2011

Bob Jones University
IGVC Design Report for Firebrand

Bob Jones University B-Team

5/1/2011

1. INTRODUCTION

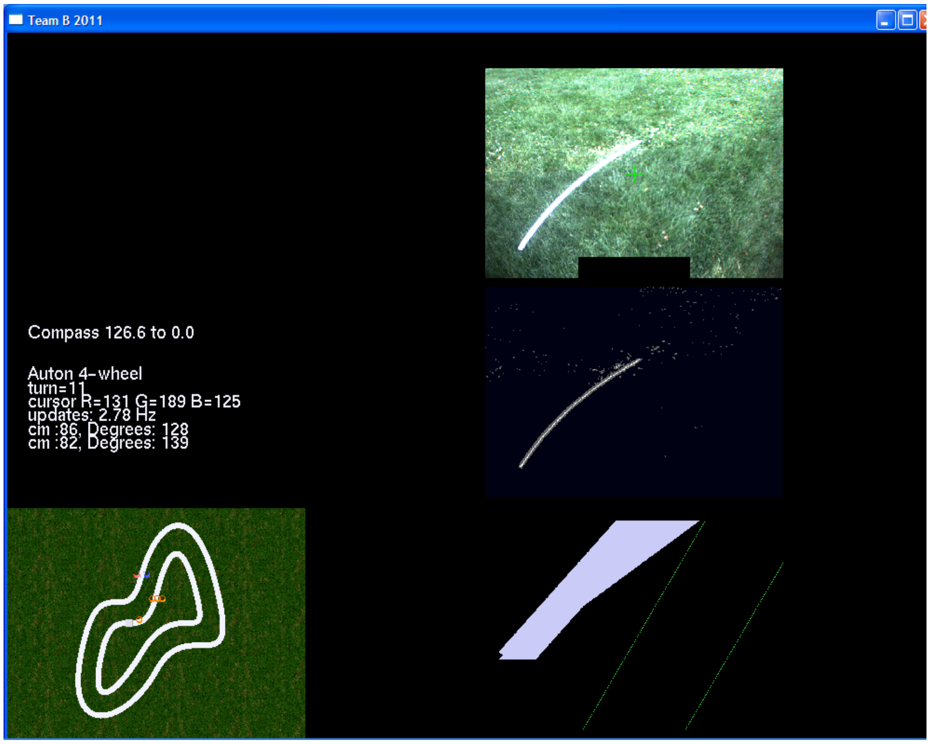
As autonomous vehicles emerge from the laboratory to the real world, engineers must focus on integrating autonomous technology into practical vehicle designs. Bob Jones University's (BJU) Firebrand robot bridges the gap between traditional IGVC vehicles designs and the type of vehicles found in the real world.

2. INNOVATION

Bob Jones University's Firebrand robot breaks the trend of 3 and 4 wheel differential steering IGVC robot designs by using a conventional steering system. Although differential steering designs certainly possess certain advantages (such as a small turning radius), these designs fail to meet the practical demands of most real world vehicles in both military and consumer applications. Excluding tanks, most real world vehicles use conventional steering systems that require the driver to plan how to navigate obstacles and dead ends with a limited turning radius. When a differential steering robot comes to a dead end, it often "turns on a dime" to face a new direction which is more favorable. However, "turning on a dime" is impossible in real world conventional steering applications where drivers must consider the dangers of backing up with limited vision in order to execute a 3-point turn. Because the Firebrand robot design team seeks to develop robots for real world applications by using a convention steering system, the team faced new problems which required unique new innovation that other teams using a differential steering system will never need or be able to replicate.

Firebrand's environment detection and decision making processes use several innovations. First, Firebrand detects the local environment through use of a single camera. Many real world applications prefer this passive detection of the local environment because it is often much cheaper and easier to use. In military applications active detection of the environment through use of LIDAR, ultra-sonic range finders, or IR range finders will give away the position of the robot. A robot that accomplishes its mission while maintaining radio silence (autonomous instead of drive by wire) and passive detection of its environment would be ideal for missions requiring stealth. Passive detection of the environment is difficult and required innovations in image processing.

Second, the BJU Firebrand robot team developed an innovative texture recognition technique to help Firebrand detect obstacles. In past years the BJU team relied sole upon color recognition, but this technique fails to detect certain obstacles such as green barrels. The BJU team developed a new method to overcome this problem. The texture recognition algorithm is used to detect the smoothness of sectors of the image by summing the differences in the RGB values from pixel to pixel. Because grass is composed of many colors that vary widely from pixel to pixel, the total sum of the changes in RGB is compared to a threshold value to determine if a sector is to “smooth” to be grass. For example, a smooth green barrel would have a relatively low sum of color changes from pixel to pixel compared to picture of green grass that has a much higher sum of changes. Sectors below the threshold are then marked as obstacles.



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Compass 126.6 to 0.0

Auton 4-wheel
turn=11
cursor R=131 G=189 B=125
updates: 2.78 Hz
cm :86, Degrees: 128
cm :82, Degrees: 139
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Screen shot of the robot while it is finding a line. The top right image shows the camera view after being corrected by a distortion algorithm. The right center ima shows what the robot found as ‘white’ in the image. Pixel groups of white that are two wide or two skinny to be parts of a line are shown as gray. The center of whit groups that are the correct width to be a line are shown as white and passed on to the Hough transform. The bottom right image shows the mapping of the area in front of the robot with the lines successfully detected. The green lines show the pa the robot plans to follow. The left center image shows text giving information current decision. The “cm: 86 Degrees :128” is the distance (in centimeters) and angle to the line as calculated by the Hough transform. The bottom left image is a simulation of the robot from a top-down view.

Third, the Firebrand team developed a unique implementation of the Hough transform to return information about the angle and distance to a line. This technique is simple but innovative. The key innovation is simply moving the origin around which the Hough transform is computed. By moving the origin to the bottom center of the image, the rho relates to the actual distance to the line and the theta is the actual angle to the line from the front of the robot. Angles are taken with respect to the positive x-axis where an angle of 90 degrees would represent a line that is directly in front of the robot and perpendicular to the robots path. This innovative use of the Hough transform allows the robot to gather useful information about the robot's orientation to the course.

Fourth, Firebrand uses a simple method to remember obstacles it has seen in its near past. This method consists of copying the obstacle information from the previous frames and inserting it into the current frame. Obstacles that were 150 and 100 pixels away from the bottom of the image are inserted at 100 and 50 pixels away from the bottom of the image respectively. This allows for a simple memory of previously seen obstacles so that Firebrand does not turn too soon after passing an object.

Finally, Firebrand integrates all of these innovations to combine a mixture of reactive and deliberate navigation techniques into one decision making strategy. By a simple algorithm firebrand seeks to find a path through the blocked path in front of it. Adding information from the previous frame helps Firebrand have a short memory of previously blocked routes, but doesn't require the computational expenditure to create an actual map of the environment around it. The Hough transform gives information about the robot's current orientation to lines. By knowing the angle to a line and the current compass heading of itself, Firebrand computes the compass heading of the course. This information is used to insure that Firebrand does turn around and go backwards down the course. Knowing distance and angle to a line is also used to compute which way to turn while backing up. If Firebrand detects a line on its left side and the distance to the line is small, then it knows it is on the left side of the course and should back up so that is faces toward the center of the course. By storing information about previously seen lines and inserting previous obstacles into the current image, Firebrand uses an innovative and computationally simple deliberate navigation technique coupled with a simple reactive navigation technique.

3. DESIGN PROCESS AND TEAM MEMBERS.

The team used the spiral design model while developing the robot. By segmenting a project using the spiral model, milestones become tangible, each having a clearly defined product and deadline. The spiral methodology mandates a software-hardware co-design approach, since a fully functioning prototype is expected after each spiral. The BJU team chose this design model because many of the team members worked on the robot for just one semester. By completely solving well defined problems in specific amount of time, the team passed a fully functional robot with completely functional solution to the next group of students. The next group of students identified new areas needing improvement, prioritized potential improvements, and implemented solutions so that the robot continued to improve in performance. The BJU team found that this design model works well. Students working on the robot during both the fall of 2010 and spring of 2011 semesters represent two distinct design spirals. The first group of students worked on the robot as part of a senior level capstone engineering design class, mechatronics. This group of students consisted of Lauren Boyle, (Senior, Electronics and Computer Technologies (ECT)), Eric Woelkers (Senior, Engineering Science (ES)), Samuel Eckman (Senior, ECT), and Gilbert Lara Romo (Senior, ECT). The team addressed several significant design challenges including creating excellent documentation, identifying optimal operating parameters, fixing the steering sprocket design, improving detection of obstacles through texture analysis, avoiding turning into obstacles that were recently past, and adding a strobe light. At the end of the semester the robot was fully functional with many important improvements.

The second group of students volunteered to work on the robot during the spring semester of 2011 and represent a new spiral in the design process. This group consisted of Nathan Moorehead (Sophomore, ECT), James Wolcott (Senior, ES), Isaac Lloyd (Sophomore, ES), and Anthony Garland (Senior, ES). The team addressed a completely new set of significant design challenges including code documentation, increasing the range of E-stop, creating a water proof cover for the robot, adding GPS capabilities to the autonomous mode, replacing batteries, and creating a modification of the Hough transform to give information about the robots position relative to course lanes.

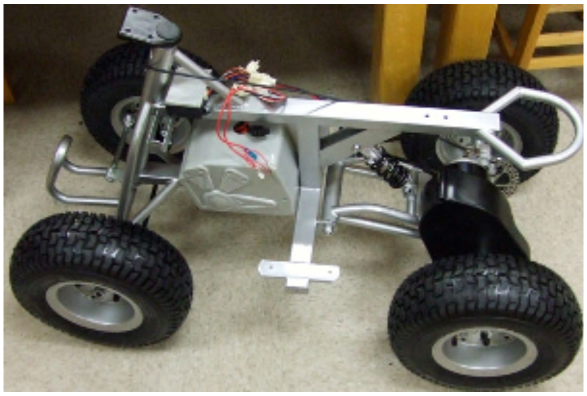
Faculty advisor, Dr. Bill Lovegrove taught the mechatronics class during the 2010 fall semester and oversaw the volunteer team during the 2011 spring semester.

4. DESIGN

4.1 Hardware and Electrical Design

4.2 Chassis

In order to replicate real-world vehicles a design was chosen with a conventional steering system. To reduce the complexity of making a chassis from scratch, a small electric All-Terrain Vehicle (ATV) was stripped down to the bare chassis. The ATV



ATV Chassis of robot

came complete with a working electrical drive motor, batteries, and charging system.

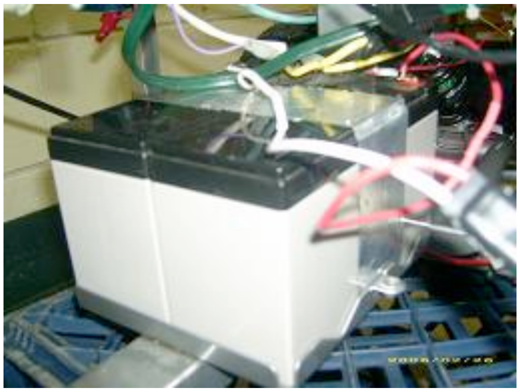
4.3 Cover

In an effort to make the robot more rugged for all potential environments, the team worked with the University's creative services department to create a new waterproof external cover for the robot. The cover protects the robot from rain and functions as a safety shield protecting outside objects from getting in the moving parts. It also blocks the sun from the screen so that it is easier to see. The cover is made out of foam sheets of Sintra PVC and sealed with silicon sealant caulking.

4.4 Propulsion

4.5 Battery

Firebrand has three man electrical systems; propulsion, electronics, and computer. Each system has a separate battery system to help prevent sensitive electronics from high voltages and voltage drops caused by the main drive and steering motors. The team upgraded the batteries that power the drive and steering motors to give more amp-hours per charge.



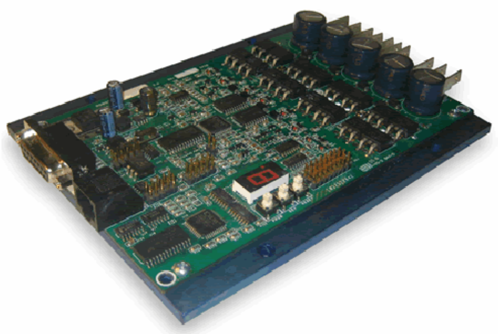
Main batteries

4.6 Motor Controllers

The robot was designed around the 2-channel RoboTeq AX3500 motor controller. However, testing revealed that this controller would not work reliably when one motor was in speed control and the other in position control. To solve this problem two identical controllers were installed, one for each motor. The controllers do closed loop control using an optical encoder on the rear drive shaft for velocity feedback and a potentiometer on the steering mechanism for position feedback.

4.7 Steering

The original steering mechanism from the 2009 entry was by direct drive from a motor mounted to the chassis where the ATV's handle bars were formerly located. However, the 34:1 direct-drive system lacked enough torque to turn the wheels on some terrain resulting in stalls that burned out 2 steering motors. Firebrand's chain-driven mechanism gives higher torque on the wheels per unit current in the motor. A bracket mounted to the chassis gives the motor sprocket (14 teeth) the proper height and



RoboTeq AX3500 motor controller

angle in relation to the shaft sprocket (60 teeth). The wheels turn more slowly but with less current in the motor. The 2010 design included a sprocket mounted to the steering column with only a set screw. This proved to be mechanically unreliable, so this year a custom sprocket mount was designed that bolts the sprocket to the driveshaft.

4.8 Drive

The ATV uses a 350 watt motor drawing 14.5 amps with a chain drive for added torque; the ATV motor was designed to propel 94 kilograms of rider and ATV at speeds up to 8 mph. Because the final weight of the robot is only 65.75 kilograms, the motor is more than powerful enough to propel robot at speed up to 10 mph.

4.9 E-Stop

Wireless E-stop

E-Stop

The emergency stop system on Firebrand is straightforward. A keyless entry module, the JC Whitney ZX478506T, is adapted for the wireless component of emergency stop. Powered by 12V, the module has an original range of 80 :. The relay outputs of the lock and unlock button are configured to allow er button to perform an emergency stop. In order to increase the range of the wireless module to et the 100ft rule requirement, a 15 cm wire was soldered to the internal antennae of the module which helped increase the range to over 100ft. A wired emergency stop is provided by a simple momentary pushbutton, located on the rear of Firebrand. Both of these systems provide the robot with the ability to safely operate in crowded environments.

4.10 Electronics

4.10.1 Batteries

The Electronics are powered by a standard 18 V NiCd wireless drill battery. This system allows for ease in charging and quickly changing the 18 V battery using off-the-shelf battery packs and chargers.

18 V Battery for electronics

4.10.2 GPS

Firebrand is equipped with a U-Blox Antaris 4 GPS, which provides more features than a standard GPS receiver but can be bought for a fraction of the price of a differential receiver. The U-Blox Antaris 4 comes with features that allow Firebrand to read a GPS signal fix at 2 Hz, and it is designed to be able to receive satellite signals in locations where other

U-Blox Antaris 4

receivers have difficulty. The U-blox Antaris 4 is also very efficient in its power usage. The GPS can be set to different modes that can save power. Sleep mode uses 80 µA, and the backup mode only uses 8 µA. Finally, the U-blox Antaris 4 is more accurate than most GPS units, featuring a 16 channel receiver. Since the standard GPS receiver has only 12 channels, four extra channels provide Firebrand with the ability to be accurate within 2.5 meters.

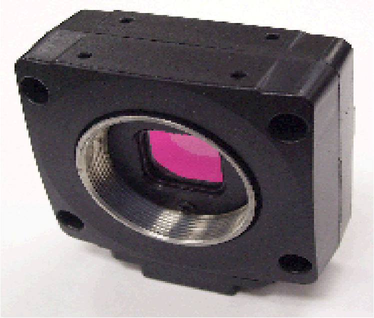
4.10.3 Compass

Firebrand is equipped with an Ocean Server OS5000-US compass. The OS5000-US is a full three axis compass which uses Honeywell anisotropic magneto-resistive sensors to detect the earth's magnetic field. Solid state accelerometers provide pitch and roll information. The data is sent to a small processor which determines bearing to within one degree of accuracy, pitch, and roll. The OS5000-US can be accessed using either USB or serial connections. Power consumption is also very low, only using 20mA at 5V when operating in RS-232 mode. The entire compass module is packaged on a single one inch by one inch circuit board, making the OS5000-US one of the smallest three axis compasses in the world.

Ocean Server OS5000-US

4.10.4 Camera

Our vehicle is outfitted with a Chameleon USB 2.0 digital video camera. The camera's tiny casing is only 25.5 mm x 41 mm x 44 mm, and is positioned at the pinnacle of the wooden frame. Mounted on the camera is a 2.8 mm lens to give it a wide field of view. The camera is the only means of boundary line and obstacle detection. The camera transmits the captured video to the computer at rates up to 18 frames per second.



Chameleon

4.10.5 Computer

The brain of Firebrand is an IBM ThinkPad® G40, complete with an Intel Pentium 4® running at 2.6 GHz. Because many of the robot sensors and controllers are powered by USB power, the battery life on the computer is around 30 minutes. An DC-AC inverter was added last year to allow the laptop and all of the USB-powered accessories to be powered directly from the drive batteries. A 16 Giga-byte hard drive provides ample room for program files, hardware drivers, and data storage. The RAM size is 512 mega-bytes.

5. SOFTWARE DESIGN AND DEVELOPMENT

5.1 Mapping Technique

Firebrand uses a unique mapping system that minimizes computational and memory requirements. First, the camera takes a picture of the area in front of the robot. The image is sent through a correction algorithm to remove distortion so that the image coordinates represents the ground plane in front of the robot. This corrected image is analyzed for white lines and obstacles which are marked in an array as impassable. Next, Firebrand copies the obstacle information from the previous frames and inserts it back into the current frame (see the section on innovation). Firebrand then searches the array to find a continuous path through the array (map) representing the "passable" areas in front of the robot. When Firebrand is not able to find a path that is wide enough then it turns while backing up so that it faces toward the center of the lane or in the direction of the course. Firebrand is able to store its position with respect to the course by calculating the distance to lines and the compass heading of the lines (see the section on innovation). Firebrand's unique mapping system allows Firebrand to successfully navigate itself through switchbacks and most obstacles.

5.2 Obstacle Avoidance

Firebrand uses a single camera to detect obstacles through color recognition and texture recognition. The obstacle detection system is based off the assumption that areas that clear will look "normal". This assumption is generally valid for any autonomous vehicle seeking to drive down a path. The primary difficulty in this assumption is how to define what "normal" is for the vehicle. For the IGVC, normal areas are primarily green grass. Firebrand therefore defines non-normal as areas that are not green or areas that are too smooth to be grass (see the innovation section). Firebrand's obstacle detection system works well in avoiding all obstacles. Once obstacles are found, they are inserted into a map representing the area in front of the robot. Firebrand then finds a path through the blocked path and steers in the direction of the path. Firebrand's speed is a function of how hard of a turn it must make to stay on its path. If it makes a sharp turn, then it will proceed slowly similar to a human driver who would slow down for a sharp turn or slow down when unsure if the vehicle will clear an obstacle.

5.3 Performance

5.4 Speed

Per IGVC rule changes, the max speed of Firebrand is limited to 10 mph and the minimum speed is set at 1 mph. We theoretically predicted the speed by measuring the actual circumference of the tire, which was 40.375 in, and determining the pulses per revolution from the encoder. The encoder resolution is 400 pulses per revolution, and the controller sample window is 16 milliseconds (Ms). The speed for a given pulse count is calculated as

$$speed = \frac{\text{pulses}(40.375\,\text{in})(1000\,\text{Ms/s})(3600\,\text{s/hr})}{400(16\text{Ms})(63360\,\text{in/mi})}$$

Using this equation we find that 3 pulses is equal to 1.075 mph, which keeps us just above the minimum speed restriction, and 27 pulses is equal to 9.67 mph, which keeps us just below the maximum speed restriction. The system will not allow a speed to be commanded higher than 27.

5.5 Ramping Climbing

Firebrand has a mass of approximately 66 kilograms. Using this number, the calculated power required to climb a 15% grade at 5 mph is 215 W. Because the drive motor draws a maximum of 15 Amps at 24 Volts, the maximum output power of the motor is 360 Watts, giving Firebrand more than enough power to climb the 15% grade at 5 mph. The current drive system does not have enough power to climb a 15% grade at the top speed of 10 mph, but this capability is not expected to be needed in this competition.

5.6 Reaction Times

5.6.1 Camera

The frames-per-second of the camera is 17, thereby providing Firebrand with a new picture to analyze every 59 milliseconds. However, the software is currently limited to about 3 frames per second. at 10 mph, 3 fps corresponds to 1.5 meters traveled between frames.

5.6.2 Steering

After being geared at a ratio of 34:1 with a gearbox and an additional 4:1 chain drive reduction, the steering motor is able to turn the wheels at a rate of 40.6 RPM. Therefore, the motor is able to turn the wheels one degree in 4.1 ms. Because of hardware limitations, the steering range is +/- 50 degrees. Using these numbers, Firebrand is able to turn the steering "lock to lock" (100 degrees) in approximately 410 ms.

5.6.3 GPS

The position fix is only updated at 2 Hz.

5.6.4 Compass

The compass specifications allow us to access the data at 40 Hz. It is currently set to sample at 2 Hz.

5.6.5 Battery Life

Motor Batteries: 2 21 Ah 12 V batteries with an average life of about 2 hours with the inverter in use.

Electronics Batteries: The Ryobi One+ battery supplies 1.7AH and the average current draw during operation is only 100mA, giving an estimated battery life of 17 hours.

5.7 Distance before detecting an obstacle

Camera: The camera is situated at 138 degrees measured down from the z axis, and its viewing angle is measured to be at maximum 100 degrees measured in the same manner. The height of the camera is approximately 143 centimeters, and therefore, using geometry and trigonometry, the maximum distance at which the camera can see an obstacle is 4 meters.

Comparing this distance to the reaction time for safety analysis, the robot travels 1.5 meters between frames at full speed, providing 2.5 meters of 555 ms in which to react and stop. The robot can easily stop within 555 ms and also can turn lock to lock within this time limit, so a 4 meter obstacle detection distance is safe.

5.8 Accuracy of Waypoint arrival

The specifications of the GPS give accuracy to within 2.5 meters. Therefore, Firebrand should be able to approach this accuracy estimate in arriving at waypoints. Informal testing on a practice course suggests that the robot is capable of this accuracy with a good GPS signal. Larger errors have been observed on a tree-covered course, up to 4 meters.

6. COST

Description	Details	Price	Cost to Team
Razor Dirt Quad ATV	http://www.razor-help.com/dirtQuad.html	$300.00	$300.00
Motor Controllers	AX3500 RoboTeq	$395.00	$790.00
Steering Motor	NPC-41250	$155.00	$155.00
Keyless Entry	JC Whitney ZX478506T	$30.00	$30.00
GPS	UBLOX AEK-4H	$199.00	$199.00
Compass	Ocean Server OS5000-US	$299.00	$299.00
Computer	IBM ThinkPad G40 (Used)	$220.00	$0.00
1394/USB PCMCIA card		$20.00	$0.00
ThinkPad External Charger		$40.00	$40.00
ThinkPad Batteries		$130.00	$130.00
Strobe	Action Electronics HAA110W	$11.00	$11.00
Potentiometer	P3 America R23P-RCWT	$20.00	$20.00
USB to Serial	Edgeport 4	$260.00	$0.00
Rear Encoder	Model 225q www.encoderoutlet.com	$252.00	$252.00
18V Battery	Ryobi One+	$100.00	$100.00
Steering Potentiometer	P3 America R23P-RCWT	$20.00	$20.00
Sheet Metal	Aluminum 1/8"	$100.00	$0.00
Motor Mount	Aluminum 3/8"	$200.00	$200.00
Misc Hardware		$200.00	$200.00
Camera and Lens	USB Chameleon Camera	$395.00	$395.00
Chain Drive	Sprockets and Chain	$50.00	$50.00
DC/DC Converters	TCElectronics SD-15A-5 SD-15A-12	$40.00	$40.00
Panel Meters	Futurlec.com	$40.00	$40.00
Misc Electronics		$100.00	$100.00
Spare Batteries	PowersonicPS-1270	$40.00	$40.00
Xbox Controller	Also With Wireless Dongle	$40.00	$40.00
24V Battery/charger		$13.00	$135.00
Wi-Fi Card	Wireless-G Notebook Adapter	$10.00	$10.00
Body	Creative Services	$50.00	$50.00
Sprocket Mount		$25.00	$25.00
	TOTAL	**$4,131.00**	**$3,531.00**