Black Knight

University of Central Florida

11th Annual Intelligent Ground Vehicle Competition
Oakland University, Rochester, Michigan
May 31, June1-2, 2003

Faculty Statement

I certify that the work done by all students on this project is consistent with a senior design course and that the vehicle has been significantly modified for this year's competition.

1 Acknowledgments

1.1 Sponsors

Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI)
United States Army
Orlando, FL, USA
http://peostri.army.mil

Computer Engineering Program
School of Electrical Engineering and Computer Science
University of Central Florida
Orlando, FL, USA
http://www.cpe.ucf.edu

1.2 Donors

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Maiden Marine
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Thales Navigation
Santa Clara, CA, USA
http://www.thalesnavigation.com

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2 Introduction

The University of Central Florida (UCF) is entering into its second year of competition, and the current entry, Black Knight, is the result of a senior design project, independent study work, and sponsorship from the U.S. Army PEO STRI (formerly the U.S. Army STRICOM). Participation comes from a continuing effort at UCF to make research an integral part of its undergraduate program. Particularly, the School of Electrical Engineering and Computer Science and the Computer Engineering Program have encouraged the team by providing support in the form of equipment to the UCF Undergraduate Robotics Laboratory. The laboratory, which was founded last year by Dr. Fernando Gonzalez and Frank Goergen, hosts several undergraduate thesis projects in addition to the IGV project.

3 History

Knightrous was UCF's first entry in the Intelligent Ground Vehicle Competition. Although it was unable to compete due to a circuit failure, its second incarnation, Black Knight, is ready after a complete redesign of the power distribution and vehicle controller systems. Additionally, the primary software systems, namely the navigation and computer vision systems, had solely been tested through simulation, but are now reformed and have proven to be fully functional. The redesign of the power system, controller circuits, controller software and vehicle body were the responsibility of the senior design students, while the other team members were responsible for completing the remaining portion of the vehicle.

4 Overall Design Goal

The overall goal for redesign of the vehicle was to make it more compact, stable and modular. The vehicle is based on a Pride Mobility Celebrity electrical wheelchair. This base easily carries the weight of all components and is capable of climbing grades well above those required by the competition. The circuits were redesigned using two Microchip microcontroller units (MCUs) to control speed, steering and emergency stop. This is a less complex and therefore more robust approach than that previously used. The power system was redesigned to be lighter, more compact and efficient. The vehicle was also redesigned to be more stable. All circuits were redesigned to provide stability for both the vehicle and vision system. Speed and steering algorithms were rewritten to provide better performance and an error code system. This allows the software to control the vehicle more accurately and to stop under undesirable conditions. In addition, the approach to sensor fusion has been reevaluated, and a separate hardware unit is no longer used for parsing and conditioning sensor data. The new implementation uses spare CPU cycles for these functions. Finally, the vehicle's design focuses on modularity which allows “pit crew” style repair in a matter of minutes.

5 Electrical System

The following section explains in detail how the electrical system was redesigned. In the previous vehicle there were five circuit boards running five separate MCUs. The new vehicle only uses two MCUs on one circuit board to control all aspects of the vehicle's motion. This and the H-bridge board are mounted in a metal box which slides into the vehicle like a drawer. For easy troubleshooting, the team has two of these circuit boxes so that one can be worked on while the other is on the vehicle. Another new feature of Black Knight is a manual control box which allows the vehicle to be controlled with two potentiometers for easy movement from place to place. On this box there is also a switch which selects whether a human operator or the computer is in control of the vehicle.

Figure 5.A - MCU Circuit Board

Figure 5.B - View of Circuit Box Mounted

6 Steering Control

Figure 5.C- Manual Controller Box

The improvements to steering control are refined programming and a new scheme for obtaining feedback from the steering system. Additional safety features were added to the vehicle to ensure a smooth and stable steering design. Software for the steering system was completely rewritten this year, also on a PIC16F877 MCU. Steering software was rewritten from assembly to C language for ease of implementation and troubleshooting. The circuit was redesigned both to make it more compact and to increase its modularity. This circuit now fits with all other circuits on one board which easily mounts in the circuit box. Also, the H-Bridge circuit that is used to control the polarity of the steering motor was redesigned to handle higher current. This circuit was redesigned replacing store bought Darlington pair transistors with Darlington pairs composed of discrete power transistors. This new design eliminates circuit failures encountered previously. New software was added which incorporates a delay when steering motor direction is reversed. This protects the H-Bridge circuit from damage. Error handling was added in software to limit steering travel so that the chain and motor bracket cannot be harmed. The software was also modified to dampen oscillation and provide more accurate control of the steering motor.

7 Speed Control

The speed control MCU of Black Knight is a Microchip PIC16F877. It has five ports for multiple input/output lines and a 4 MHz clock for quick execution. An encoder on the left rear wheel is used to obtain the current speed of the vehicle. The PIC controller processes the encoder values and relates them to the main computer via RS-232. The main computer receives the current speed and compares it to the desired speed. In response, a new desired speed value is calculated and sent to a D/A chip on the circuit board which sends the specified voltage to the motor. This scheme provides smooth and stable speed control of the vehicle. The software for speed control is written in the C language, eliminating the need for assembly programming which was problematic during the previous year. The algorithm includes a ramping method to smooth the acceleration and deceleration of the vehicle. The vehicle itself is equipped with a potentiometer that limits the overall speed. This potentiometer will be used to limit the speed of the vehicle to a maximum of 5 mph.

8 Safety

The emergency stop (E-Stop) system was completely redesigned for Black Knight. In the previous year the E-stop system was implemented in software. For this competition a hardware solution was used to ensure E-stop capability is unaffected in the event of software failure. The design takes advantage of the onboard Curtis speed controller embedded in the vehicle. It has two methods of triggering an emergency stop. A Futaba RC controller and a stop button are used to break one of the control lines to the Curtis controller which in turn causes an error condition and completely stops the drive motor. This new design ensures that if either software or hardware malfunction, the vehicle will stop safely. The system has been tested and brings the vehicle to a stop in well under the specified six foot distance.

9 Sensors

The sensor suite used for this year's vehicle uses the same sensors as last year, however, the method of sensor fusion has been completely redesigned. Provisions have also been made on the circuit board to easily allow for the inclusion of additional sensors in the future. A TCM2-50 Digital compass with an accuracy of ±1° RMS and a BR2G Differential GPS with a circular error probability of 40 centimeters are used. The MDFKG2101 magnetic encoder is reused, however, its output is now passed to the main computer by the speed MCU. To simplify the design, a separate board for data conditioning is no longer used. GPS and compass are given individual serial ports on the main computer so that data can be collected directly from them. The new design takes advantage of unused computer capacity and reduces the circuitry significantly.

The Kalman Filter has been eliminated from this year's design to help simplify the vehicle and make the design more compact and easier to troubleshoot. The Kalman Filter proved to be difficult to work with after testing the vehicle and it was decided to eliminate it to further simplify the design. The data conditioning and parsing are now handled by the main computer.

10 Mechanical

The steering motor is a Bodine Electric 24V motor with a 60:1 gear reduction. This motor is linked to the steering input shaft of the vehicle via a chain and two sprockets which add a further 3.75:1 reduction. Feedback to the steering microcontroller is needed to allow accurate control of the steering angle. Two switches and a potentiometer are included in the design to provide this feedback. One of these switches is positioned at the front of the vehicle so that it is depressed when the steering is within ±4° of center. The other switch is positioned so that it is depressed by the steering cross member when the steering is at either limit of its travel. The mechanical limits of the steering system are at ±45°. Feedback about the current angle of the steering system between center and turn limits is also needed. Last year's design used a belt between the output shaft of the steering motor and a pulley on the shaft of a potentiometer to provide this feedback. Currently a ten turn potentiometer is mounted above the steering cross member. A cord is attached between the steering knuckles and wrapped around the shaft of this potentiometer so that it rotates as the front wheels turn. The potentiometer provides a feedback voltage to the steering microcontroller proportional to the current steering angle. This method was chosen because it increases the feedback voltage range and limits slippage by eliminating the pulley on the potentiometer shaft used in the previous design. Both of these improvements increase the accuracy and stability of the feedback voltage.

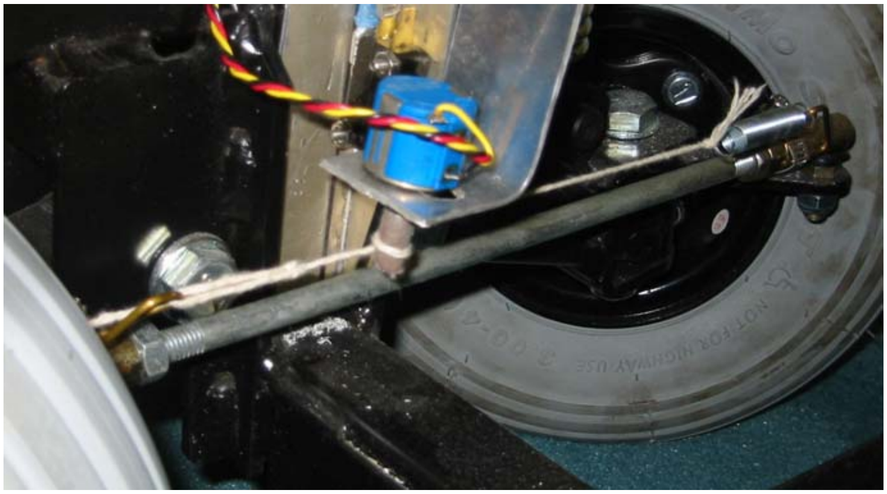

Figure 10.A - Steering Feedback Potentiometer and Limit Switch

11 Power System

For the 2003 IGVC the power system has been redesigned to improve efficiency, weight, and run time. Last year's vehicle was powered by the original batteries and a UPS system. The current system does away with the heavy and bulky UPS. Currently the vehicle is powered by a total of four batteries. The two deep cycle batteries that were the original power source are retained. They power the steering and drive motors in addition to the 24 V portion of the steering circuit. Two additional 55 amp hour batteries are used. One of these powers all 12 V circuits mounted in the circuit box, vision cameras, camera multiplexer, and sensors. The final battery powers vision and main computers through a 1200 Watt Mobile Power inverter. Separate fuses on the 12V and 24V supply lines protect the circuits. Extensive testing has shown that this power system is capable of powering all systems for times in excess of an hour.

12 Chassis

The body of the Black Knight has been redesigned from that used on last year's vehicle. The old body offered less protection for the components inside while making access difficult and uncomfortable. The new body is a two piece design fabricated out of foam-cored fiberglass. The rear half of the body is permanently attached to the vehicle. It has a window for the on-board monitor as well as two doors. The doors provide easy access to the interior of the vehicle where the inverter and battery for the computers are located. The removable front portion of the body covers the computers. The two parts of the body join with a seal and provide protection from the elements. This body design allows quick and easy access to all the modular components of the vehicle.

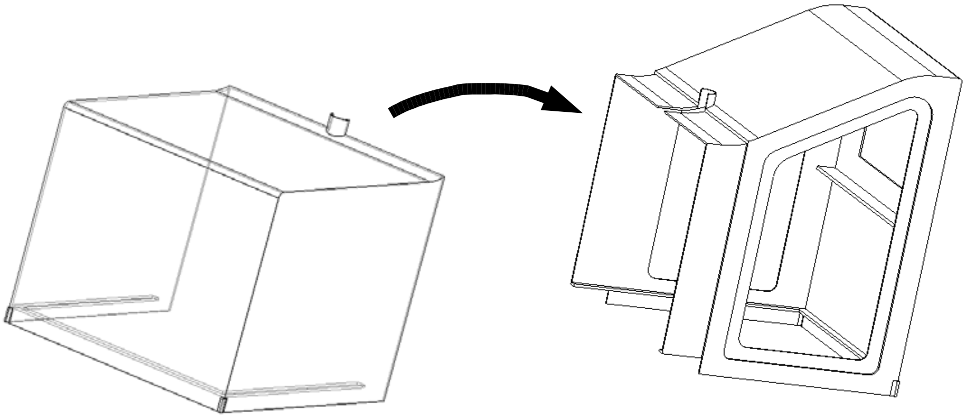

Figure 12.A - Illustration of how the two piece body fits together.

13 Software

13.1 Main Computer

The main computer provides the majority of the computations that deal with motion planning and control of the vehicle. A majority of the software base was constructed for the 10th Annual IGVC competition, however, since the vehicle testbed was not fully completed it was not extensively tested. At that point in time, all the work was purely simulation of vehicle motion with estimated movements and artificial terrain. This year some software organization was changed and tasks were reassigned. Because of the modular design this could be accomplished without having to rewrite any of the subcomponents, only changing which components are used.

13.1.1 Organization

To recap the previous design, the main computer's program is broken up into many small subprograms. Each of these does a specific task and shares results or gains input from a different program. This can be done through the Linux operating system's inter-process communication and shared memory. The general structure uses a maritime nomenclature that provides each subsection a name that is descriptive of what it does. Input comes from the GPS and compass and provides position and direction to the Coxswain program which then sends this information to the shared memory. The Cartographer receives map updates from the vision computer and sends back position, direction, and camera values. The Captain program determines the current challenge and controls what relevant information is passed to the other components. The Navigator takes the digital map from shared memory and finds a reachable node path during the navigation challenge. During the autonomous challenge it finds the path of least resistance. Necessary information is passed back to the shared memory where the Captain controls the Helm program which tries to physically match the theoretical path physically by looking ahead and adjusting the vehicle's desired angle. The values are interpreted by the Engineer which redefines the data and sends out specific information to the speed and steering MCUs which physically control the motors at regular intervals. In addition, the Lookout scans all incoming path data and compares it to the current position to determine any obstacles that

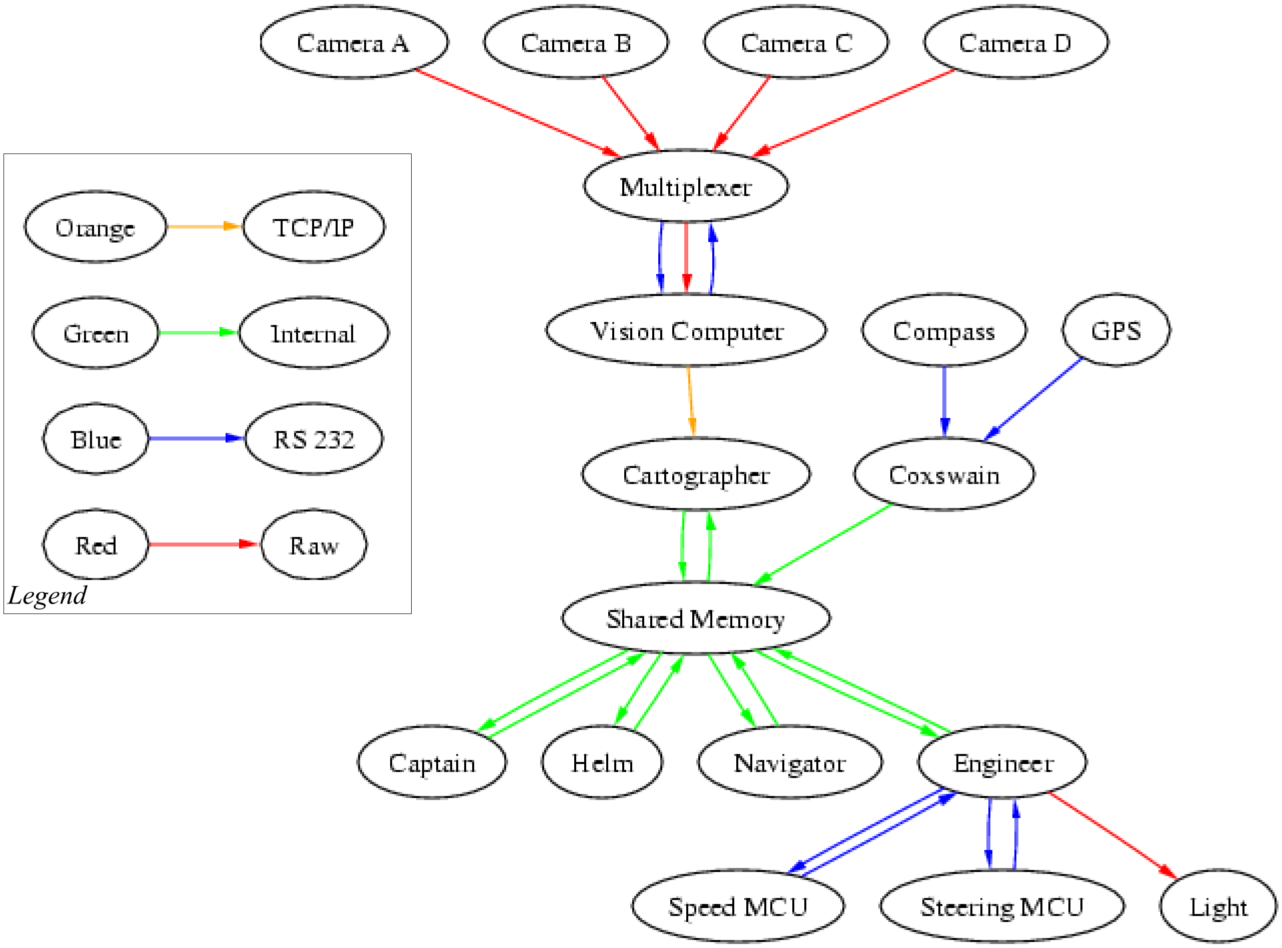

Figure 13.A - Computer Systems Data Flow

need to be circumvented. Then it sends a message to the Captain to stop and tells the Engineer to turn on the obstacle light. Due to data transfer time and the way in which these messages are sent, this process can occur approximately five times a second. All the information in shared memory is also processed into a human readable format and sent to the on-board monitor. These programs run simultaneously on the main computer which allows the information to be constantly updated and shared to all programs such that the data is always current. In total, these programs provide the intelligent control of the vehicle.

13.1.2 Major Changes

The first major change to the overall system was to add the follow-the-leader challenge which was not part of last year's competition. This process was greatly simplified by the modular nature of the system. The Captain was given a new function for motion control and the Cartographer takes in some additional information from the vision computer about target position. The Captain then determines desired direction from that information and starts the other processes. The rest of the system remains unchanged because control of the vehicle is broken up into different subprocesses. These subprocesses do only low-level tasks which do not change for the individual challenges.

Another major change from last year is a more complex system of path determination during the autonomous challenge. In the new process, map data in the local area is filtered with a Gaussian blur. This expands the obstacle positions in a normal distribution, which provides a buffer around individual obstacles and combines closely spaced objects into one obstacle. The local map is then processed through a system of linear traversals in the forward direction and the safest path is selected by the degree of "obstacle" in immediate vicinity.

In response to experience gained from last year’s competition, much more emphasis was put on slippage and error conditions due to the slick nature of the course. More vehicle correction and correlation subroutines were added to account for these sources of error.

The most drastic change, from an organizational standpoint, is to data collection such that the Coxswain directly communicates with the GPS and compass. In the previous year there was a high-speed microcontroller called the Data Conditioner which took the physical information, processed it, and passed on only what the main computer needed. After analysis of processor usage on the main computer, this functionality was migrated to the Coxswain running on the main computer. There the data is conditioned before being sent to shared memory. This allows a simplification of hardware without impacting software execution, thereby decreasing complexity and increasing reliability.

13.1.3 Implementation

Software implementation for the individual challenges has been altered for this year's competition. Depending on the current challenge, different path planning schemes are used to fit the specified task. The modular design of the software allows the same subprograms to be used differently to achieve individual goals. The underlying subprocesses that relate to motion control, sensor capture, and vision processing are separate entities. The higher level abstractions calculate the desired path of the vehicle which the rest of the system attempts to actualize.

13.1.3.a Navigation Challenge

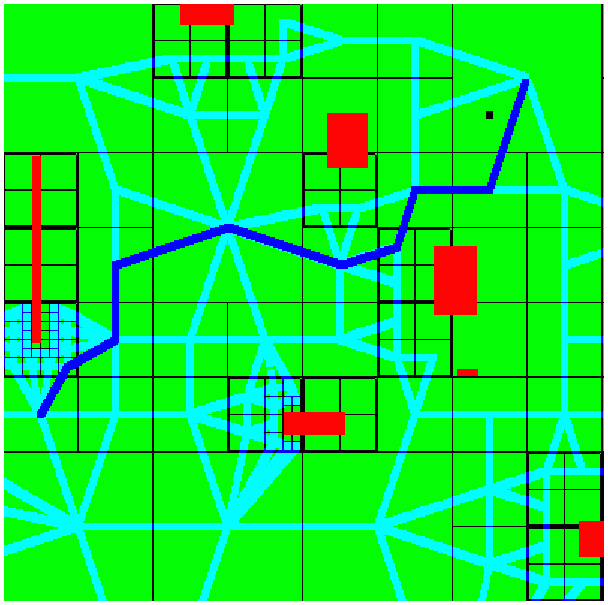

Figure 13.B - Navigation Decomposition Map

For the Navigation challenge, a method of abstraction is applied to the map constructed by the vision computer. Since the GPS coordinates for the waypoints are given, they must first be put in an order which allows the generalized quickest traversal. This can be done by using a Traveling Salesman method on the points to determine the order from start to finish. Once the points are ordered, the program then attempts to travel the straightest path toward the next point from the current location. The algorithm plans the path such that the center of the vehicle's rear axle comes within 0.25 meters of each waypoint. Initially, the map is an empty square field. As obstacles are detected, the map is subdivided into smaller squares based on the position of the obstacles. Of all possible paths, the algorithm then selects the appropriate one based on these bounding squares. This implementation was chosen due to its ability to robustly track around a large set of unknown objects and dilate them to create a safe path.

13.1.3.b Autonomous Challenge

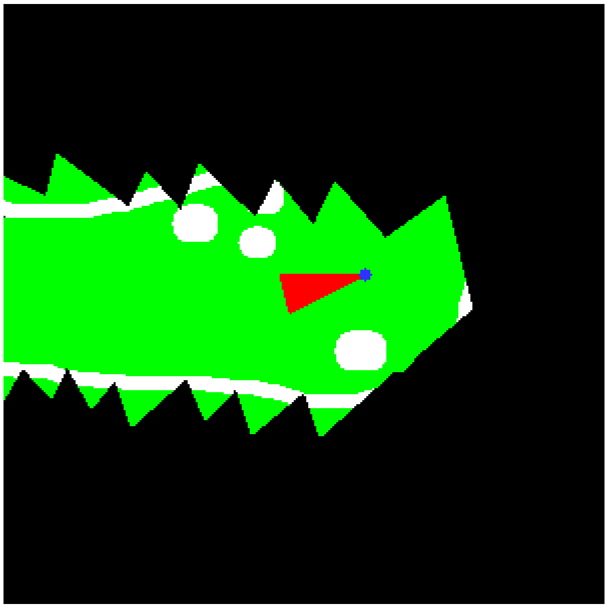
Figure 13.C - Display of Autonomous Mapping

The autonomous challenge provides different requirements with respect to path planning. For this challenge the algorithm must complete as much as possible of the given track without being given prior information. This is done by traveling the route selected from the local map constructed in the main computer. This map is derived from the global map made from camera input by the vision computer. In the event of a dead end trap, it is possible to backtrack to the last known safe position using past data points stored in memory. This allows the program to reevaluate the previous branching point if necessary. The ability to reverse out of a trap on the course was felt to be an important innovation. Lines bordering the course are classified as obstacles to be avoided, therefore keeping the vehicle's desired path safely away from the edge of the course. The Gaussian blur used by the algorithm allows it to interpolate dashed lines and treat them as solid.

13.1.3.c Follow-the-Leader

There is one main difference required by the follow-the-leader challenge. Only in this challenge does the vehicle have to react in a positive manner to a detected object. Through the vision computer, the leader is marked as an unique obstacle. The algorithm now plans a path toward this obstacle while avoiding any others as they are detected. At the same time, the fact that the leader is categorized as an obstacle keeps the vehicle from approaching closer than its three foot buffer distance. This system was chosen to take advantage of the modular nature of the software and reuse existing subprograms for this new goal.

13.2 Vision

The vision system is tasked with capturing real-time data and transforming it into a 2D map. As this is the primary sensor system, it must be reliable, robust, and simple to use. Specifically, the system gathers visual data, processes it, and develops an orthographic map based on this data, while the main computer handles all navigation and control using the generated map. In addition to the data provided to the system by one of four cameras, it is also supplied with GPS and digital compass data, which is used to correct the transformation of images into navigable obstacle information.

The main components of the vision system are the vision computer, a video digitizer, a video multiplexer, and four externally mounted cameras. Three of these cameras face forward, and one rearward. Of the three forward facing cameras, two are angled to the sides such that they provide a 180 degree field of view in front of the vehicle. The cameras' field of view extends approximately nine feet in in front of them. The cameras are calibrated before use by a simple series of initialization processes. After calibration, the system gathers video from a selected camera and processes the video one frame at a time. Each pixel of every frame is then classified as either “Obstacle” or “Non-obstacle” by using the statistics of previous frames and information about its color and local texture. Next, this information is manipulated with two transformations: an orthographic projective transformation from image space to world space, and a rigid-body transformation from world space to 2D map space. As updates occur on the map, they are stored and sent to the navigation system after the frame is completely processed.

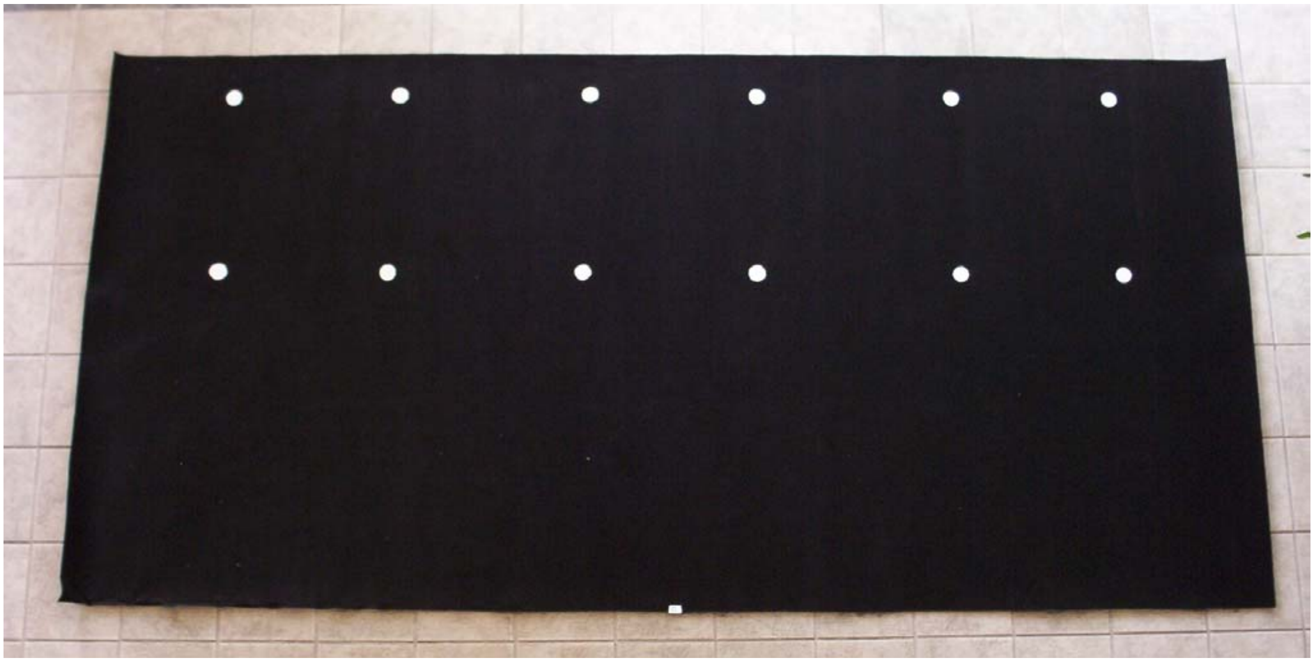

Figure 13.D - Carpet for Vision System Calibration

The positions of the cameras give the vehicle a wide forward field of view and the option of viewing to the rear of the vehicle, providing a versatile platform for gathering visual information about the vehicle’s surroundings. The navigation system then selects the desired camera and notifies the vision system of its request. At this point the vision system responds by processing data from the new camera after a nominal switching delay. Therefore, the navigation system controls the direction of the robot's vision.

During the calibration process, the cameras are positioned and adjusted manually. The physical calibration parameters are unknown to the user, however this extrinsic data is discovered automatically using a special calibration frame. The data is then used in the routine image warping as previously discussed. Color calibration is also automated, and is established by placing an object of precisely prepared color in the view of each camera. The system uses this data to better understand global lighting conditions and eliminate the effects caused by changes in lighting, thus finalizing the calibration process.

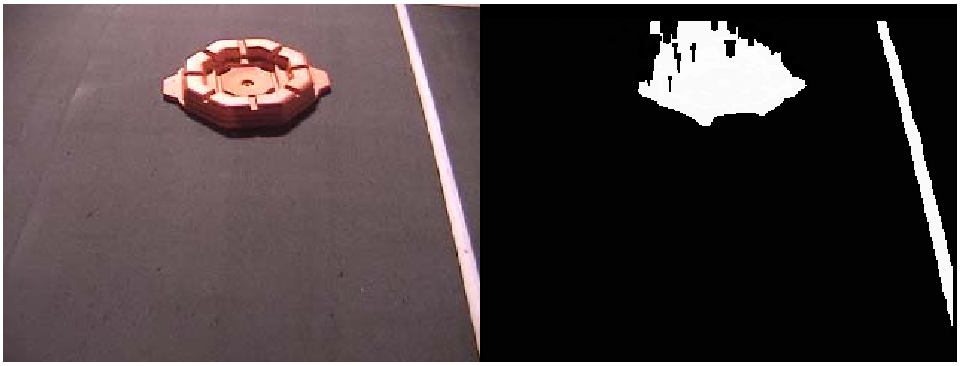

Figure 13.E - Image before and after Vision System Calibration

Figure 13.F - Additional Classifications

Visual processing is computationally expensive, so all but the most essential computations have been eliminated from run-time processing. For example, all transformation and color adjustment information is calculated and stored during calibration. During processing, the data is loaded once and retrieved from active memory only as needed, allowing the classification of each pixel of every frame to occur in the most efficient manner.

14 Budget

Description:	Vendor:	Quantity:	Unit Price:	Total Price:
All:				
Dell workstations, display, CD-RW, etc.	Dell	1	$5,339.12	$5,339.12
KVM and Serial PCI	Dell	1	$100.00	$100.00
Celebrity XL 4 wheel scooter	Pride Mobility	1	$1,100.00	$1,100.00
Electronics:				
SC34 DA Optima Yellow Top deep cycle	Insight/Auto Zone	6	$150.00	$900.00
Ashtec BR26-S DGPS	Thales Navigation	1	$1,000.00	$1,000.00
Electrical Components	Newark		$168.61	$168.61
Mobile Power Inverter	Mobile Power	1	$200.00	$200.00
MDFKG2101 Magnetic Encoder	Baumer Electronics	1	$35.00	$35.00
TCM2-50 Digital Compass	PNI Corp	1	$800.00	$800.00
Electrical Components	Skycraft Components		$80.00	$80.00
Vision:				
PC 33C Color Camera	SuperCircuits	4	$169.95	$679.80
CML-4mm IF2,Cs mount lens with iris	SuperCircuits	4	$24.95	$99.80
DC 12/500R Power Adapter	SuperCircuits	4	$14.95	$59.80
AVR80000 RS-232 8:1 video multiplexer	Ontrak Control Systems	1	$100.00	$100.00
Chassis:				
Bodine electric motor	Power & Pumps Inc.	1	$469.00	$469.00
Sprockets and Chain	Miller Bearing	1	$150.09	$150.09
Fiberglass Body Fabrication	Maiden Marine	1	$780.00	$780.00
Total:				$12,061.22

15 Conclusion

Black Knight is a significantly improved vehicle over that brought to last year's Intelligent Ground Vehicle Competition. The major improvements consist of a modular approach to all aspects of the vehicle. The modularity of the hardware design allows quick and easy repair and troubleshooting of all components while the vehicle continues to operate. Software modularity allows a set of individual subprograms to be reused for the various challenges with a small number of controlling high-level algorithms. Overall, the current vehicle is a much more robust, complete, and functional design which better meets the requirements of the competition's challenges.