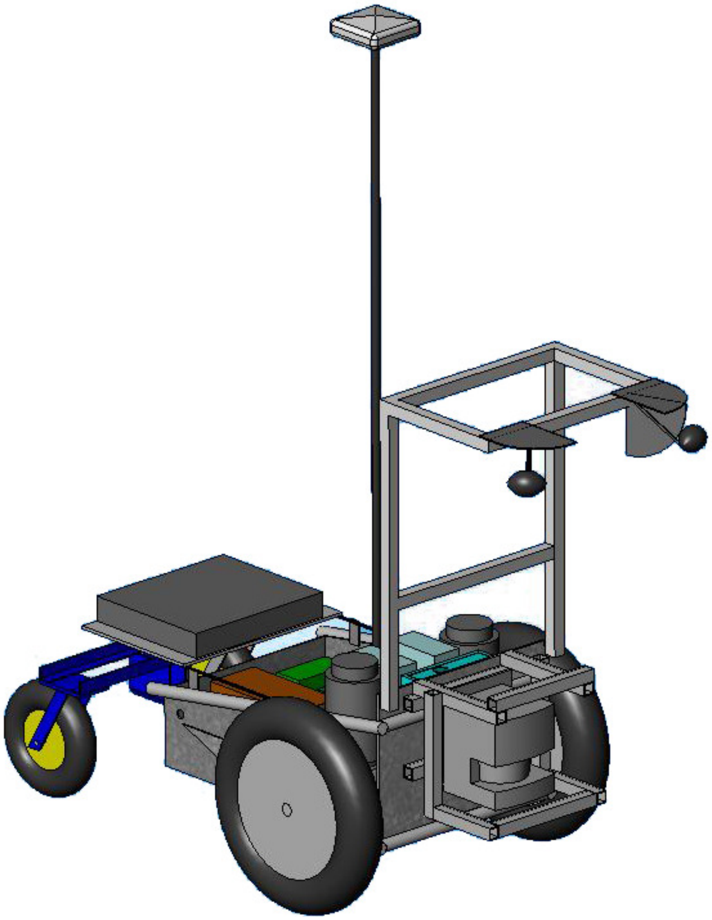
Q

2009 IGVC DESIGN REPORT



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Faculty Statement

This is to certify that Q has undergone significant redesign in both hardware and software from last year's IGVC entry. The Q team members worked on the robot as an Independent Study project and received 1.0 credit (3 credit hours) per semester. This project is significant and has led to many senior design projects in both Computer Science and Engineering.

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1. Introduction

The Trinity College Robot Study Team presents the third iteration of Q, an autonomous vehicle for the Intelligent Ground Vehicle Competition (IGVC). Q is named after the omnipotent entity found in Star Trek and for the gadget guy in the James Bond series. There is a focus on a simplified control system, rather than the highly modular systems of previous years. Based on a modified wheel chair chassis, Q is a stable and reliable platform. The team continues its tradition of exploring innovative technologies by employing a modern high density battery system.

2. Innovation

Q has undergone several significant design improvements for this year's competition. Emphasis was put on improving the run-times of the various processes involved with the operation of the vehicle. The obstacle avoidance algorithm has been optimized for smoother motion and the overall intelligence code for the autonomous and navigation challenges were modified to achieve greater processing speeds. In order to predict the behavior of the vehicle under the navigation algorithm, a controlled simulator environment was created using National Instrument's (NI) LabView. This greatly increased the ease of testing the robot's actions. Using the simulator, the motion of the vehicle could be observed under various control variables. The simulator also allowed for error(s) to be introduced into the system so as to model real life uncertainties. Extraction of path history information in the form of odometry data from the optical encoders and bearing data from the compass now provides the vehicle with a general sense of direction. This allows for it to avoid going backwards in the autonomous challenge when posed with that possibility. With such extensive overhaul in the software section of the design, it was deemed important to implement a form of version control. The Tortoise SVN application was used alongside a network server to store, retrieve and update code. This was particularly useful in tracking changes made to the same files by several users and progressing without conflict.

Specific hardware changes have also been made. The vehicle's safety of operation has been further improved by introducing Emergency Stop mechanisms including an RF encoded remote e-stop. However the most significant hardware change came in the form of a new Compact RIO from National Instruments. The compact RIO reduced the processing load on the laptop by using its real time processor and FPGA. The sensor data is pre processed on the FPGA while the real time processor ran the navigation algorithm.

Q uses a SICK laser range finder and a DGPS smart antenna. It features JAUS Level 3 compliance and a centralized control system. Additionally closed loop speed control and dynamic image processing algorithms enables efficient obstacle avoidance. A modern power system increases efficiency by using state of the art high energy density batteries.

The base platform is a modified PerMobil Trax off road wheel chair frame. This offers a significant improvement in reliability and stability of the platform compared to the custom built platforms of previous entries.

A Dell Inspiron D820 with an Intel T7400 Core 2 Duo processor and 2GB of RAM running National Instruments (NI) LabVIEW 8.21 acts as the central control for Q. A Roboteq AX3500 dedicated motor controller and a pair of US Digital E5S optical encoders act the platform for the closed loop speed control. As explained above, the compact RIO is used to pre-process sensor data and run the navigation algorithm.

Q also features new control algorithms in order to take advantage of an improved sensor suite. The Kalman filter is implemented in order to efficiently combine data from each source. A dynamic waypoint algorithm is used for the navigation challenge; this is an improvement over the static waypoint order of previous years. A modified Vector Field Histogram (VFH) algorithm is used to avoid obstacles and stay within lane boundaries for the autonomous challenge.

Q uses cutting edge battery technology by employing a pair of Nilar 24 Volt 9Ah NiMH batteries for driving the motors and an UltraLife 30V 6Ah battery for the electrical systems. These batteries provide high energy densities and are ideal for autonomous robotics.

3. Design Process

3.1 Team Organization

The team was organized into five main groups based on the various task families within the scope of Q. Most members of the team worked in more than one group. This year sees the addition of the systems, management and testing groups to the software and mechanical groups. The systems group was created in order to facilitate communication across specialties and to improve collaboration.

Traditional project management techniques were implemented throughout the project. This includes a clear definition of the scope before design began as well as a group dedicated to managing risk throughout the design process.

3.1.2 Group Definitions

The following is a definition of the responsibilities of each group.

Management

This group defines the scope of the project and designates team members and tasks to each group. The group is also responsible for identifying risk throughout the project. Risk includes falling behind schedule, changing the scope of the project or not documenting a task. This group is also responsible for recording weekly progress and updating the Gantt chart accordingly. Each team member contributed approximately 200 man-hours towards this project.

Documentation and Testing

This group is in charge of creating testing procedures and identifying the required documentation for each task. The group also makes sure that Q complies with all IGVC design regulations.

Systems

The Systems group works with the mechanical and software groups to implement an optimized design. The group is responsible for connections between components as well as power, sensors and communications.

Mechanical

This group is responsible for the design, mounting, and documentation of all hardware.

Software

The software group follows standard software design protocol to meet the scope of the project.

3.2 Design Methodology

The design process for Q began with the definition of a project scope based on the analysis of customer requirements as determined by IGVC rules, innovation goals and an evaluation of previous performances. An iterative process of reverse scope creep was used to design Q. In this process, the initial goals were scaled back until the design became feasibly based on the time and resources available.

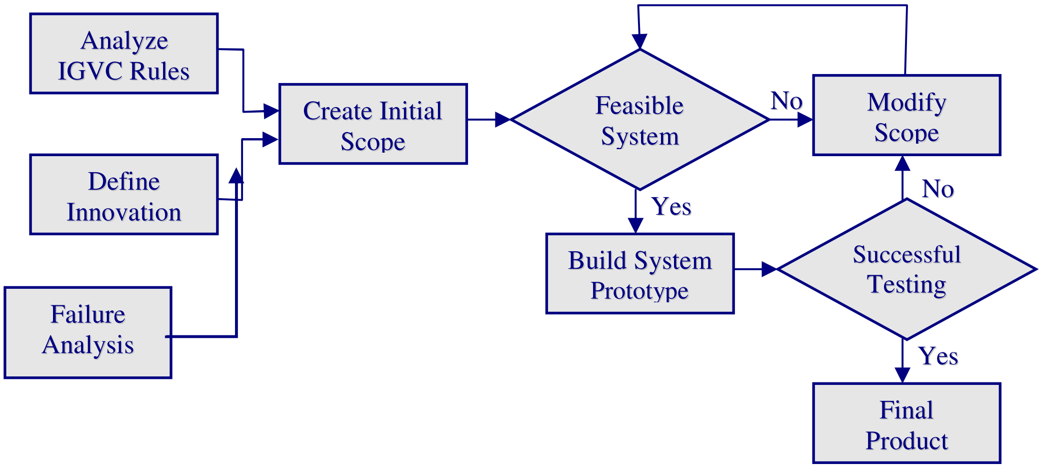

Figure 3.1: Iterative Design Cycle

4. Mechanical System

4.1 System Layout

The physical platform of Q is a modified Permobil Trax off road wheelchair. It has a steel frame with designated compartments for each component. The frame can support a payload of over 250 lbs and has a small footprint of 40” by 26”. Component placement was carefully designed in order to isolate the power and control systems and to minimize wire lengths. A sensor frame was constructed of 80/20 extruded aluminum channel, which allowed for quick changes to component layout. The sensor frame folds down onto the body for easy transportation. Figure 4.1 shows the modified chassis.

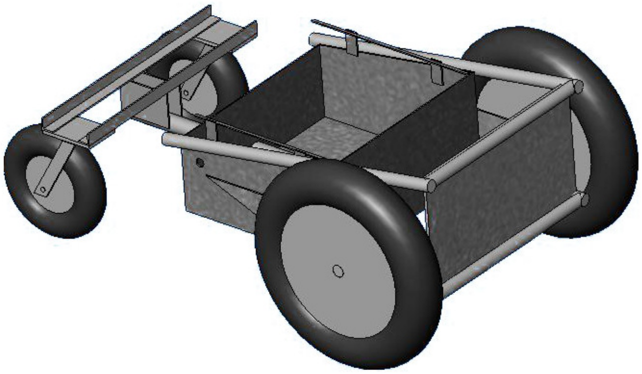

Figure 4.1: Q Chassis

4.2 Drivetrain

Q is powered by a pair of 500W Leroy Somer MBT1141 motors geared with a 26:1 ratio. The 24 Volt DC motors provide high torque. A Roboteq AX3500 motor controller provides 40A per channel with 250A peak. There is a theoretical maximum speed of 9.5 mph although the speed is limited to 5 mph in order to comply with IGVC regulations.

4.3 Mobility

Q has a differential front wheel drive system and uses a pair of rear mounted casters. The casters are mounted on a pivot pipe that keeps at least one caster in contact with the ground on any terrain. This configuration significantly improves mobility by enabling Q to turn around in place if confronted with a dead end. This configuration also allows a greater range of motion as there is no restriction on the heading of Q due to turning radius.

4.4 Reliability

The professionally manufactured Permobil Trax off-road wheel chair offers a reliable and safe platform. There is a front suspension system that limits vibration to the components and provides greater accuracy for the sensor systems.

The 80/20 extrusion forming Q's sensor frame is designed for industrial environments and is resistant to dirt, moisture, and vibration. The extrusion's profile is tapered to allow all hardware attached to it to be self-locking, simplifying the choice of hardware and further reducing weight. All critical electrical connections utilize positive locking connectors that are immune to shock and vibration and provide tactile feedback to confirm proper connection. Wiring is carefully dressed with strain reliefs to prevent fatigue failure. All components are mounted using multiple points and protected by durable acrylic panels that are resistant to the environment and to impact, for all-weather operability. The wheels and casters are loaded at a fraction of their rated design loads, giving a large margin of safety in the mechanicals.

5. Electrical System

The onboard electronics and power distribution system have been dramatically improved in Q to ensure reliability and robustness during operation. A custom power distribution circuit with redundant safety features supplies three voltage levels from one battery source to accommodate the various power requirements of the electronics. A separate power source is used for the drive system; this isolation reduces the effect of noise caused by the motors on the rest of the system.

5.1 System Integration

The Dell Inspiron D820 laptop acts as the central control of Q. All image processing and navigation algorithms are performed on the laptop. The IEEE1394 cameras connect directly to the laptop. The digital compass and DGPS are connected to the PC over RS232. The NI cRIO is responsible for processing of the laser range finder data, this data is sent over ethernet to the laptop. The motor controller uses a PID algorithm in order to determine to correct amount of power to send to each motor. The optical encoders provide feedback for this algorithm. An RF remote control is used to control Q and an additional receiver/transmission set is used perform a remote emergency stop if required.

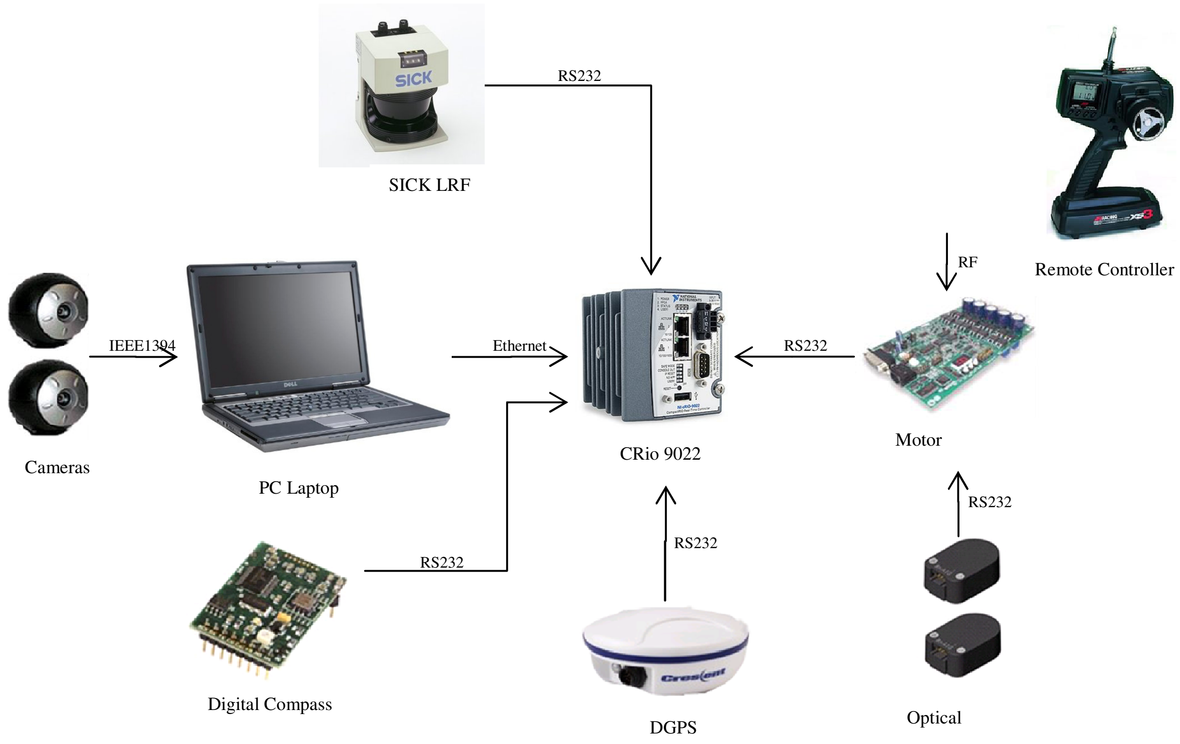

Figure 5.1: Control and Sensor System

The cRIO was the newest addition to Q’s system architecture. Last year, the main bottleneck on Q's speed was processing speed. Q already has a robust algorithm from the year before, but traveled through the course very slowly. The team identified the image processing and the code that reads data from the SICK LRF as the slowest part of Q's algorithm. The SICK code currently suffers from buffer overrun (the SICK transmits data faster than the laptop can process it) in certain situations, and is sometimes forced to run slower than its maximum speed, in turn slowing down Q as a whole.

In order to make Q faster in the autonomous challenge, the processing load was distributed among a dual core laptop, a real time processor and an FPGA. The image processing runs on the laptop, the real-time processor handles the navigation algorithm, and the FPGA is used to pre-process sensor data. For this purpose, the National Instruments Compact RIO (Reconfigurable Input and Output) rapid prototyping system was used. This system has two main parts: a controller which contains a real-time microprocessor and a chassis which contains an FPGA. National Instruments sells many modules for input and output that can be plugged into the chassis. The FPGA has access to the IO modules, and the controller has access to the FPGA. Q's Compact RIO uses an RS232 module to communicate with the motor controller, GPS, compass, and SICK laser range-finder. In addition, an analog input module is used to monitor battery voltages.

To speed up Q's operation, the FPGA was programmed to pre-process sensor data before passing it on to the controller. Since the FPGA is hardware, it is substantially faster than the real-time processor. Using the FPGA to process the SICK data drastically increased the speed at which the SICK is read. Now the real-time controller use all of its CPU time for the navigation algorithm, instead of decoding sensor data from serial ports.

In addition to improving sensor read time, the real-time processor used by the Compact RIO will help with system synchronization. Last year, Q's main system ran on windows XP, which can crash or slow down when too many processes are running. By using a real-time processor, Q's algorithm can operate at a fixed frequency, and if a task is taking too long, the system won't slow down to complete it. In this way, separate tasks that run in parallel will not become unsynchronized.

5.2 Power Supply

Q's power supply comes from two different battery sources. The two DC motors are powered using a pair of Nilar nickel metal hydride (NiMH) 24 VDC 9Ah batteries. This battery has a relatively flat discharge curve that enables it to provide a steady power over a range of voltages. It is highly compact and lightweight with dimensions of 278 x 129 x 57 mm and weight of 4.3 kg. Its features such as deep cycle capacity and high energy density together with its robustness makes this battery ideal for powering motors in an autonomous robotics setting.

The Nilar batteries are connected through the motor controller to each of the motors. A 100A circuit breaker is installed between the batteries and motor controller in order to safely limit the current drawn by the system.

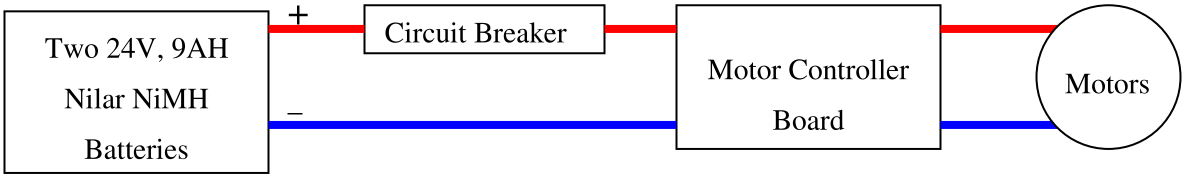

Figure 5.2: Drive Power System

A third Nilar battery drives the SICK laser range finder. The power requirements of this sensor call for a dedicated power supply, a separate power supply also improves the running time of the system.

The entire sensor and control system, except for the laptop and laser range finder, is powered using one UltraLife Lithium Ion battery. The battery provides 6 Ah continuous at 30 VDC, resulting in a run time of approximately one hour. It is lightweight and compact, weighing in at 1,440 grams. The state of the art design of the UltraLife battery allows it to have a high energy density and provide a total of 173 WH of continuous power.

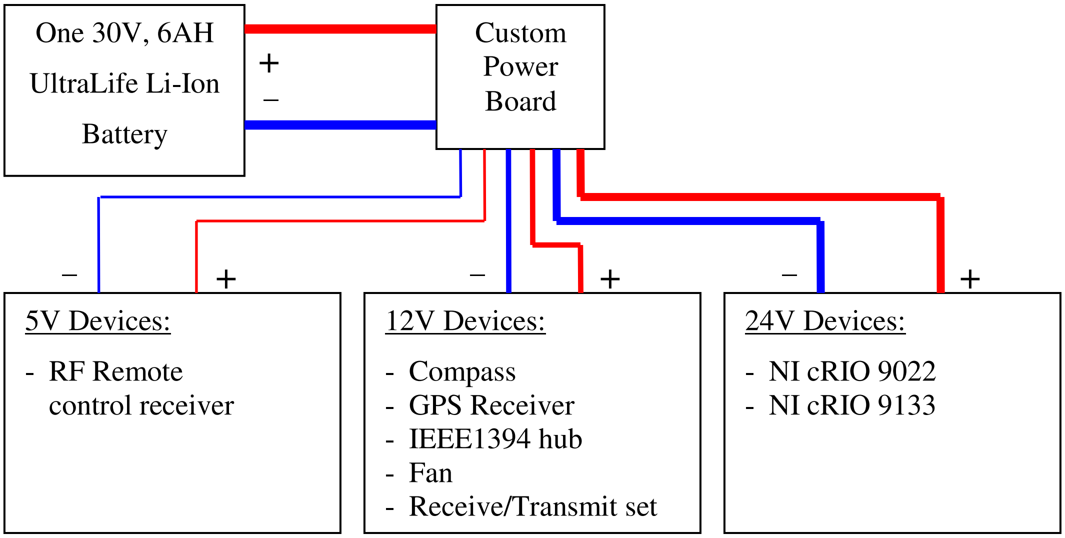

Figure 5.3: Control and Sensor Power System

The power from the UltraLife battery is converted to +5, +12 and +24 Volt regulated potentials by highly regulated DC-to-DC converters that are mounted on a custom printed circuit board. For safety, several circuit breakers and heat sinks are put in place to limit the current and dissipate heat respectively. A regulated clean supply of voltage is important for onboard equipment, and bypass capacitors between each voltage line and ground achieve this purpose. Figure 5.3 illustrates the power distribution.

5.3 User Interface

User initialization of Q occurs via the user control panel located next to the laptop. The control panel features an on-off switch for the main system along with a switch to select either navigation or autonomous challenge mode. The panel also features an analog display for the current voltage level of the system battery as well as the 5 V, 12 V, and 24 V lines on the power supply. Q can also be operated using a remote control that directly controls the motors and the E-Stop as a safety precaution. Q can be programmed over Wi-Fi or directly from the onboard laptop.

6. Sensors

Advances in sensor systems have enabled intelligent and efficient obstacle avoidance in mobile robotics. Q utilizes one laser range finder, two digital cameras, a compass, a pair of optical encoders and a differential GPS to perceive its environment and support intelligent operation.

6.1 Digital Cameras

Q uses two ADS Tech Pyro cameras for its vision system. Both cameras use a 640 by 480 pixel resolution with an update rate of 15 frames per second (fps) and a 52° viewing angle. They are interfaced to the laptop through an IEEE1394 hub. The cameras are mounted with custom built devices that allow for 90° of freedom in both the vertical and horizontal direction.

6.2 SICK Laser Range Finder

A SICK LMS-291 laser range finder (LRF) a 180° field of vision with an angular resolution of 0.25° and a measurement resolution of up to 10mm. The LRF is implemented with a dedicated power supply in the form of a single 24V NiMH battery.

6.3 Digital Compass

Vehicle orientation on Q is obtained using a Honeywell HMR-3300 digital compass that is interfaced to the NI cRIO over RS232. The compass provides precise readings for the azimuth angle and has a range of ±60° for pitch and roll data with an accuracy of ±1°.

6.4 Differential Global Positioning System (DGPS)

Vehicle localization is achieved by means of a Hemisphere Crescent A100 DGPS smart antenna. The DGPS beacon, GPS antenna and GPS hardware are enclosed in a single compact unit (2.2”H x 5.1”W). The system has a maximum error of 0.6m with 95% confidence. The antenna is mounted on a carbon fiber rod at six feet, which is the highest allowed by the IGVC competition.

7. Software

This year there was a focus on efficient software design; source control using Subversion was implemented and the NI LabVIEW 8.6 programming environment was used. LabVIEW provides a graphic programming interface which allows complicated algorithms to be represented with simple graphic controls.

7.1 Path History

Q has exhibited some undesirable behavior in past year's performance in the autonomous division, The past algorithm was such that it did not provide the vehicle with any sense of direction. Under this condition the vehicle is prone to making the mistake of moving backwards instead of forwards on the track. This possibility is avoided by collecting path history data. Using odometry data collected from the optical encoders and the bearing information from the compass, the path history of the robot is built. Using this information the robot then makes an estimate of its overall sense of direction over a stretch of its recent motion. Based on this estimate the robot can avoid going back in the direction it has already traversed.

7.2 Obstacle Avoidance

The obstacle avoidance algorithm is based on the Vector Field Histogram Plus (VFH+) algorithm. This algorithm uses an expanded polar histogram of the obstacles to calculate the optimal headings. Here, the cameras and laser range finders provide environment occupancy data to form a binary polar histogram. After accounting for the width of the robot the candidate directions are evaluated. The algorithm applies a cost function utilizing the target direction, current direction, previous direction as well as width of opening to calculate the cost. Thus the direction with least cost is chosen as the decided heading.

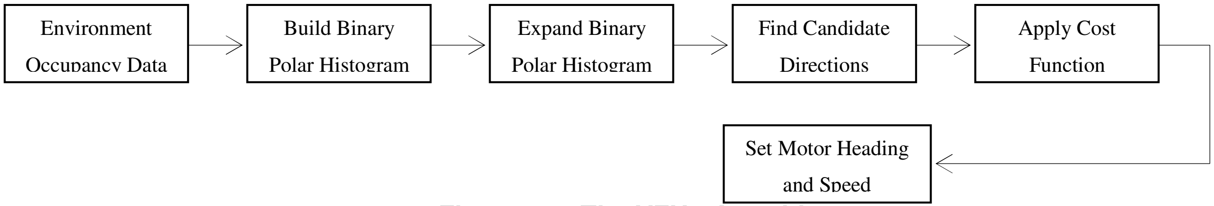

Figure 7.1: The VFH+ Algorithm

7.3 Navigation

Navigation is performed by applying the A* search algorithm on top of the obstacle avoidance algorithm. The combination of these algorithms allows for look ahead verification and ensures that a candidate direction of the obstacle avoidance algorithm actually guides Q around an obstacle. This is mostly important in the navigation challenge, where there is no clearly defined path. The navigation algorithm performs several iterations of the obstacle avoidance algorithm in order to determine the best path up to a defined distance in front of Q. For each candidate direction, a new polar histogram is created based on the projected location of Q, the obstacle avoidance algorithm is performed and another set of candidate directions is calculated. This results in a tree of candidate directions. The A* search method is used in order to select the candidate direction with the lowest cost.

7.4 Image Processing

Images are extracted from two IEEE1394 digital web cameras. The raw images are passed over to the laptop and processed by an algorithm which detects lines and obstacles. The image processing algorithm was developed using National Instruments IMAQ Vision Builder and utilizes hue, saturation, and luminance of an input image. In addition, the image is sent through a number of low pass and particle filters to reliably identify lines, potholes and any other obstacle. The thresholds for filtering are determined through statistical analysis, which makes the algorithm effective in a variety of outdoor lighting conditions. First a color analysis is performed in order to detect any non-white obstacle. A mask is created from this analysis and added to the original image. A threshold which identifies lines and white obstacles is applied to the masked image. The result is a binary bitmap which clearly defines obstacles. This bitmap is used by the obstacle avoidance algorithm. All this processing will be done in two different processors available in the laptop computer for faster and optimized performance and synchronization.

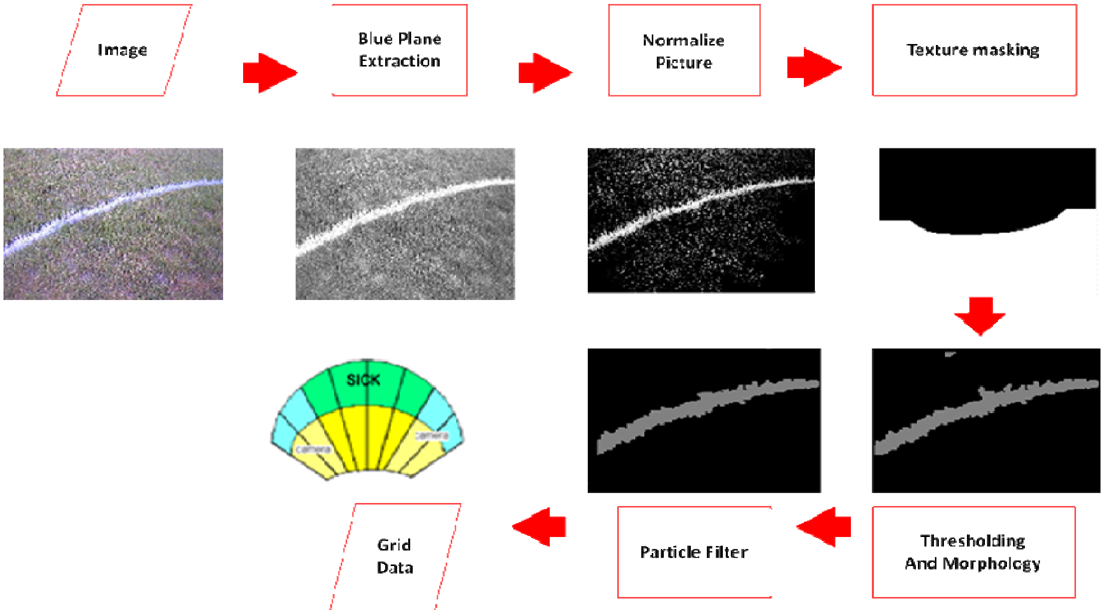

Figure 7.2: Image Processing Algorithm

7.5 Autonomous Challenge

The autonomous challenge is performed by setting an arbitrary target heading and then applying the obstacle avoidance algorithm. Here, initially target heading is assumed to be along the along the direction of the track. This is then dynamically changed as the obstacle avoidance algorithm accounts for the track boundary and obstacles. Here, a path history is also maintained based on previous GPS coordinates. This data is utilized to plan heading and to avoid repetition.

7.6 Navigation Challenge

The navigation challenge strategy represents another improvement over previous years. The waypoint target will dynamically change based on information the robot leans about its environment. As more information is learned about the course, Q decides which waypoint is closest to its current location.

The first step in the path planning strategy determines the drive order of the waypoints. Since only the coordinates of the waypoints are given, and not the obstacle coordinates, the order is initially determined assuming that no obstacles are present. This is done by a fairly simple program that was written using knowledge of graph theory and discrete mathematics with ideas being borrowed from Dijkstra's algorithm. The program calculates the shortest path between all waypoints from a starting position.

Distances of straight line segments from the starting location to each of the waypoints are calculated by the program. As Q gains knowledge of obstacles on the course, new waypoint orders are calculated based on the most efficient path to waypoints with obstacles in the way. After each waypoint is reached, the program is run again, with the most recently reached waypoint as the source, and all previous waypoints ignored. As more information is obtained about course obstacles, a more efficient waypoint order is determined.

7.7 Motor Control

The motor control is a closed loop system utilizing PID control. A lookup table is used in order to convert the speed and heading generated by the VFH algorithm to motor controller commands.

7.8 Simulator

In order to reliably verify the functionality of our navigation algorithm in a more controlled environment, and also to research possible improvements to the algorithm, team members used NI's LabVIEW software to implement a robot path simulator, which uses a recursive algorithm to simulate the behavior of a robot in a given environment.

The environment is simulated as a wide-open course with circular obstacles placed throughout the course. The basic architecture of the simulator consists of three components: sensor simulation, control and path calculation. The sensor simulation component uses the position of the robot and its surroundings to calculate sensor data. The sensor data is then processed by the control component, which essentially mimics the decision-making process of the actual robot and outputs control variables (motor speeds, heading, etc). The path calculation component uses the control variables, current position and velocity to compute the next position and velocity of the robot. A notable feature of the simulator is that it is capable of simulating random errors in sensor readings and control values, in order to represent the behavior of a robot more accurately.

Having a controlled testing environment is crucial to any design process and our simulator proved to be greatly helpful by allowing small changes to the algorithm to be tested on any computer without using the actual robot. Besides from helping team members test the navigation much more efficiently and saving us a great deal of time and effort setting up obstacles, this also allowed team members to test algorithms when suitable testing locations were not available because of snow, rain, etc.

8. Safety

Safety has been given the utmost priority in Q. Care has been taken to properly wire all components with strain relief. The power supply also ensures safety of the electronic components by its use of circuit breakers to limit the current from exceeding two amps for each voltage line. In addition, the control panel serves as a safe interface to operate the vehicle.

The high current draw throughout the motor power system necessitate proper handling and care to ensure safety of the vehicle and team members during operation. The Nilar battery is equipped with a nylon-insulated, AWG 6 copper wire and quick connectors, rated at 50 Amperes, for easy and efficient connections to the vehicle's onboard circuitry. An industrial grade 100A circuit breaker interfaces the batteries and motor controller for additional safety.

The stopping of the vehicle is another safety consideration. In order to stop the vehicle in case it fails to respond to the program or the remote controller, an emergency stop or e-stop was implemented. Q can be stopped in three ways, each of which can bring the robot to a complete stop within a distance of two feet. One method is to use the red E-stop push button at the rear of the vehicle. Another method is to use a remote E-stop, the mechanism for which has been modified due to its failure in the past competition. Previously, the controller was used to remotely stop the vehicle during its run. However, the data sent form the remote to the receiver was not appropriately encoded which made the vehicle prone to external signal interference. Furthermore, the method depended on the reliability of a commercial remote which could have been used by several other teams during the competition. This compromised the authenticity of the stop signal used for Q. This year, however, the remote controller has been replaced by a commercially available transmitter and receiver set which obviated all the complications that arose due to the use of the previous remote controller. Moreover, the signal is uniquely encoded, which makes it even more reliable. The last method for stop is the use of the on/off switch on the control panel.

The motor controller instruments safety features as well. The circuit breakers and fuses throughout the power system ensure that power will be cut to the motors in the event of a power failure.

9. JAUS

The Joint Architecture for Unmanned Systems (JAUS) has been a top learning priority for the Trinity Robot Study Team since it was added to the IGVC competition in 2006. That year the team completed Level 1 compliance with its ALVIN VII vehicle. Over the past two years, team members have worked to establish a new software framework for its latest vehicle, Q, and further JAUS implementation was pursued.

For this year, the state machine-based software architecture developed for last year's IGVC was reworked into level 3 JAUS compliance as part of a larger RST effort toward code organization, modularity, and reusability. A planning phase included reviewing Reference Architecture v3.3 and teaching JAUS concepts to new team members.

The framework developed for Q combines features from the two most established university JAUS toolkits currently available: Virginia Tech and University of Florida. The Virginia Tech's Master's Thesis by Ruel R Faruque, "A JAUS Toolkit for LabVIEW, and a Series of Implementation Case Studies with Recommendations to the SAE AS-4 Standards Committee," provided us with practical and detailed documentation of creating a JAUS-compliant system using NI LabVIEW. However, his source code is still unavailable and the system's implementation includes many unnecessary (for our purposes) JAUS features that could become troublesome and complicate matters. The University of Florida openJAUS project is completely open-source, but is customized for linux and runs on Java and C languages. The communication protocol, however, uses UDP via loopback between JAUS components and the node manager, a solution that is particularly appealing to the Q team as components maintain their independence as sub-VIs and can be split amongst multiple processors (i.e. Laptop and NI Compact Fieldpoint).

10. Predicted Performance

Extensive testing of all system was performed in order to ensure that Q is able to successfully complete each of the IGVC challenges.

10.1 Mobility

Q is driven by a pair of 500W motors at 3000rpm with a 26:1 gear head and 16” diameter wheels. This corresponds to a theoretical maximum speed of 9.5 mph on level surfaces. However, in compliance with IGVC speed regulations, the motor controller is configured to limit speeds to 5 mph. The drive system was designed for rough terrain and ramp climbing has been tested up to 20°.

10.2 Battery life

There are three battery systems; the laptop battery, Nilar batteries for the motor system and UltraLife battery for the remaining subsystems. The laptop battery has been tested at 2.5 hours runtime at full CPU load. The pair of Nilar batteries has been tested to a half hour of continuous runtime at maximum motor speed. With one lightweight UltraLife battery running aboard the vehicle during operation, the system is capable of 70 minutes of continuous runtime before the battery must be replaced.

10.3 Complex Obstacles

The best way to handle obstacles such as dead ends is to avoid them by following a well planned path. If Q finds itself in a dead end, the VFH algorithm will cause Q to turn around until it finds a clear path. Potholes are detected using image processing and are consider in the same manner as all other obstacles. The SICK laser range finder is capable of obstacle detection of up to 80m; for the purposes of this competition, we limit obstacle detection to 20m.

10.4 GPS Waypoint Accuracy

In testing, Q reached a variety of waypoints within an accuracy of about 1 meter. Readings given by the GPS hardware were tested on a one-dimensional 50m space. Readings were taken at 1 or 2m intervals. 31m corresponded to 1 sec according to the Global Geodetic System. Thus, 1m corresponded to 1/31m, which equals 0.032 seconds or 0.0005 minutes. Hence a 0.0005 minutes change was expected in every 1m interval, and a 0.0011 minutes change was expected in every 2m interval. The average error for this test was 1.26m. The implementation of an extended Kalman filter will further reduce the error.

10.5 System Reaction Time

The overall system reaction time is 2Hz, the bottleneck in the system is data processing; the table below shows data rates of each component. Testing has shown that a 2Hz decision cycle is fast enough to make appropriate decisions. Below is a table of data rates of each component.

Component	Data Rate
SICK LMS 291	70 Hz
Cameras	15 fps
Motor Controller(linked to optical encoders)	16.6 Hz
Compass	8 Hz
DGPS	20 Hz

Table 10.1: Component Data Rates

11. Vehicle Cost

Throughout the design and fabrication process of Q a concerted effort was placed on minimizing the cost by actively pursuing industry donations and support as well as reusing components from previous robots. The table below shows each component used in Q along with retail cost and cost to the team. Improved navigation algorithms also allow for a less accurate and less expensive DGPS system and a less expensive encoded receiver/transmission set among others. The team also uses inexpensive sensors such as a standard webcam. The SICK LMS291 and the two NI cRIO components represent the majority of the cost; the improved sensing ability makes this a worthy investment.

COMPONENTS	RETAIL COST ($)	COST INCURRED ($)
ADS Tech Pyro Cameras(2)	180	180
Crescent A100 DGPS	2000	0
Caster Assembly	150	150
Chassis	650	0
Encoders	100	100
Honeywell Compass (HMR-3300)	750	0
IEEE1394 Hub	50	50
Motors	1000	0
NI cRIO-9022 Real-Time Controller	3199	3199
NI cRIO-9133 Reconfigurable Chassis	1999	1999
Nilar Membrane NiMH 24V 9Ah Battery (3)	1000	0
SICK LMS291 Laser Range Finder	4000	4000
Power Supply Board	150	0
Encoded Receiver/Transmission Set	77	77
Remote Control	180	0
Roboteq AX3500 Motor Controller	400	300
UltraLife 30V Lithium Ion Battery	385	0
Wiring	50	50
Total	16320	10105

Table 11.1: Cost Itemization

12. Conclusion

Q is an autonomous vehicle designed by the Robotics Study Team (RST) at Trinity College. The vehicle features a reliable and sturdy frame which enables it to be used on many different types of terrain. Substantial innovation in the areas of control algorithms and the mechanical platform are combined with advanced sensing equipment such as a SICK laser range finder. These features enable Q to perform in any situation. Q provides a solid research foundation for a military autonomous vehicle. Its payload capacity and small footprint makes Q ideal for transportation of equipment in hostile environments. An adjustable accessory frame allows for multiple sensor configurations. By the process of iterative design along with the help of the latest software tools and cutting edge battery technology, the RST has Q, which is an example of an efficient and effective autonomous vehicle that should perform well at the 16th annual IGVC competition.

13. Sponsors

- Enterprise Rent-A-Car
- Hemisphere GPS
- Honeywell International Inc.
- Travelers Insurance
- Trinity College
- UltraLife Batteries
- National Instruments
- Nilar, Inc.
- PerMobil Corporation