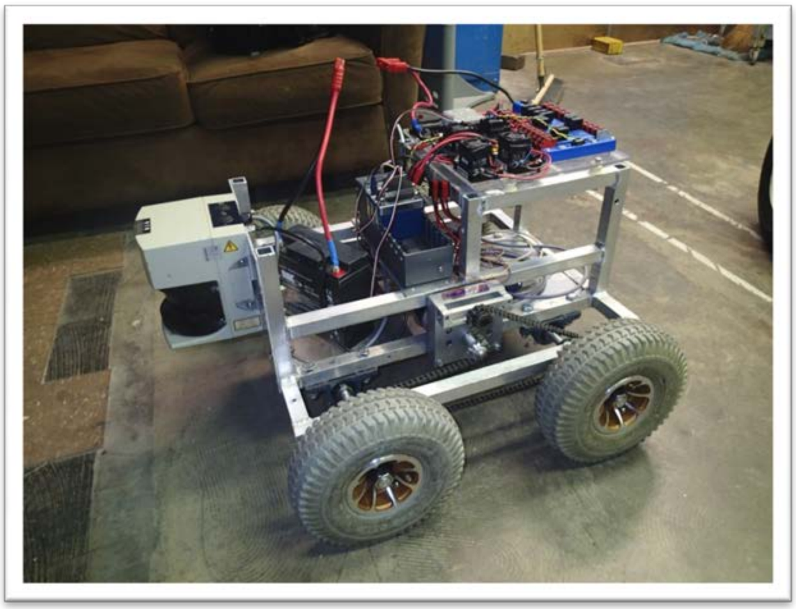
KURT

Kettering University Robotics Team - A

Robot Name: Sidetracked

2013 IGVC Design Report

Team members Adlai Milbitz, Jason Weihman, Justin Cetnar, Rick Pease, Jon Wieskamp, Anthony Padalino, Alexandra Czukkermann, Luke Partin, Eric Barch, Eric Salem, Don Ebben, and Jacob Rener



Faculty Statement

I certify that the design and engineering of the new vehicle described in this report has been significant and equivalent to what might be awarded credit in a senior design course.

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Girma Tewolde
Assistant Professor of Computer Engineering
Kettering University

CONTENTS

TEAM OVERVIEW

Name	Degree Program	Class	Contribution
Adlai Milbitz	Mechanical Engineering	Senior	Captain
Jason Weihman	Mechanical Engineering	Senior	Mechanical Lead
Justin Cetnar	Electrical Engineering	Senior	Software Lead
Rick Pease	Electrical Engineering	Junior	Electrical
Jon Wieskamp	Computer & Electrical Engineering	Senior	Software
Anthony Padalino	Electrical Engineering	Junior	Software
Alexandra Czukkermann	Mechanical Engineering	Freshman	Welding
Luke Partin	Mechanical Engineering	Senior	Mechanical
Eric Barch	Computer Engineering/Computer Science	Senior	Software
Eric Salem	Electrical Engineer	Senior	Software/E-Stop
Don Ebben	Computer Engineering/Computer Science	Senior	Software/Vision
Jacob Rener	Computer & Electrical Engineering	Senior	Software/Laser Range Finder

ROBOT OVERVIEW

Robot Name: Sidetracked

Sidetracked represents the culmination of several semesters worth of preparation in a unique school rotation environment. Input from over four classes of students was instrumental in the final product. The support of the Kettering University ECE department has been invaluable along with the advice and expertise of professor Tewolde.

TECHNICAL SPECIFICATIONS

STRUCTURE & MOTION SUBSYSTEMS

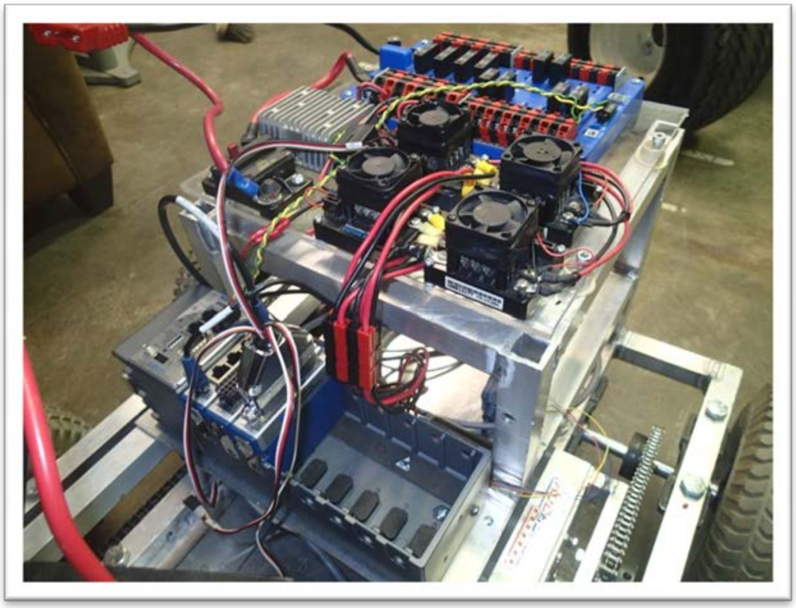
Highlights

- → Welded aluminum frame
- → Four wheel drive
- → Tank steering
- → 10” Pneumatic tires
- → AndyMark Toughbox Gearboxes
- → Four CIM motor drive train
- → Custom chain tensioning system

Custom chain tensioning system

Sidetracked is designed to effectively traverse a semi-rugged outdoor course. The welded structure and rigid design throughout allows for high speed operations. A custom chain tensioning system ensures flexibility and durability of the drive train. The motors and gearboxes were selected for an optimal balance of speed and power.

Electrical, Control, & Power Subsystems



Highlights

- → National Instruments C-Rio 9022
- → 12V power system
- → 4 motors with individual speed controllers and feedback control loop from gearbox

The electrical design of sidetracked emphasized off the shelf components and pre-designed systems to minimize time and financial resource expenditure.

Logic Subsystem & Sensors

Highlights

- → Sensors
  - o Refurbished LS 291 SICK Laser Range Finder
  - o GPS - 20 Channel EM-408 SiRF III Receiver with Antenna/MMCX
  - o Compass - OS5000-S Evaluation Kit (3 Axis Digital Compass RS232)
  - o Camera – Axis M1013 Camera
- → Mapping – AD* occupancy grid with mask overlay
- → Programmed in labview to ease in system integration

The logic and sensor subsystems were developed by two groups. The first group was responsible for the integration of the SICK Laser Rangefinder, the compass, and the GPS module. The second group was responsible for the vision system and the high level mapping and path planning as well as its integration with the drive system.

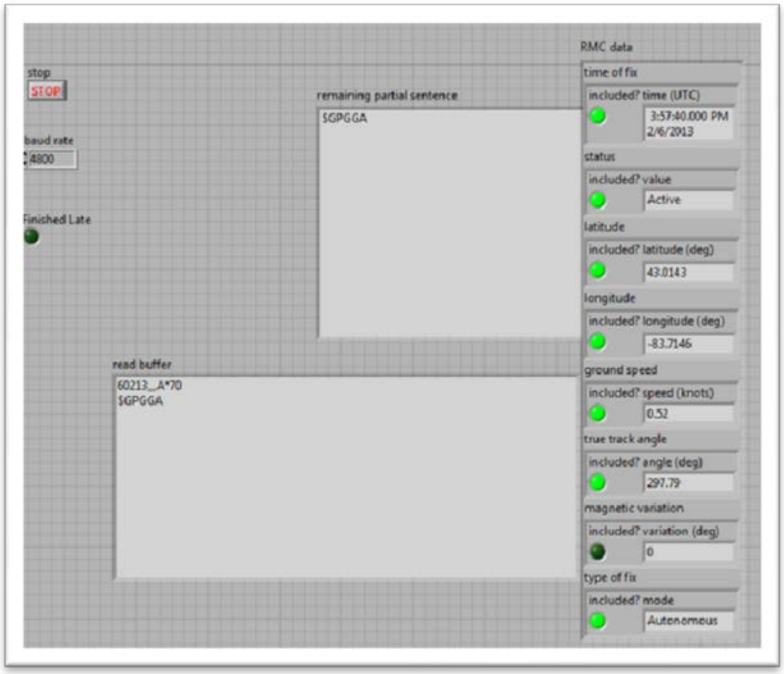
The primary challenged faced by group one was the creation of a serial read-write method and its implementation on the FPGA. After establishing the basic groundwork signal processing was each of the three sensors was simplified. The laser rangefinder program parses the output string from the rangefinder and converts the polar coordinates into Cartesian coordinates.

SICK Laser

The SICK LMS 291 Laser Range Finder is set to give the distance of objects in centimeters every one degree. The SICK must be sent a string for it to send the output. The SICK output string is parsed and the individual degree measurements are exported in polar form and the converted Cartesian line. The lines are plotted within the VI for debugging.

GPS

The GPS module that was selected for development and the IGVC competition was the SparkFun GPS Eval board with an EM408 GPS module. The Eval board was chosen as it already provided an RS232 connection which could be wired directly into the cRIO serial module. One of the challenges of utilizing the GPS as a serial device was that it would have to work in unison with other serial devices onboard the robot (the SICK laser for instance). Once the baud rates were sorted out, serial devices were able to be used simultaneously without interference. The EM408 module in particular uses a baud rate of 4800 bits per second. One of the nice features of the module is that it requires no data to be transmitted to it. As soon as it has a fix to enough satellites, the GPS data begins to stream out of it. The EM408 module supports the NMEA 0183 protocol. Digging into the Robotics modules provided with LabVIEW Robotics revealed advanced VIs that handle parsing of NMEA sentences. Because serial data was already pouring in through the existing serial VI, this made the handling of GPS data much simpler. The NMEA sentence parsing VI expects a type of sentence and any previous sentence data. Because data ‘streams’ in from the GPS module, it is possible that data will get handed to the NMEA parsing VI that is incomplete. The VI handles this and has an output node that contains any leftover data. This data is fed into a shift register and then sent back into an input node of the VI. Every time the NMEA parsing VI finds a GPRMC sentence, it updates its outputs with the most recent values. Seen in the image below, indicators have been created for all the relevant fields.



Now that valid GPS data was being parsed successfully, the next step was to calculate distance and heading between two GPS points. One of the interesting bits of information gleaned was that the simple distance formula would fail for any sort of long distance GPS navigation. Although this wouldn't be an issue for the IGVC competition, the algorithms were implemented correctly so that if the same VIs ever needed to be used for long distance waypointing, it would be possible. The Haversine formula is the key to calculating distances on the Earth. As the Earth is more spherical than flat, the Haversine formula takes this into account. This was key during integration between the GPS and Compass data.

COMPASS

The compass that was selected to use with the IGVC robot was the OceanServer OS5000S. This 3axis digital compass reports heading from north, pitch, and roll, as well as temperature. It was donated to the Mobile Robotics Club for use with this competition robot. It uses a RS232 serial connection to communicate and the baud rate it uses standard is 192000. As soon as you power it, it will begin sending out data packets giving all available data in this format:

$C[heading]P[pitch]R[roll]T[temperature]*[checksum].
For example:
$C320.5P0.2R18.3T19.0*3C

This is interpreted to say that you are turned 320.5° clockwise from north, angled 0.2° up, and rolling 18.3° and the device temperature is 19.0°C. The 3C is the checksum, which is the XOR of all values between the $ and the *. The next step is to take this incoming data and parse it, using Labview, into usable data for navigation. This was done using a very simple VI which breaks the string into four parts, extracts the numbers and converts it to a double. These values can be easily used by other VI's for navigation.

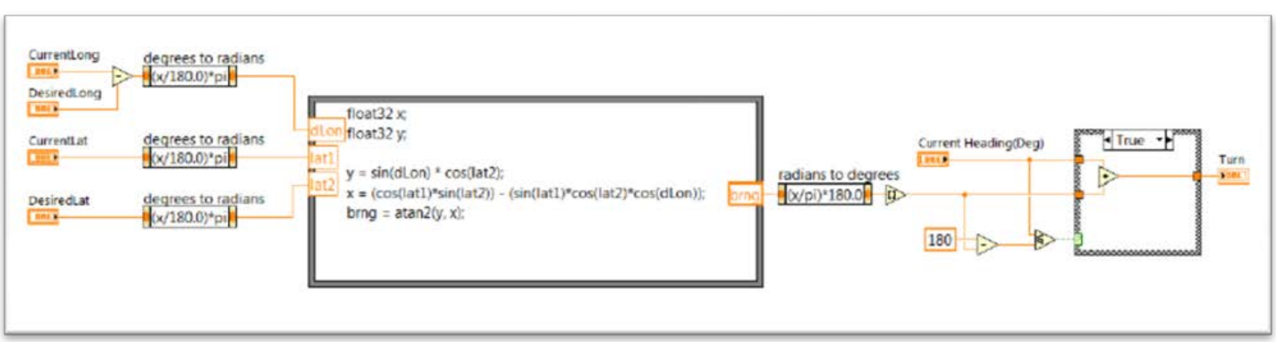
GPS and Compass Combination

The next essential step after gathering both the GPS and Compass data was using it to get bearing. With the current GPS location and the target GPS location given as a goal point for the IGVC competition, the desired bearing could be calculated. However, without the current orientation of the robot, that information is useless. That is where the compass data comes into play.

The formula used to calculate bearing from the GPS coordinates was:

$atan2(\ sin(\Delta\lambda).cos(\varphi_2),\ cos(\varphi_1).sin(\varphi_2)\ in(\varphi_1).\theta = .\ s\ cos(\varphi_2).cos(\Delta\lambda))$

So, given the two latitudes (φ_1 & φ_2) and the change in longitude ($\Delta\lambda$), it is possible to determine the desired bearing in degrees from north. This formula gives it in the form 180°: 0° for the bearings clockwise from north and 0°:180° for bearing counterclockwise from north. The compass gives an angle clockwise from north 0°:360°. Using this information, a simple VI was written to find bearing and calculate the amount the robot must turn to be facing the desired bearing.



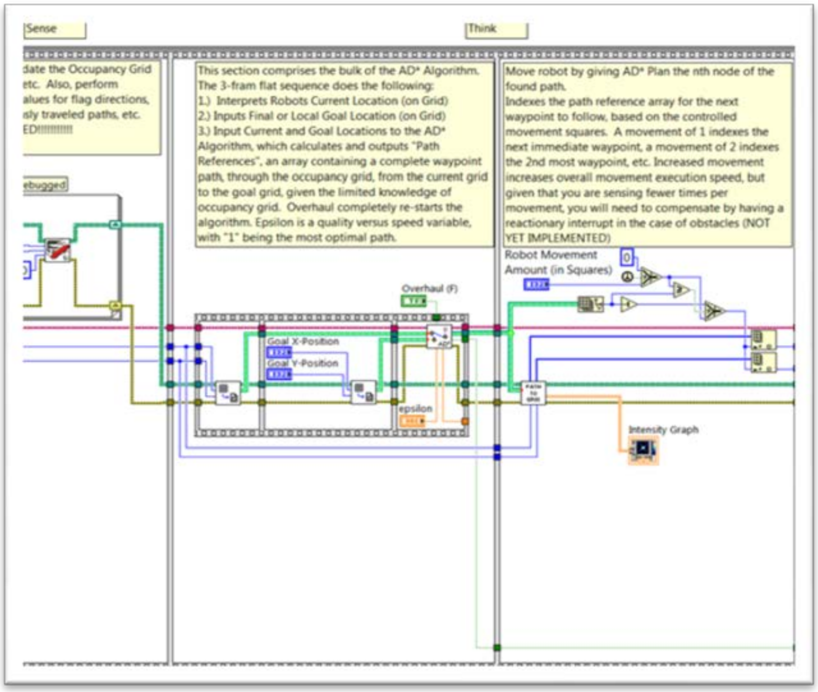
Vision

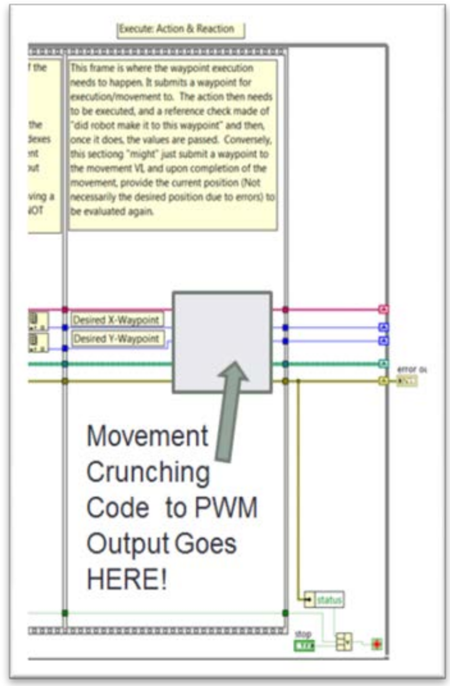
Off the shelf computer webcams ended up working well enough for this application. There are also many free and open software libraries and solutions for line tracking and computer vision. The one chosen for implementation was OpenCV, a computer vision library containing many of the fundamental transforms and algorithms taught in class. Additionally, both off the shelf webcams and the OpenCV library require a coprocessor in order to interface with the National Instruments hardware. This proved advantageous because a vision pipeline could be developed outside of the NI workflow. Additionally, this opens up options for future sensors/peripherals, and means most of the heavy lifting of the vision processing will be handled outside of the cRIO. In addition to setting up a vision pipeline, a set of tools for adjusting parameters of the vision processing needed to be created in order for the team to adapt to whatever conditions the actual field presented. Using OpenCV, an algorithm was created to detect and report back detected ground lines within an image. The algorithm consists of using color thresholds to identify only the white lines, a canny edge detection algorithm, and the probabilistic Hough line transform for picking out the lines. At this time, the algorithm remains untested on an actual image stream from the course. The algorithm has been tested and shown to run on the coprocessor, however, integration of the coprocessor into the overall software architecture of the robot has not yet been implemented as of this writing.

Navigation and Path Planning

For the navigation and path planning code, an Anytime D* algorithm was implemented. The navigation loop first initializes a 0.1m resolution object occupancy grid, and utilizes a hybrid sense-think-execute paradigm. First, the sensors are polled and relevant data is allocated to the occupancy grid. In future revisions, this section will also include sensor weighting, and integrate object growth algorithm.

The figure below demonstrates the calculation and higher level intelligence VI's calculating an optimum path through the known grid, as it is, and outputting the optimal least-cost path in an XY array. This XY array is then parsed for the most recent value, which is passed to the execution loop. The execution loop integrates the GPS and compass, as well as the optimum path, to determine a localized waypoint heading with bearing and distance information. This will then be translated to required motor velocities for performing an orientation and translation maneuver, which will then be handed to the motor control VI's for execution. Upon this handover, the robot ceases certain high level functionality, and will enter a reaction based state until either the maneuvers are completed or an obstacle impedes its movement and cannot be surmounted by reactionary processes.





DESIGN & PLANNING PROCESS

CAD

Our designers utilized Solidworks and AutoCAD Inventor. This approach allowed previously obtained components and materials to be fully utilized. Sidetracked was designed to carry at least 150 lbs. and testing showed it capable of easily handling more by a significant margin.

SAFETY CONSIDERATIONS

Sidetracked features a wired E-stop, an easily accessible battery compartment, and an elevated control and electrical system for easy access. The custom chain tensioning system ensures safety in the chain system by increasing the engagement of the chain on the teeth and thus reducing the tension necessary in the system, preventing flying material in the event of a chain failure.

Reliability & Durability Considerations

The welded tube aluminum frame and gearboxes incorporate design principles generally found on high speed and collision prone vehicles of a comparable size. The pneumatic tires minimize shock and vibration maximizing the life expectancy of the system. All electrical connections are crimped and soldered.

Challenges Encountered

Shortage of resources combined with the challenges of reviving a program created by individuals no longer available for consultation made this project an exercise in existing system integration.

Predicted Performance

Speed

CIM Motor Output – 5,130 RPM

Gearbox Ratio –12:75:1

Sprocket Ratio – 2:1

Output – 201 RPM

Wheel Diameter – 10”

Miles Per Hour – 5.981 mph

General Performance

Ramp Climbing Ability	Low center of gravity to easily navigate at least a five degree incline
Reaction Times	Designed for ½ second reaction times E-Stop reaction times ¼ second
Battery Life	Minimum 30 minutes
Detection Distance	25 meters
Accuracy of Arrival at Navigation Waypoints	5 meters
Complex Obstacles	Design to manage potholes and switchbacks

CONCLUSION

Overall, the KURT A Section IGVC project has been an excellent learning experience, teaching those involved the value of interdisciplinary cooperation and its unique challenges. Our team hopes to continue our iterative processes and improve our performance in the years ahead.

BILL OF MATERIALS

Material/Component	Qty.	Unit $	Total Value	Total to Team
GPS - 20 Channel EM-408 SiRF III Receiver with Antenna/MMCX	1	$64.95	$64.95	$64.95
Compass - OS5000-S Evaluation Kit (3 Axis Digital Compass RS232)	1	$299.00	$299.00	$0.00
Camera - Axis M1013 Camera (am-	1	$187.00	$187.00	$0.00
Laser Range Finder	1	$3,000.00	$3,000.00	$3,000.00
National Instruments CRIO-9022	1	$3,315.00	$3,315.00	$0.00
National Instruments Eight Slot Reconfigurable Chassis	1	$1,300.00	$1,300.00	$0.00
National Instruments 32 Channel Digital I/O Module	1	$400.00	$400.00	$0.00
National Instruments Serial Module	1	$535.00	$535.00	$0.00
Structure & Motion Subsystems	1	$600.00	$600.00	$500.00
Electrical & Power Susbsytems	1	$850.00	$850.00	$150.00
Total			**$10,550.95**	**$3,714.95**