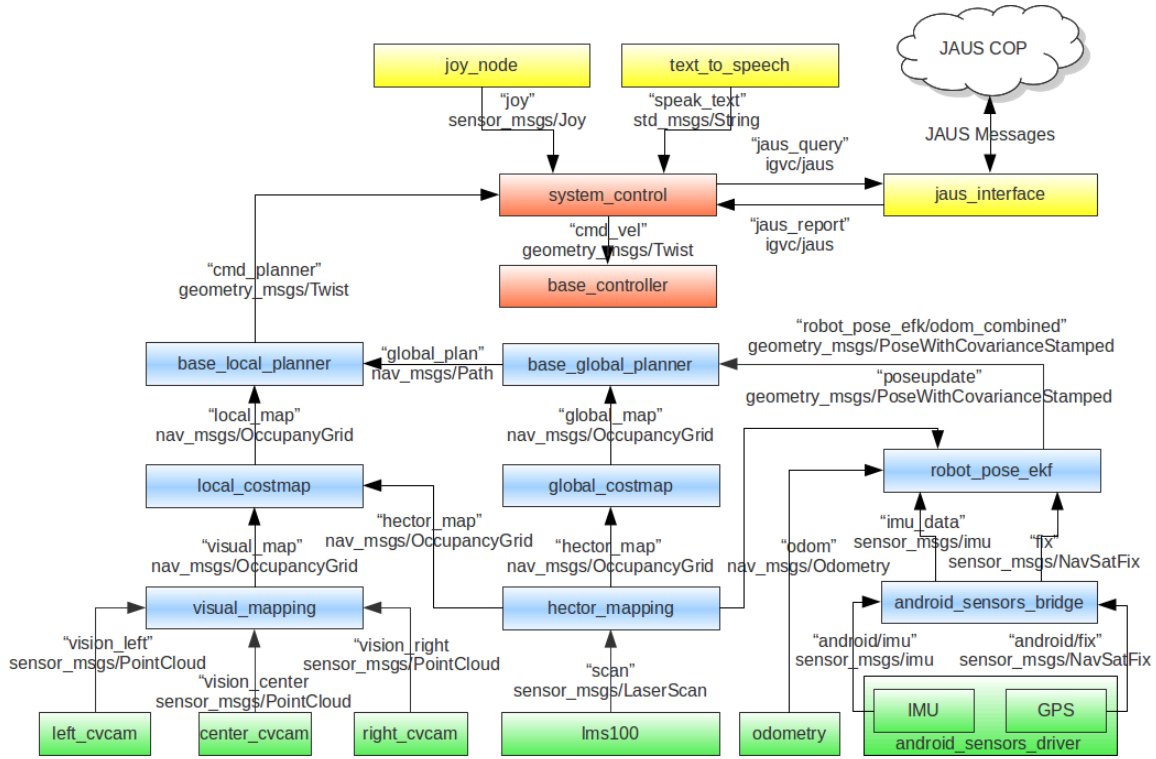


Figure 7: Marauder ROS software architecture

4.2 Vision Processing

Vision processing for the Marauder system is provided using the 3 camera array and the OpenCV vision processing library. In our approach, the forward facing camera is primarily used to identify obstacles that the laser does not easily perceive (flags and lines). The left and right facing cameras are used to detect only lines. The 3 independent vision processing nodes each use adaptive color thresholding of known values of interest (orange, red, white, blue, yellow, etc). Once these regions are thresholded individually, a blob tracking algorithm using connected component analysis is applied in order to identify large color regions. These regions are interpreted as either lines or objects based on their color, and are added to a visual occupancy grid map.

4.3 Navigation and Inertial Sensing

GPS and IMU data are provided by the Android tablet. These data streams are fused, along with hector mapping pose estimates, using an Extended Kalman Filter in the robot pose ekf node. The result of the EKF node is an updated pose estimate that is filtered based on known covariances of the tablet sensors and hector mapping technique. The EKF also handles odometry measurements, but the current platform does not provide these readings. The covariance of the odometry readings in the EKF node are set such that the odometry node is effectively ignored.

4.4 Data Fusion

The occupancy grid maps provided by the hector mapping and visual mapping nodes are combined in the local costmap node. This node is responsible for identifying intermediate motion goals in order to navigate around obstacles and lines within the platform's immediate vicinity. When new items are added to the occupancy grid, any cells lying between the new cell and any previously occupied cells within a euclidean distance threshold are also marked as occupied (this marks small gaps between obstacles and lines as occupied). Similarly, a global cost map is generated using hector mapping occupancy grides in the global costmap node. This node is responsible for identifying long-term motion goals, such as GPS waypoints.

4.5 Path Planning

Path planning is achieved in the base global planner and base local planner nodes. The global planner utilizes the A* algorithm to generate rough path segments in the global reference frame. These path segments are provided to the base local planner, which generates paths in the local reference frame. This node is also responsible for

detecting local minima conditions, such as switch backs, dead-ends, and traps. The local planner maintains a time window record of progress, which is defined as a decrease in euclidean distance from the current location to the end of the path segment. When an amount of progress below the window threshold is detected, an exception is generated and the the local occupancy grid is modified with virtual obstacles. These virtual obstacles are added until the platform is pushed into a previously unexplored occupancy grid cell, which then causes the time progress window to reset. This effectively marks areas as problematic such that the robot does not stay in the location or venture there in the future.

4.6 Motion Control

Control of the Marauder platform is achieved using servo signal mixing based on desired X and Y linear speeds and a desired rotational speed. Since the platform is holonomic, we are able to move in any vector direction with any orientation. This allows the platform to navigate around obstacles while pointing the sensors in the goal direction. Given the desired linear and angular velocities v_x , v_y , and $R\omega$, and current wheel orientations $\theta_1, \theta_2, \theta_3, \theta_4$, the motor speeds v_1, v_2, v_3, v_4 can be solved using the formula below:

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} = \begin{bmatrix} -\sin \theta_1 & \cos \theta_1 & 1 \\ -\sin \theta_2 & \cos \theta_2 & 1 \\ -\sin \theta_3 & \cos \theta_3 & 1 \\ -\sin \theta_4 & \cos \theta_4 & 1 \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ R\omega \end{bmatrix}$$

This formula is implemented in the base controller node, which computes motor speeds based on given velocity commands from the system control node.

5 Equipment Expenditures and Work Summary

Components	Per Item Cost	Total Quantity	Total Cost	Amount Spent 2013
Wheel Assemblies				
Aluminum 6061 1/4" Sheet	\$20.11	4	\$80.44	\$80.44
Scooter Wheels	\$2.99	32	\$95.68	\$95.68
Aluminum 8020 1" Extrusion	\$14.20	4	\$56.80	\$56.80
Metric Keyed H-Bushing	\$5.50	4	\$22.00	\$22.00
Motors and Power				
Jazzy Select Wheelchair Motors	\$50.00	4	\$200.00	\$200.00
2x60A H-Bridge	\$385.00	2	\$770.00	\$770.00
12V 20AH SLA Battery	\$42.60	4	\$170.40	170.40
Misc. Electrical	\$100.00	1	\$100.00	\$100.00
Structural & Suspension				
Aluminum 8020 1" Extrusion	\$26.68	6	\$160.08	\$160.08
Suspension Springs	\$2.78	8	\$22.24	\$22.24
Misc. Hardware	\$100.00	1	\$100.00	\$100.00
Computing				
Atom Motherboard	\$179.99	1	\$179.99	\$0.00
4GB RAM	\$24.99	1	\$24.99	\$0.00
60GB Solid State Drive	\$89.99	1	\$89.99	\$0.00
250W DC Power Supply	\$89.50	1	\$89.50	\$0.00
Power Supply Enclosure	\$2.95	2	\$5.90	\$5.90
Wireless Router	\$49.99	1	\$49.99	\$49.99
Electronics Enclosure	\$39.99	1	\$39.99	\$39.99
Misc. Connectors	\$50.00	1	\$50.00	\$50.00
Sensors				
SICK LMS100 LIDAR	\$5,630.00	1	\$5,630.00	\$0.00
PlayStation 3 Eye Camera	\$19.99	3	\$59.97	\$59.97
Nexus 7	\$199.99	1	\$199.99	\$0.00
Control Electronics				
RC Servo Multiplexer	\$19.95	1	\$19.95	\$19.95
USB Servo Controller	\$19.95	1	\$19.95	\$19.95
RC MOSFET	\$9.95	1	\$9.95	\$9.95
Servo Extension Cable	\$1.95	12	\$23.40	\$23.40
Teensy USB Microcontroller	\$16.00	1	\$16.00	\$0.00
Emergency Stop / Safety				
ESTOP	\$58.46	1	\$58.46	\$58.46
Radio Controlled Relay	\$24.99	2	\$49.98	\$49.98
DX6i RC Transmitter	\$209.99	1	\$209.99	\$209.99
Safety Light	\$14.99	1	\$14.99	\$14.99
Totals				
	\$7,603.47	X	\$8,720.62	\$2,490.16

Work Task	Hours (per student)
Meetings	1
Fabrication and Development	8
Total for period November 2012 through May 2013 (23 weeks)	207