

YELLOW JACKET III

Cedarville University

Intelligent Ground Vehicle Competition Design Report

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Team Organization

To facilitate team design cooperation and time efficiency each member of the team was assigned a single focus based on an area of interest and expertise. In order to keep the competition alive for 2008 a junior student was assigned to learn and help oversee all design processes. This organization is illustrated below in Figure 1.

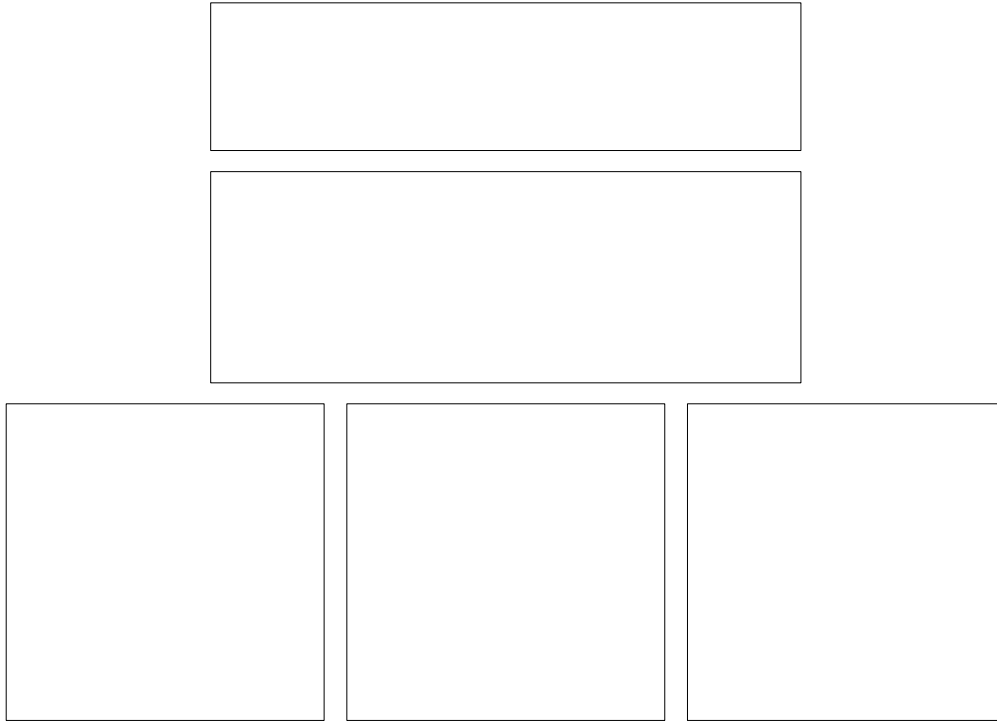


Figure 1 – *Yellow Jacket III* Team organization.

Design Approach:

The driving design philosophy revolved around the idea that we desired to build upon the previous year without implementing design changes that were not beneficial. We believed that many processes used for the 2006 competition were well suited for the competition and all that remained was tackling the difficult issues that would have been ignored had we entirely rebuilt the robot. Our robot chassis and motor controls worked without issue during 2006 and so they were not altered. The C++ image processing library written by a previous team member provided many high speed functions with much room for capability expansion. The difficult problems that needed to be addressed included shadow as well as tarp detection and removal in real time, intelligent image processing and GPS decision integration, course forward/reverse direction tracking, and robot size awareness.

Old Chassis Design

Robot Chassis

The old robot chassis is in the shape of a box with dimensions of 22 inches high, 22 inches wide, 36 inches long and it was constructed using one inch square stock. The front shelf houses the Z8 board, the circuit board for switches, voltage regulators, and connectors, the two motor controllers, the wireless router, and the central power hub from the batteries. The rear shelf was a slide out drawer to allow easy access for the notebook computer. An adjustable height post extending from inside the chassis near the drive wheel axis held both the camera (the adjustable height provided more versatility for changing light and terrain conditions) and the GPS reception. To weatherproof the chassis, easily removable plastic panels were affixed on the sides, top, and rear. A 3D rendering of the chassis is shown in Figure 2 while a photograph of the new *Yellow Jacket II* vehicle is shown in Figure 3.

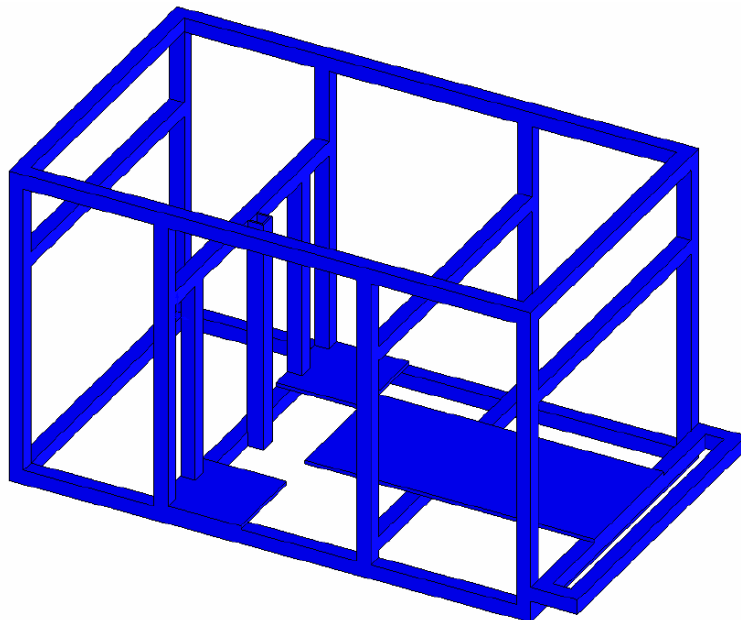


Figure 2 – 3D rendering of new *Yellow Jacket III* chassis.

Drive Train

The drive train consists of two custom fabricated 26-inch bicycle wheels mounted close to the center of the robot. With the rear drive wheels mounted closer to the center of the robot, turns of tighter radii could be made. Each wheel is mounted on a shaft with a gear sprocket which is connected to the motor via a chain so each wheel it is driven independently, allowing the robot to maneuver in tight spaces using differential steering. Two five-inch casters were used at the front corners of the robot instead of only one caster centered at the rear of the robot as in last year's design. This provided more stability during movement for the robot and better distribution of the weight of the chassis.

Motors and Gearing

We chose $\frac{1}{4}$ horsepower right angle gear motors from Bodine Electric Company to propel our robot. This motor is shown in Figure 4. These motors have 24VDC windings and draw a maximum of 8.8A at max load. Since the maximum output speed of the gear motors is 125 revolutions per minute, we used a 2:1 gear reduction to couple the motors to the wheels so that the maximum speed of our robot is 4.83 miles per hour. This ratio meets the speed limit of 5 miles per hour established in the competition rules.



Figure 3 – Bodine $\frac{1}{4}$ horse power motor.

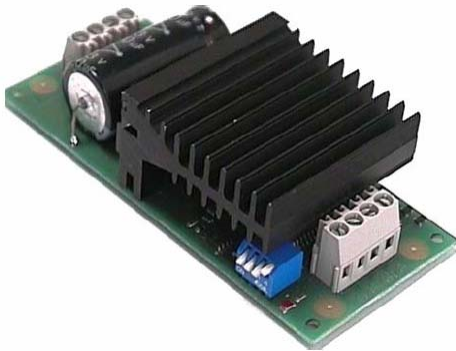


Figure 4 – Motor Controller.

Motor Controllers

The motor controllers used have built-in inrush current limiting and are rated for 20 amps at 50VDC, providing plenty of margin for our 8.8 Amp motors. The motorcontroller that was used is shown in Figure 5. These controllers interface to the Z8 Microcontroller and provide pulse width modulated speed control of the motors.

Power and Electronics

Two compact 12VDC 12AH gel cell sealed lead acid rechargeable batteries from Power Sonic were chosen to power the robot. One of these is shown in Figure 6.



Figure 5 – Batteries used to power *Yellow Jacket III*.

An additional pair of batteries purchased last year exist so that the robot could be operated and recharging of the batteries could occur simultaneously. These batteries were connected in series to provide 24VDC for the motors. A 12VDC line was pulled from one battery to power the wireless router. This 12 VDC line was used to power our Garmin GPS receiver and is regulated down to 9 VDC to power the Z8 board as well as our Fire-I firewire camera. To enhance the safety of the robot and meet contest requirements, a manual emergency stop push button from Mouser Electronics that required a quarter twist for reactivation was connected in series with the 24 VDC line running to the motors at the rear of the robot. With this arrangement, the 24 VDC motors could be shut off independently of the electronics. Furthermore, this quality emergency stop button from Mouser was much more secure than the previous year's home-made stop button.

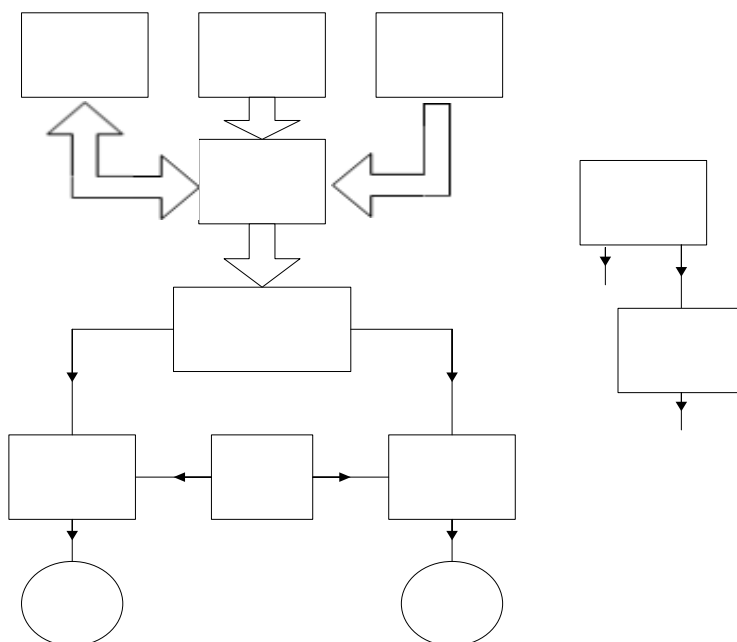


Figure 6 - Robot Electronic System Diagram.

A system block diagram for the *Yellow Jacket III* electronics system is shown in Figure 7. The laptop functions as the primary controller with exclusive access to all inputs and outputs of the system. The wireless router for robot PDA control and debug is connected to the laptop NIC card via an Ethernet cable. The Fire-I firewire camera is connected to the laptop through firewire and the Garmin GPS system along with the Z8 microcontroller are connected through separate USB ports via USB to serial converter dongles. The only function of the Z8 microcontroller is to create a PWM signal to each motor controller based on a command and data byte from the laptop. An interrupt structure was established so that whenever the computer was sending information, the Z8 would run a particular interrupt service routine. The motor controllers were controlled by PWM through the included timers on the Z8. In order to communicate through PWM, the computer sent the Z8 a one byte number. This number is scaled and offset by the Z8 such that the lowest value produces a 1.1 ms pulse and the highest value produces 1.9 ms pulse, which correspond to full speed backward and forward. A value of 7F produces a 1.5 ms pulse, which corresponds to the stopped position.

Wireless
Router
(12v)

Software

A standard 802.11b/g wireless router was installed on the robot allowing the robot to be remote controlled from a 802.11b enabled PDA. In this design the PDA is used to gather telemetry from the robot while in autonomous mode, allow for remote manual control when not in autonomous mode, and implement a wireless E-Stop. The PDA is a large benefit over RC control as debugging information as well as imaging can be easily updated in real time without requiring access to the onboard laptop.

A Dell Inspiron 1505 with Core 2 Duo processor was chosen as a laptop upgrade from the 2006 competition for image processing and IO control. The obvious advantage of a new laptop would be higher frame rates from a 1.66GHz processor with 2Mb cache and quicker RAM access speeds with 1Gb of dual channel DDR2 at 533MHz. During the 2006 competition frame rates limited our image processing capacity to mask shadow and tarps as the frame rate became too low for efficient robot control. The 2 core processor of the Inspiron 1505 allowed us to make efficient use of processing power by dividing the processing between IO access and image processing algorithm threads one running on its own core.

The Gentoo Linux operating system was chosen because of the open source nature of the software libraries that are used to access the hardware and the ability to customize the kernel to improve the performance of the system. Open source libraries were used to access the hardware interface to the Firewire camera and the display. Taking advantage of the library to access the camera it was possible to operate the camera in a 15 FPS RGB8 DMA mode to allow the image processing algorithm to continue to process while a new image is being fetched. Under the current threading architecture the IO thread fetches images from the camera meaning that the thread has 1/15 of a second to communicate with all other IOs. This amount of processing time allows us to send an enormous amount of debug data back to the PDA without hindering our image processing running at around 30 FPS on a separate thread. Since processing a single image twice is a complete waste of processing power a decision was made to synchronize the threads every frame. The thread synchronization starts the IO thread and the image processing thread at the same time via a control thread which simply sleeps until both threads return that they have completed processing on the given frame. Upon completion of each thread the main control thread performs a DMA memory dump between the threads before restarting them to synchronously communicate information between the threads without asynchronous mutex operations.

Image Processing

The primary image processing algorithm for object avoidance remains in edge detection from a camera as in the 2006 competition. The edge detection algorithm is preferred because of its universal solution application. The image from the camera is convolved with a gradient kernel in the H,S, and I channels (Hue Saturation Intensity color space). This means that our algorithm can detect objects regardless of one specific color, size, or specific height of the object on the course. The resulting edge detected image is filtered through a series of erosion and dilations along with majority filters and a final thresholding to form a binary image. A seed point is placed at center and slightly in front of the edges of the robot on the edge image. From this seed point a radial scan is performed which maps the available area as constrained by the edges to a separate image. Intrinsic in a camera's perspective is a non-linear distance mapping with distant objects being mapped to the top of the image and near objects being mapped to the base of the image. The x and y centroid of the area produced from the radial scan is then used as the primary image decision output. The edge detection along with radial scan and centroid calculations can be seen from figure 8.

Image segmented weighting masks were implemented after the centroid calculations so that the robot could be calibrated to perform more sensitively to objects directly on it's two sides. For barrels in the center of the robots view an algorithm was implemented which forces the robot to make a hard decision between two locations of large area and retain that decision throughout the turning process until around the barrel.

The most significant contribution of the teams work for the 2007 season was the successful removal of shadows and tarps. The first taste of successful shadow removal stemmed from an image entropy test. The original RGB image was divided into variable sized boxes upon which each box would calculate its own entropy between the box pixels. The entropy calculation assigned a quantitative measurement to the 'randomness' of the pixels in a given set. The idea was that the grass in an image would have very high entropy and would remain high in the presence of a shadow as the pixels, although less intense, would still be just as random in nature. The results of some of our testing are shown in figures 9 and 10. The disadvantage of the entropy calculation was that it was inconsistent for thin objects such as lines as the entropy must be performed over some finite block of pixels.

The final solution for shadow removal was an HSI color space solution. The theory was that the only properties of an image that are effected by a shadow is that of intensity. This made sense because shadows simply meant that less electromagnetic waves were able to reflect off of an object under a shadow and return to our viewing camera. The original plan was simply to normalize the intensity and hope for the best. The error with this method of shadow masking is that the intensity in the HSI color space represents white light while we are attempting to mask out the effects of the sun which emits inconsistent intensity over the visible electromagnetic spectrum.

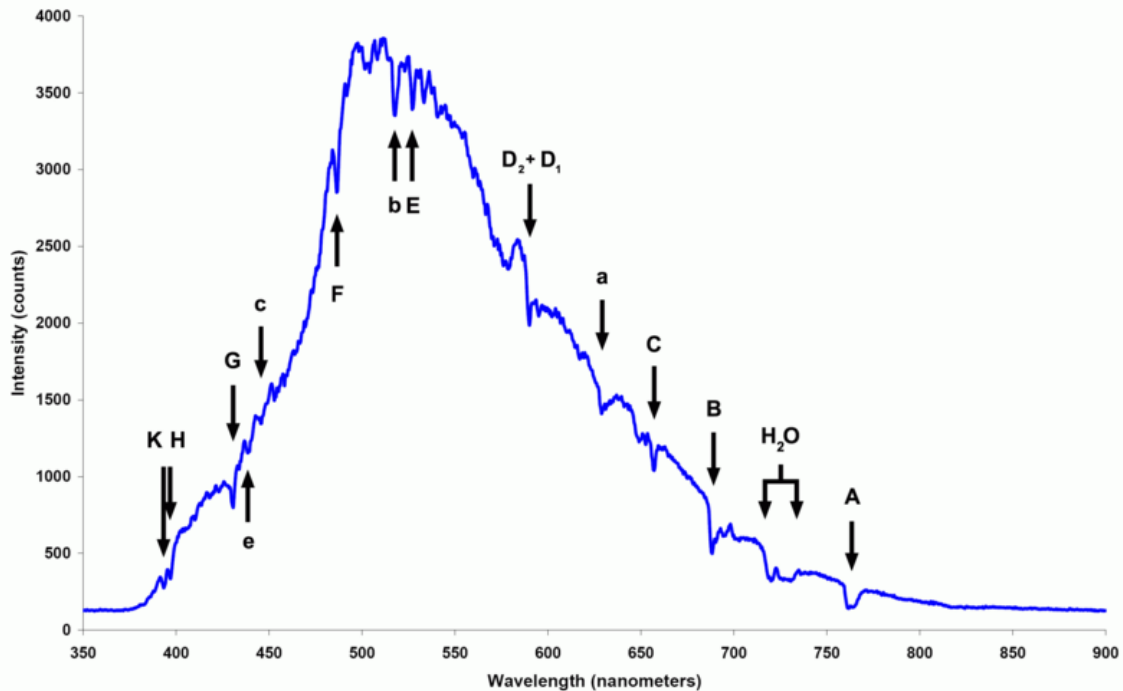


Figure 7: Sun light intensity as a function of frequency through a blue sky atmosphere
(Image taken from Wikipedia)

The problem was solved by first rotating the hue in the HSI color space 60 degrees such that the 550nm wavelength (yellowish light) was approximately mapped to the previous R axis. The image is then converted to RGB where the red channel now represents yellow. The yellow is masked out and the image converted back to HSI for edge detection effectively executing a wide 550nm triangular notch filter to approximate the triangular intensity pattern emitted from the sun.

The new image is then normalized in intensity from the HSI color space which causes the high intensity problem regions on the tarps caused from wrinkles to disappear. The tarps then appear as large objects with only edges on parallel sides and a constant color consistency which can be easily detected with a large 'color blob' algorithm. The algorithm does a few conversions from HSI to RGB and the reverse which are performed with large HSI2RGB and RGB2HSI lookup tables loaded into RAM allowing a single pixel conversion to take no longer than one memory access time.

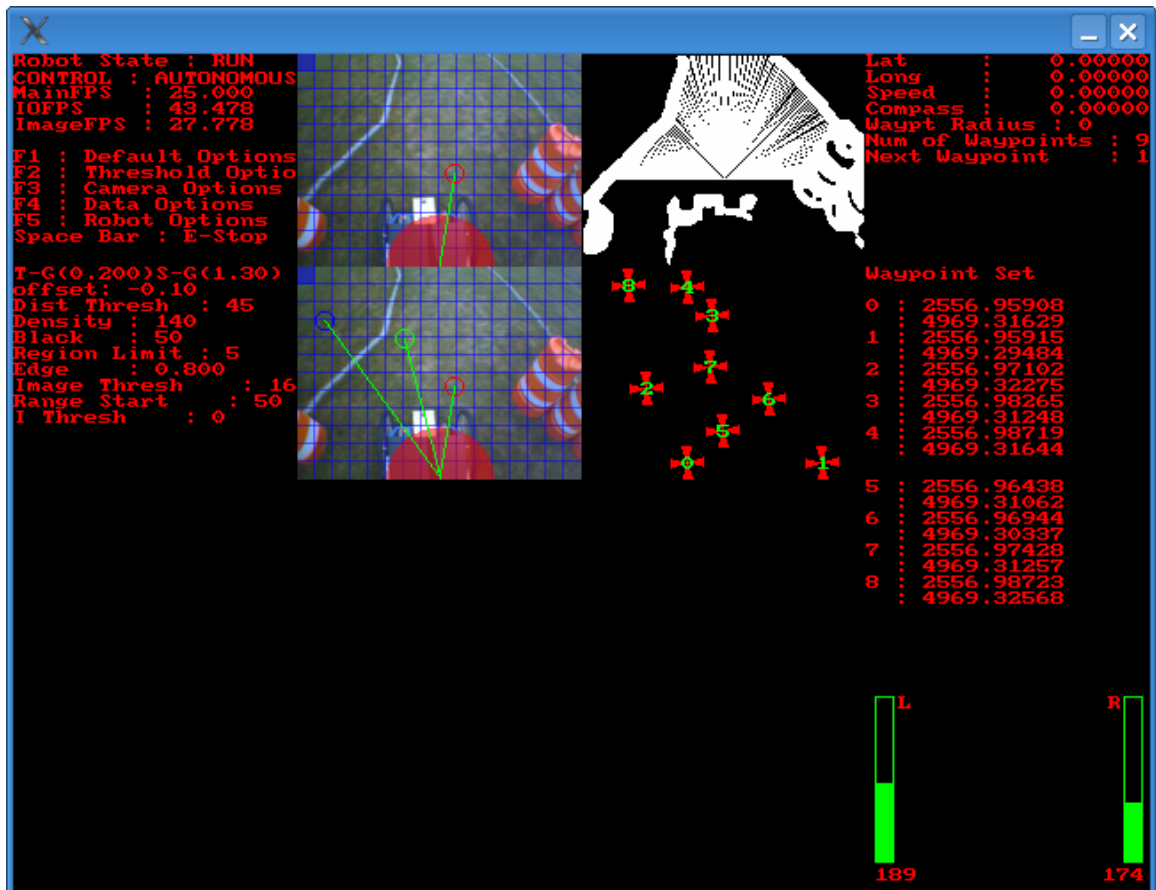


Figure 8: Main image processing and robot control screen

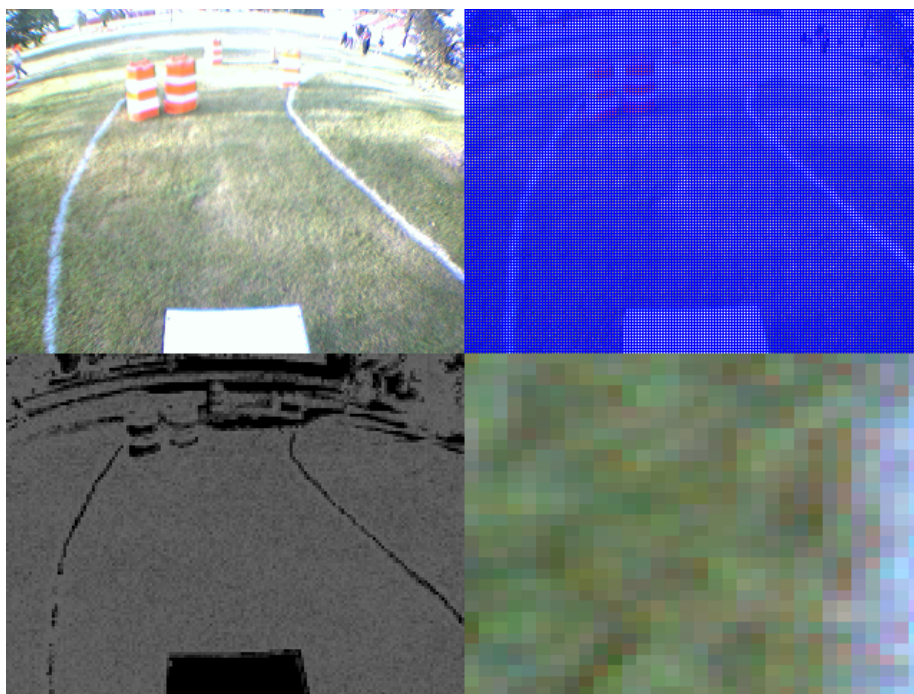


Figure 9: Image entropy : shadow image 1

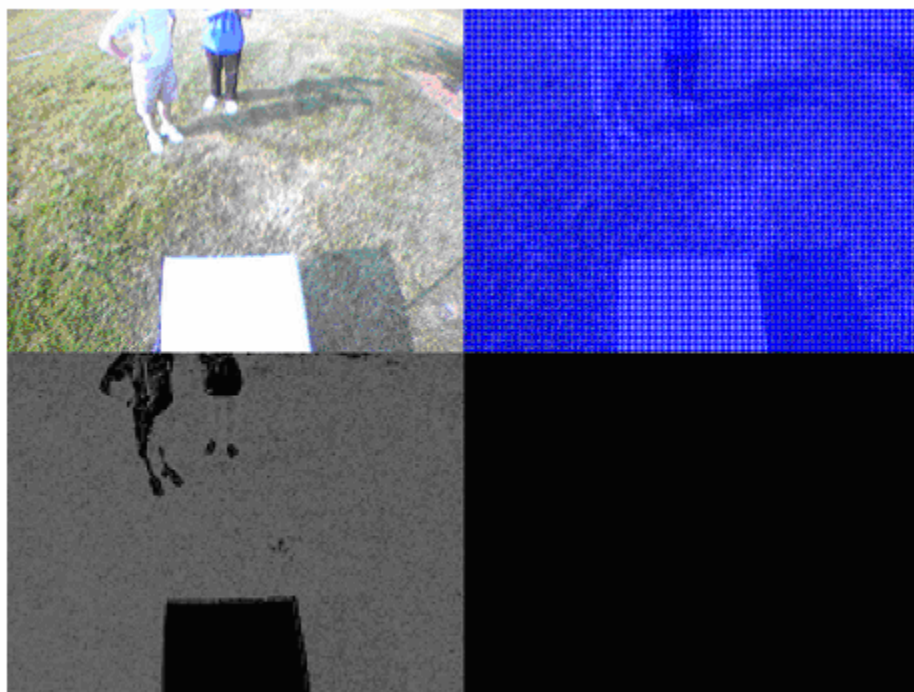


Figure 10: Image entropy: shadow image 2

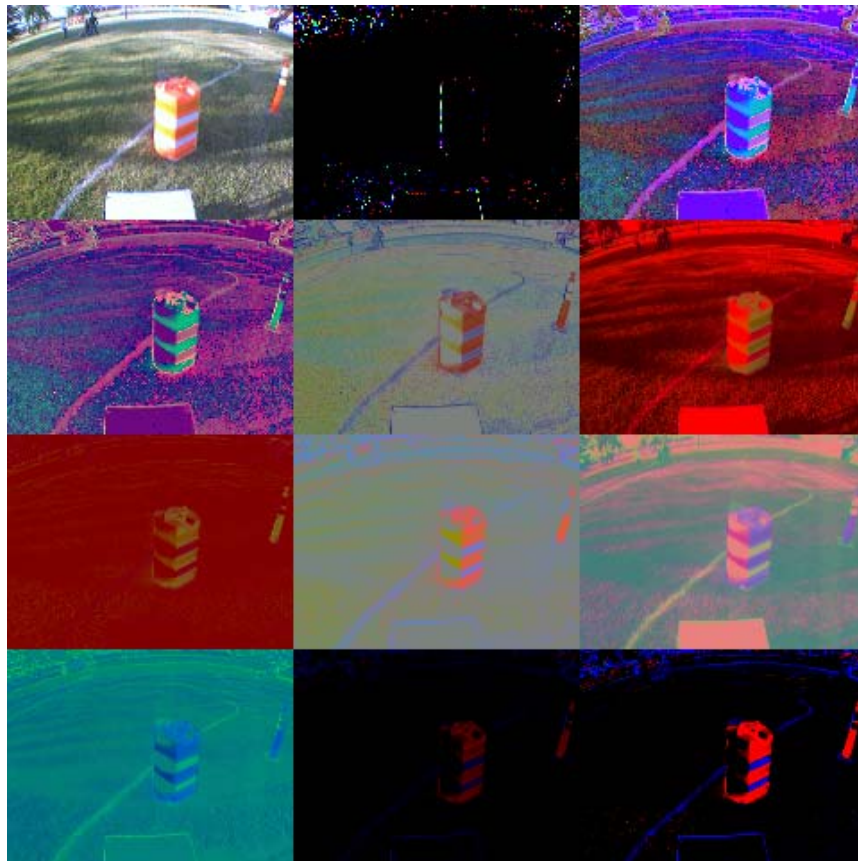


Figure 11: Image sunlight correction

Navigation

The image processing and GPS navigation systems integration was tackled by first mapping the solutions of each individual processing thread. The image processing thread solved for a rho and theta solution as did the IO thread. The two opposing rho and theta solutions were then balanced by evaluating the 1st and 2nd derivative of theta. The design philosophy was that we only wanted to respond to the image when there was an immediate danger but under normal conditions would head in the general direction of the GPS waypoint. As the robot approaches an object the image processing solution drastically alters the theta vector position thereby resulting in an extreme theta derivative. The theta derivative is used as a base to decide that the robot must make a drastic decision. As the theta slowly approaches the straight forward position the robot begins to lock back on to the GPS heading for an effective general heading.

Vehicle Cost

Item	Unit Cost	Total Cost
Gear-motors*	\$450	\$900
Motor Controllers	\$130	\$260
Chassis Materials	\$75	\$75
Bicycle Wheels	\$100	\$200
Casters	\$15	\$30
Fire-I Firewire Camera	\$83	\$83
Z8 Development Board	\$150	\$150
Electronics Interface Board	\$40	\$40
Emergency Stop Button	\$29	\$29
Laptop Computer	\$1100	\$1100
GPS Unit**	\$200	\$200
Ipaq	\$300	\$300
Wireless Access Point	\$60	\$60
Batteries	\$23	\$46
Misc. Parts		\$250
Total Cost:		\$3,723

*Donated by Bodine

**Donated by Garmin

Conclusion

Cedarville engineering students are not afraid of difficult problems. All of our team members were totally capable of rebuilding the robot from the ground up and avoiding last years difficulties. All of our team members have built robots before, programmed microcontrollers, evaluated data from external sensors and generated command driven motors and actuators. The Cedarville team believes that if we as humans can navigate and make decisions based only on vision than a robot should be able to as well. We stuck with our plan for this year as a rebuilding year and produced working solutions to our previous problems which will make the Yellow Jacket III a competition force in 2007.

Faculty Statement:

I Timothy R. Tuinstra certify that the level of effort expended by this five member team of undergraduate students from Cedarville University has been significant and has been on the level of the effort required for a typical senior design competition.

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