



RedBlade

Building a Better Robot

Miami of Ohio engineering students build a lawn mowing, snowplowing robot and navigate it with GNSS in national competitions

Don Talend

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Anyone who has gone to college is probably familiar with the idea of a capstone course. A final hurdle to clear in receiving a degree, students take such a course to demonstrate their practical knowledge by pulling together all of the main concepts taught throughout the program of study.

There are capstone courses — and then there is the two-semester Computer Science/Software Engineering ECE 448/449 Senior Design Project in Ohio's Miami University School of Engineering & Applied Science. Students taking this course can tinker with “RedBlade,” a differential GPS-guided robotic lawnmower/snowplow that has undergone several

The stationary base and rover GNSS antenna mounted on the RedBlade work together to provide real-time kinematic (RTK) position information, revealing the machine's three-dimensional location. Here team members set up the system for a trial run at Miami University: (left to right) Harrison Bourne, Mark Carroll, Chad Sobota, and Robert Cole. Photo by Don Talend

improvements and gained national notoriety for its robust operational capabilities since its first incarnation in 2004.

Currently, RedBlade is in its fifth generation, having been completely rebuilt during the 2011–12 academic year. In 2012, Team RedBlade won second place in both the ninth annual Institute of Navigation (ION) Robotic Lawn Mower Competition in Dayton, Ohio and the ION Autonomous Snow Plow Competition held in January in Minneapolis. Team RedBlade was also the winner of the university's 2011–2012 Interdisciplinary Technology Development Challenge. These are the latest milestones in a continuous improvement evolution over the past nine years.

Yu (Jade) Morton, a Miami University professor of electrical and computer engineering, led a team of undergraduate students and faculty that developed the first generation of the machine. In 2004, ION started the autonomous lawnmower competition targeting university students and seeking participants. Miami's RedBlade was one of three participants in the first competition that year in which teams design and operate an unmanned lawnmower to rapidly and accurately mow a field of grass.

Double Duty

By 2010, buoyed by the growing popularity of and participation in the lawnmower competition, ION launched its first autonomous snowplow competition. RedBlade was one of seven robots in the inaugural event.

In preparing for the snowplow competition, the Miami students decided to convert the machine to dual-purpose to save time and money, says Morton, whose research interests include advanced GNSS receivers, ionosphere effects on GPS performance, and non-GPS RF navigation sensors. “I remember it was at the beginning of fall 2010, students went up to the board and started drawing and figured out how to accommodate both a cutting deck and a plow on the machine,” she said.

Morton was particularly impressed with how Team RedBlade 2012–13 was able to take the new design and run with it — or, rather, mow and plow with it. (See the sidebar, “Team RedBlade,” for details about the 2012 participants.)

Precision Positioning

For the purposes of geospatial positioning, the RedBlade lawnmower initially used two inexpensive receivers that had typical 15- to 20-meter errors. The team extracted data from them and developed custom software algorithms to refine the data into a differential system that had centimeter-level accuracy. This “homemade” differential system served during the first four years of competitions in which RedBlade participated.

In 2009, Morton sought commercial differential positioning technology that would allow students to focus on robotics control, obstacle avoidance and artificial intelligence rather than ensuring positioning accuracy. Her search for a reliable and user-friendly real-time kinematic (RTK) system led her to the Topcon Positioning Systems Educational Partnership Program. The program, which normally is implemented through Topcon’s dealer network, provides financial support and training for educational institutions. More than 300 educational institutions in the United States and Canada are involved in the program.

Morton participated in the program and purchased a dual-frequency multi-GNSS receiver at a roughly 90 percent discount. She favored a dual-constellation capability, one that can process signals from both the Russian GLONASS satellite constellation as well as the U.S. GPS constellation, providing roughly double the number of signals available and provides a high degree of positioning accuracy. This configuration was largely responsible for ensuring sufficient signal reception amid tall buildings at the ION Autonomous Snow Plow Competition in Minneapolis. Team RedBlade field tests indicate location accuracy within a few centimeters.

“I’m really glad we got this receiver because we don’t have to worry about the positioning accuracy as much — instead, we worry about the robot, how to integrate the sensors, how to control the robot motion,” Morton says.

RedBlade System Design

The RTK system’s stationary base and the rover antenna are mounted on the lawnmower or snowplow equipment as part of RedBlade’s navigation and obstacle avoidance sensor suite “top layer” of system architecture. The receivers work together to provide 3D position information for the machine’s location on the competition site. The rover is located directly above the wheelbase to aid in a path planning algorithm.

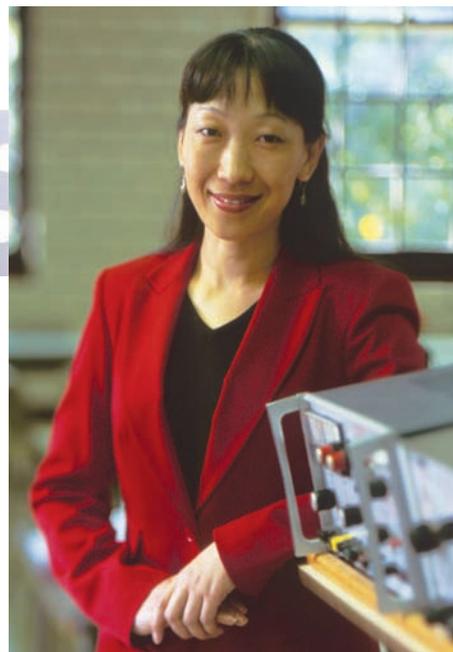
Three navigation sensors — GPS, an inertial measurement unit (IMU), and wheel-mounted quadrature optical encoders — are employed to determine position, heading, and velocity (PHV). RedBlade also utilizes a light detection and ranging (LIDAR) laser rangefinder, and two string potentiometers for obstacle detection, the latter for touch sensing. The on-board computer — viewable through an upward-facing monitor and remotely — processes the PHV information and waypoints and implements a proportional-integral-derivative (PID) control algorithm to adjust vehicle heading.

The “middle layer” of system architecture is the collection of software that provides driver functions for the sensors, sensor fusion algorithms, path planning, and vehicle motion control algorithm. The raw geodetic coordinates provided by the receiver are converted to an East-North-Up (ENU) local coordinate system before being sent to the on-board computer that

runs a control algorithm. The team wrote custom driver software to allow all of the sensors to send their position measurements to the on-board processor.

The “bottom layer” of system architecture is the mechanical platform and electronics hardware. This layer includes the motor controller, safety systems, power supplies, and processors that carry out the software functions. The RedBlade vehicle is driven by two 24-volt electric motors that each outputs 1.5 horsepower through a 20:1 reduction gearbox. An optical encoder reads the position of each motor for use with a motor controller.

RedBlade’s motors are powered by two 12-volt, 32 amp-hour gel-cell batteries wired in series. A wireless router



Miami University Professor Yu (Jade) Morton

Miami University



Team RedBlade members watch in background as their dual-use robot pushes ahead in the ION Autonomous Snow Plow Competition held in January in Minneapolis.

Team RedBlade

allows remote access to the machine, which helps with troubleshooting and testing.

The lawnmower configuration houses a custom dual-blade cutting deck with two 24-volt motors contained inside polycarbonate. The machine also has three 18-volt lithium string trimmers that help it get the closest cut possible to both flowerbeds and fences.

Navigation in Action

During operation, RedBlade uses a PID control algorithm for navigation between waypoints. The algorithm adjusts wheel speeds based on present and past errors using two methods of defining errors.

The first method defines x_0 and y_0 as the starting point and accepts a waypoint vector that serves as the destination waypoint for its input; both points are defined in a local ENU reference frame. At any point during travel between the two waypoints, the GPS can find RedBlade's x , y position and the IMU can determine its heading. Using this current position and the destination waypoint, a desired heading can be found. The difference between the current position and heading serves as the error input to the PID loop and the signal is adjusted to drive the motors and minimize the error.

The second method accepts two waypoints as inputs: the start waypoint (x_0 , y_0) and the destination waypoint (x_d , y_d). In this method, too, both points are defined in a local ENU reference frame and the origin is the original starting point. A line is drawn between the starting waypoint and destination waypoint.

Signals from the rover receiver, which is mounted directly above the wheelbase, indicate the position of the back of RedBlade. This position and the heading of the robot, indicated by the IMU, determine a second imaginary position for the front of RedBlade. Two errors, one from each of these points, are then derived to establish a cross-track error.

RedBlade's navigation system has built-in redundancy to address obstructive situations that can adversely impact GNSS accuracy. Through testing, Team RedBlade found that the error from the robot's true position during a GPS outage has not been large enough to cause significant problems with navigation.

Nonetheless, if GNSS problems persist, RedBlade has the ability to switch over to odometry. This solution uses the optical wheel encoders and the IMU to obtain a relative position. The number of clicks received from the wheel encoders can be directly translated into distance, and the heading is measured by the IMU.

“During the snowplow competition, most teams used a visual aid for laser or camera,” Morton says. “I think we were the only ones who used RTK. Downtown Minneapolis has a lot of high buildings and we were afraid we couldn’t get the accuracy we needed and that snow patch is only one meter wide. What really helped us was that this receiver not only gets GPS signals but also GLONASS.”

Together, the two constellations always provided the RedBlade system with enough satellite signals to ensure a good position fix.

Looking ahead

This year Team RedBlade again placed second in the snowplow competition, which was won nearby Ohio University’s Avionics Engineering Center. The Institute of Navigation has decided to evolve its lawnmower contest into a new competition concept for spring/summer 2014.

For the first time, the Miami team will also take part in the Intelligent Ground Vehicle Contest (IGVC) at Oakland University in Rochester, Michigan, June 7–10. RedBlade is sure to get some attention at IGVC as the only one with interchangeable lawnmower and snowplow attachments. By then, the robot will be equipped with a stereo vision camera to identify obstacles on the path.

The project helped the students to develop advanced computer and electrical engineering knowledge, according to Morton and the Team RedBlade members. For example, current senior Mark Carroll was only a sophomore when he joined the team, but Morton says, “When we realized this kid has a good work ethic, we put him on the project.”

“That’s how we keep continuity on the team,” she adds. “At first, we were not this organized. Now, the graduate students play an advisory role. We have a core senior capstone team working on it and we have a prep team that is getting ready, shadowing the core team.”

Morton’s own role in the competition has become increasingly hands-off. “I didn’t turn a single screw here,” she says. “I didn’t write a single line of code — the students are doing it.”

Another Miami senior, Chad Sobota, agreed that the team does consist of the cream of the crop from the university’s School of Engineering & Applied Science, and team members share knowledge with the up-and-comers.

“It’s not like when we leave, the next group has to come in and start from scratch,” Sobota said. “We knew some general concepts, but building this, thinking about what we did since we started until now, we learned a lot.”

Morton added that she has been impressed with team members’ self-sufficiency.

“It’s more than just doing the design — you have to deal with vendors, and we have a

Team RedBlade

Mark Carroll is a computer engineering major who focuses on GPS receiver technologies with embedded systems. He enrolled in Miami’s graduate studies program with Professor Jade Morton’s research group in fall 2012.

Robert Cole, a Miami University senior, also majors in Computer Engineering and is interested in robotics control and navigation and will join Carroll in the graduate studies program in spring 2013.

Chad Sobota, another senior, has a dual major in computer engineering and electrical engineering and after graduation will serve as a commissioned officer in the U.S. Air Force, where he will work as a developmental engineer.

Mark Stratis, a senior computer engineering student with minors in computer science and entrepreneurship, has participated in research to develop a GNSS signal playback system and is now pursuing a career in web and mobile development.

Steven Taylor is a second-year master’s student and is interested in embedded and autonomous systems. After receiving his master’s degree, he planned to pursue work in global satellite navigation sensor deployment. After receiving his master’s degree, he planned to pursue work in multi-constellation receiver design.

In fall 2012, seniors **Harrison Bourne**, **Rachel Grady** and **Elizabeth Ahles** spent a great deal of time working on the project and Bourne will continue his research as a graduate student in the area of GNSS remote sensing in 2013–14.

limited budget,” she says. “You have to make sure what you buy is the best use of money.”

Such a hands-on project motivates the students to learn more and even attend graduate school, Morton says. “We talk about centimeter accuracy; you can talk about it in a book, but when you see that this machine is doing what it’s supposed to do, that makes a big difference.”

Sobota is proud of the fact that RedBlade was built from the ground up. “There’s no ‘autonomouslawnmowerpart.com’ or something like that — you have to find each individual



RedBlade, operated here by Miami University senior Mark Carroll, uses multiple navigation technologies, including GNSS and Light Detection and Ranging (LIDAR).

part,” he says. “You have to actually research every part. There are parts that meet your needs, but sometimes they cost \$500 and you can build something pretty equivalent yourself using a \$50 part.”

Another Miami senior, Harrison Bourne, has been tagging along with the team since he was a freshman and likes the hands-on aspect of the project.

“I definitely think that doing any project where you try to build a product, you actually learn what is required to work in almost any industry,” he said. “What we do in classes is relatively theoretical; so, having this opportunity to do a real-world product with a goal, a deadline, and a budget is very helpful.”

Team member Robert Cole admits that math was not his first love when he joined the team. But, as he immersed himself in RedBlade’s control design, which was math-intensive, he found himself asking instructors in several departments for help.

“I think that a lot of people who get engineering degrees don’t get to do something like this,” Cole says.

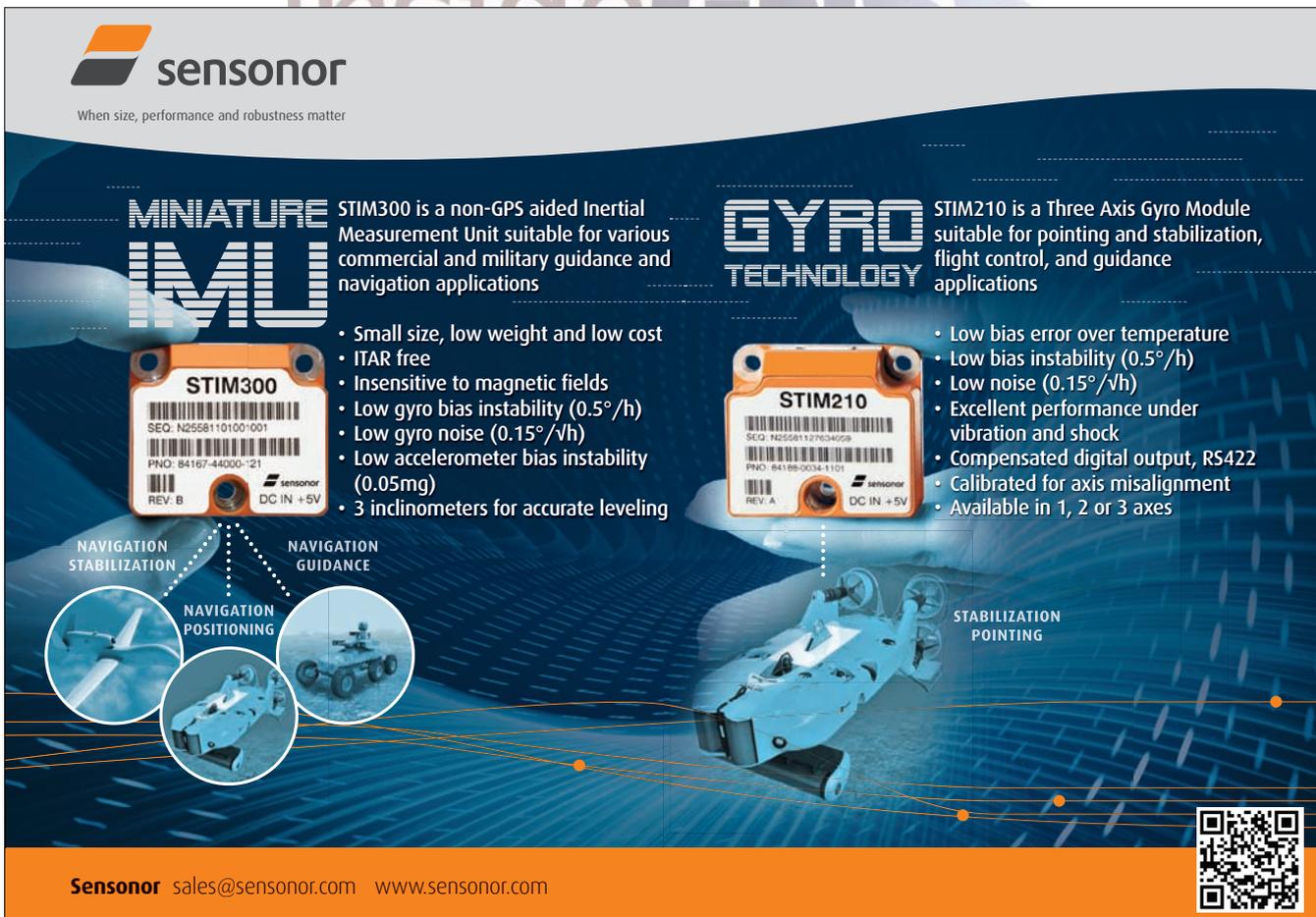
Adds Morton, “I really think that experience taught Bob that just because these professors have PhDs doesn’t mean that they know all of the details and, in no time, he became the expert and he is now a total believer of the power of mathematics,” Morton added.

Team RedBlade’s participation in the national competitions is one way of demonstrating how interesting engineering can be. Another is outreach efforts that include inviting high school girls to campus and conducting presentations and demonstrations of RedBlade to get them interested in engineering and science.

“The [RedBlade team members] are very busy students, but they took their time for high school freshmen and sophomores several times last year,” Morton noted. “I think that these students are doing society a big service.”

Manufacturers

The RedBlade team’s automated snowplow and lawnmower use HiPer Lite+ multi-GNSS receivers from **Topcon Positioning Systems**, Livermore, California, USA; a 3DM-GX3-25 IMU from **MicroStrain**, Williston, Vermont USA; a SICK LMS200 LIDAR laser rangefinder from **SICK AG**, Wald kirch, Germany; E7MS quadrature optical encoders from **US Digital**, Vancouver, Washington USA; string potentiometers from **Celeco Transducer Products, Inc.**, Chatsworth, California USA; an AX2850 motor controller from **Roboteq, Inc.**, Scottsdale, Arizona USA; CE5 24V motors from **Neuton**, Vergennes, Vermont USA; lithium string trimmers from **DR Power Equipment**, Vergennes, Vermont USA. 



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