Faculty Advisor Statement

I, Dr. CJ Chung of the Department of Math and Computer Science at Lawrence Technological University, certify that the design and development on Culture Shock II by the current design team is significant and equivalent to what might be awarded credit in a senior design course.

Modifications from last year's entry include:

- Addition of color reference hardware and continuous camera exposure adjustment.
- Modifications to the chassis to improve ground clearance.
- Improvements to image acquisition approach.
- Updated electronic compass hardware and acquisition approach.
- Redesigned challenge software.
- JAUS implementation
- Redesigned user interface

Culture Shock II

Design Report

for the

2010 Intelligent Ground Vehicle Competition

prepared by

Lawrence Technological University

Culture Shock II Design Team

1. Introduction

This report describes the Culture Shock robotic platform, designed and built for the Intelligent Ground Vehicle Competition (IGVC). This report is organized into sections describing the design team, the design processes, and various aspects of the design, followed by performance and cost information.

2. Team Organization

The Culture Shock II design team is comprised of the following members:

Name	Course of Study	Role(s)
Dr. CJ Chung	(Professor of CS)	Faculty Advisor
Brace Stout	MSCS	(Team Captain) Mechanical, Electrical, Software
Taiga Sato	MSCS	Software
Ryan Matthews	BSCS	Software

3. Concept Development

The Culture Shock II design was conceived following IGVC 2007. A post-competition review identified the areas in which our university's entries distinguished themselves from the rest of the field, as well as the failures and design shortcomings of our entries. Particular attention was given to those failures and shortcomings that were also exhibited by a number competitor's entries.

When the 'Culture Shock' team was formed, a number of 'brainstorming' sessions were held in which each of the failures were considered and possible solutions discussed. 'Out-of-the-box' thinking was encouraged and a number of unorthodox concepts were considered, many of which matured into the innovative features found in the present Culture Shock II platform.

3.1 Failure Analysis

The following points were identified during the failure analysis phase. In addition to those points that served as inputs to the original Culture Shock concept development, failures and shortcomings observed in the 2009 Culture Shock entry are also included.

- **Communications Interfaces** – USB-to-RS232 used adapters are unreliable and lack positive locking. For some reason (most likely vibration or inadequate driver software), these adapters often become unresponsive and required a reboot of the processing component to clear the condition.
- **Mechanical Stability** – Sudden stops can cause platforms to pitch forward, occasionally to the point of tipping. The resulting impulse as the platform rights itself (or worse, crashes) can damage sensors or throw off their calibration.
- **Vibration** – Rigid structures with no additional shock absorption provide a rough ride for the platform components, stressing mechanical connections and potentially damaging sensitive components.

- **Maneuverability** – Many entries use a three-point approach, with differential drive wheels in front, and a caster that supports the 'rear' of the platform and allows it to swing about. This rear caster, depending on its orientation, can cause significant resistance to turning. To reduce the possibility of tipping, a three-point platform will often place significant mass inside the triangle formed by the three contact points, resulting in a large moment of inertia for the drive motors to overcome while turning. These factors can combine to encourage oscillations during maneuvers, particularly at higher speeds. Additionally, while a differential drive allows such a platform to perform a 'zero radius' turn, in actuality a significant amount space is required to accommodate the swing of the main body during such maneuvers.
- **LIDAR Sensor Limitations** – The typical LIDAR sensor provides distance data for a planar slice of space. When faced with either a change of platform attitude or change of terrain elevation, the sensor scan path may intersect the terrain, resulting in 'phantom' obstacle detections.
- **Power Conversion** – Many entries use an inverter to convert DC voltage to 120V AC, only to convert the AC power back to DC via plug-in adapters, dissipating power in the form of heat at each stage of the process, leading to reduced operational time between charges. Aside from being inefficient, these components add unnecessary weight and space claim.
- **Performance in Soft Terrain** – Platforms tend to spin their wheels when operating in soft, loose, or wet terrain.
- **User Interface** – Computers used for platform control generally have displays that are not designed for viewing in sunlight. Additionally, pointer (mouse) manipulation is difficult under competition conditions.
- **Clearance** – In 2009, Culture Shock became stuck on the newly-introduced speed-bump obstacles due to low clearance.
- **Ambient Light Variability** – In 2009, Culture Shock software could not adequately distinguish between the white lane markers and the yellow speed-bump obstacles, due to variability in lighting conditions. The yellow-to-blue color component, in particular, varies significantly between direct sunlight and overcast skies.

3.2 Culture Shock II Concepts

The design team recognized early on that a platform having large wheels with pneumatic tires would mitigate several of the problems identified in the failure analysis, particularly if the heaviest platform components were centered between the wheels and situated below the wheel axles. After some initial experimentation, it was determined that this concept would also require shock-absorbing casters front-and-back to enhance stability. This approach addressed the following failure analysis points directly:

- **Mechanical Stability** – Due to the low CofG, there is a much diminished tendency for this platform to pitch forward when stopping suddenly. The pitching that does occur is an anticipated and natural part of the platform movement, and is handled by the stabilizing casters. Because the upright position is the lowest-energy state of the platform, there is a natural tendency for the platform to remain upright with very little weight placed on the stabilizing casters.
- **Vibration** – The large volume of the pneumatic tires provides this platform with superior shock absorption compared to platforms with smaller-wheels. Additionally, the platform has only two wheels that are rigidly-coupled, leading to a smoother ride than platforms with three or more rigidly-coupled wheels.

- **Maneuverability** – For a rotating body, the moment of inertia increases in proportion to the square of the distance from the axis of rotation. By positioning the heavy components (e.g. batteries) directly between the wheels, the torque required to turn the platform is greatly reduced. Additionally, because there is no 'main body' swinging around, the platform can maneuver in close quarters without needing to keep track of where its 'tail' is in relation to obstacles.
- **Performance In Soft Terrain** – The large wheels provide a large 'contact patch' to support the weight of the vehicle. In soft terrain, as the vehicle 'sinks in', the contact patch for a large-diameter wheel 'grows' faster than for a smaller diameter wheel. (We estimate 24 square inches of contact patch on hard surfaces, increasing to 36 square inches when the platform sinks one-half inch into soft ground.)

The second 'radical' idea for the Culture Shock platform was to incorporate a 'desktop-style' computer into the architecture, and to use its power supply as the power source for non-propulsion loads where possible. It was further decided that this power supply should be powered directly from 12V battery power, if possible. These decisions directly address the following failure analysis points:

- **Communications Interfaces** – Virtually any standard communications interface can be accommodated with PCI expansion boards.
- **Power Conversion** – DC-to-DC conversion is more efficient than converting to 120V AC and back to various DC voltages, so the batteries last longer between charges. A standard computer power supply provides +12V, +5V, GND, and -12V DC sources, providing a wide range of well-regulated voltage differentials that can be used by various sources internal and external to the computer.
- **User Interface** – Using a 'desktop' computer allows any of a large number of display choices and input methods to be used.

The third major 'out-of-the-box' idea for the Culture Shock platform was the decision to use only (stereo) cameras for feature detection. For 2010, it was decided that color reference bars be added to support a camera auto-calibration algorithm. These decisions directly address the following failure analysis points:

- **LIDAR Sensor Limitations** – Stereo cameras provide three-dimensional sensor information, rather than the planar slice available from LIDAR.
- **Ambient Light Variability** – The use of color reference bars allows color correction to be performed on acquired camera images, which in turn makes it possible to perform reliable color differentiation in a variety of ambient light environments.

4. Platform Design

Having decided on the major concepts that would influence the Culture Shock platform, it was time to begin design. This section discusses the physical design of the platform. The mechanical and electrical systems of the platform were designed in concert. Throughout the design phase, as alternatives were considered and concepts developed, three-dimensional representations of the concepts were maintained and updated. To reduce risk, mock-ups of critical components were used to verify clearances and space claims. Once the design was firm, parts were ordered. Structural components were fabricated as the electrical systems were integrated. Once completed, the various components were integrated into the Culture Shock platform. The following sections highlight the key elements of the design.

4.1 Mechanical and Propulsion Subsystems

It was recognized from the start that using large wheels in the platform design would mean high torque motors and correspondingly high stresses on the mechanical components. As a result, the mechanical and propulsion systems were designed as a single subsystem. **Figure 1** shows front and side views of the resulting design. The paragraphs that follow describe this design process in more detail.

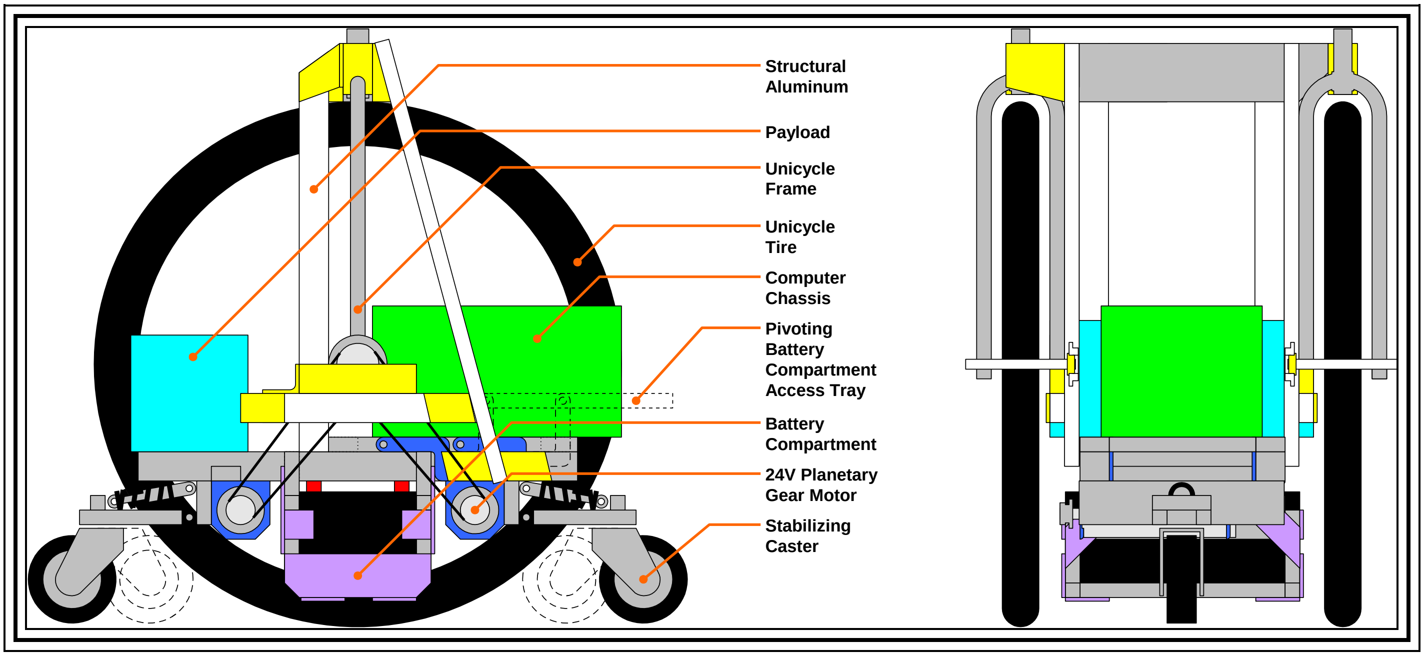


Figure 1 – Platform Mechanical Integration

4.1.1 Wheel Selection

The concept for the Culture Shock platform centered on the use of large diameter wheels with pneumatic tires, keeping in mind that these wheels should be narrow enough to minimize scuffing during zero-radius turns. Minimal platform footprint was considered a primary design goal to maximize maneuverability in the IGVC challenges, so wheels larger than the IGVC minimum platform length of 36 inches were not considered. An extensive search and tradeoff analysis determined that a wheel and tire produced by Coker Tire to be the best match. These wheels and tires, however, are available only as components of bicycles or unicycles sold by the company. After some in-depth research of these options, it was decided to incorporate two of these unicycle frames directly into the platform physical structure (as COTS), as this conveniently addressed a number of challenging aspects of the mechanical design. Specifically:

- The unicycle frames are designed to support more than 200 lbs. each. The pair provide more than enough capacity to support platform frame, electronics, payload and foreseeable future expansion possibilities.

- Complex issues relating to the mounting of the wheels as well as side loading have already been addressed by the manufacturer.
- The unicycles provide a ready-made propulsion interface for driving the wheels. Analysis shows that the torque required for anticipated platform maneuvers does not exceed that required for human-powered unicycle operation. The foot-powered cranks were removed and replaced with a custom-made chain sprocket adapted for the purpose.

Mechanical design was finalized only after the unicycles were delivered, as detailed dimensional characteristics were not available from the manufacturer. To ensure that the performance and reliability characteristics of the unicycles were not compromised, a means was devised to incorporate the unicycle frames without modification into the Culture Shock II platform structure. On each unicycle frame, a single bearing support was replaced by a machined aluminum bar in order to provide a robust and stable attachment point for the remaining platform components.

To facilitate development and testing in both indoor and outdoor environments, a design requirement for the platform was that it be capable of maneuvering through a standard size doorway (without removing the door from its hinges). This requirement in consideration with the overall width of the unicycles constrained the maximum width of the vehicle carriage, which in turn influenced carriage structure as well as selection of batteries and computer system chassis.

4.1.2 Drive Train

The large-wheel design requires substantial torque at the axle to move the platform. Direct connection of motors to the drive axles was considered, but discarded in favor of a design that would move the considerable weight and volume of the motors below the main carriage, providing a more stable configuration as well as freeing up space for electronics. Preliminary analysis showed that a gear motor would be required, even if a large sprocket were used for the interface to the drive axles. A survey of available motors led to the selection of high-torque 24V planetary gear motors. For convenience, these motors were ordered with integrated encoders and brakes. Chain sprocket ratios were determined that would achieve the maximum speed allowed by the IGVC competition at the maximum continuous rated power and load for these motors. To reduce space claim, weight, and cost, the smallest chain sprockets that achieved this ratio were selected. From this, maximum chain loading was calculated. To handle the considerable forces involved (including a large safety margin), 40-pitch chain was selected for the drive train.

4.1.3 Motor Controller

The motor controller selected is the AX3500 model manufactured by RoboteQ, Inc. Selection of this motor controller is based on its performance and drive characteristics, configurability, safety features, speed limiting capability, and sensor integration (particularly, the built-in encoder interface).

4.1.4 Frame Construction

To provide maximum design flexibility, T-slotted structural aluminum was selected for frame construction. This allows the design to be modified and adjusted when necessary, as well as being amenable to field repair. This approach also provides great flexibility in sensor selection and placement. Angle aluminum was machined as necessary to provide highstrength joins between the structural components. As a result, this vehicle has no welds other than those already present in the manufactured components and those made to adapt the chain sprockets to crank drive. It is worth noting here that the selection of T-slotted structural aluminum was a crucial factor in being able to easily adjust carriage height in response to the platform clearance failure of the 2009 IGVC competition.

The design process for the frame was iterative and dovetailed with the selection of various vehicle components, resulting in tight integration of vehicle systems. Constraints on design report length prevent each design decision and tradeoff to be detailed individually, but those considered most significant are discussed. Emphasis was placed on achieving a lightweight, structurally sound platform with a low center of gravity while providing ample room for sensors and electronics. A modified A-frame concept (selected for structural integrity) accommodates the lateral placement of the payload (which fits snugly between the wheels and counterbalances the computer system).

4.2 Electrical Power and Emergency Stop Subsystems

Battery selection was constrained by the space available in the battery compartment, which is situated low between the the main wheels. The power requirements of platform call for a 24V source for propulsion and a 12V source for the remaining subsystems. Ultimately, three identical 12V deep-cycle AGM (gel) batteries were chosen as power sources, each having a 33 amp-hour capacity. Two of these batteries are connected in series to provide the 24V required by the propulsion motors and fail-safe brakes. The third battery provides power to the remainder of the platform. Access to the battery compartment and fuse box is obtained by moving the computer system up-and-out by means of a pivoting tray. (Offset arms pivot and then support the computer system in the access position.) Battery charging is achieved through the use of polarized connectors mounted to the sides of the battery compartment.

The power supply of the main computer is driven directly from the 12V source, and was selected to have sufficient spare capacity to provide power to all anticipated external devices and sensors as well as having reserve for expansion. (A convenient side-effect of this arrangement is that the computer power switch became the power switch for the entire platform.) The wide selection of available voltages from this power supply, coupled with careful selection of sensors and peripherals allow this platform to operate without the typical AC inverter. This results in lower complexity, higher reliability, and savings of power, weight, space, and cost.

The emergency stop circuitry is integrated with the power control circuitry and provides multiple status indicators of the emergency stop and power subsystem states. Circuit design is based around four relays, as seen in **Figure 2**, which shows the realized implementation. Provisions are made for status indications of main system power, failsafe brake status, emergency stop activation status, system ready status, and motor controller power status. The circuit board provides screw-type connectors for main power, the emergency stop switch, the wireless emergency stop device, the motor controller power control input, and all status indicators.

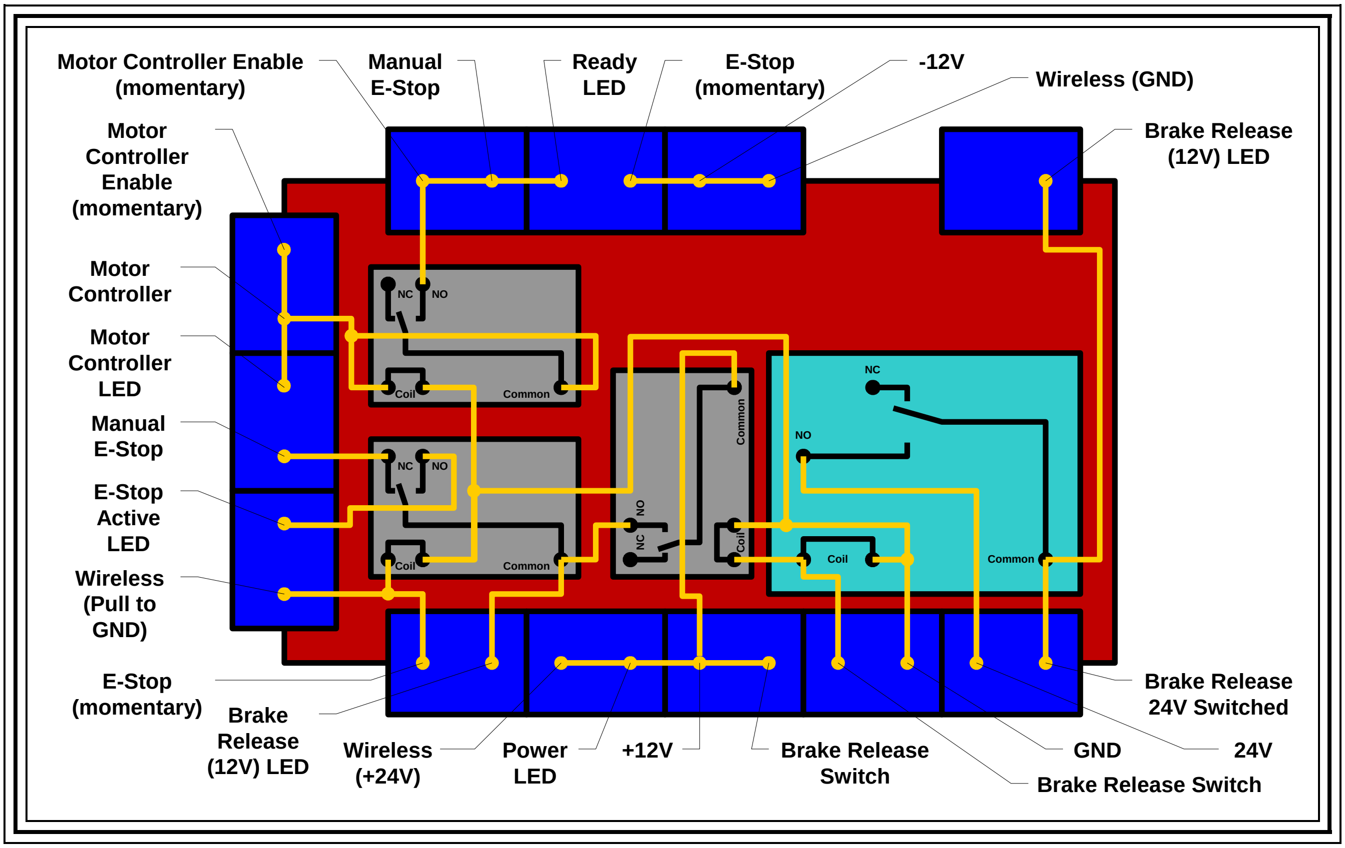


Figure 2 - Emergency Stop & Power Control Circuit Design

The wireless portion of the emergency stop subsystem requires a supply voltage between 18V and 30V. For safety purposes the -12V and +12V voltages available from the power supply are used to power the wireless receiver. As a result, the wireless emergency stop will work as long as the power supply is on. (When the power supply is off, the fail-safe brakes are always engaged.) Had the 24V propulsion power supply been used for this purpose, the wireless emergency stop would have been rendered useless when battery voltage dropped below the device threshold.

4.3 Sensors

Sensor selection for Culture Shock II began with identification of the types of information necessary to perform the challenges. The following table summarizes the data requirements and possible sensors that provide the data:

Data Required	Challenge(s)	Possible Sensor(s)
Platform Pose	Autonomous, Navigation, JAUS	Dead Reckoning, Compass
Geolocation (Lat/Lon)	Navigation, JAUS	Dead Reckoning, GPS
Solid Obstacle Detection	Autonomous, Navigation	LIDAR, Acoustic, Camera
Surface Obstacle Detection	Autonomous	Camera
Lane Detection	Autonomous	Camera

As can be seen from the table, in most cases there is little choice for the type of sensor used in the acquisition of data. The principal decision to make is the selection of sensor for solid obstacle detection. A survey of LIDAR devices found alternatives that were either limited in detection capabilities (planar) or prohibitively expensive in terms of cost, power, or volume. Acoustic detection systems were found to lack resolution in their detection capabilities. Of the vision-based detection systems considered, single-camera systems lacked the inherent ability to distinguish between surface obstacles (painted on the ground) and solid obstacles. As indicated previously, the use of a stereo vision system was determined to be the right choice for the Culture Shock platform.

A number of stereo vision options were considered. Trade-offs included the cost and availability of hardware, the availability and performance of stereo vision software, camera field of view, and resolution of depth detection. Ultimately, a pair of STH-DCSG-6cm systems was ordered from Videre Design. A primary consideration in the selection of this unit was the inclusion of usage rights to a highly optimized and configurable stereo vision software package with the purchase. These stereo vision algorithms correlate data from two simultaneously-captured images to construct an array associating a distance value to each pixel in a combined image.

For the GPS sensor, the SMART-V1-2US-VBS antenna from NovAtel was selected. This unit was selected for its integrated package, small size, compatible power requirements, and ability to accept GPS corrections from a variety of sources. These include satellite based augmentation services (SBAS) such as CDGPS and OmniSTAR. The Culture Shock II platform is currently configured to use the OmniSTAR service for differential correction.

In addition to information provided by the GPS, platform pose information is derived using an electronic compass and wheel-rotation information obtained via quadrature-type encoders integrated with the propulsion motors. The electronic compass selected is the TCM3 manufactured by PNI Corp. This compass is new for the Culture Shock II platform, with improvements in accuracy and sampling rate over the 2009 Culture Shock platform.

4.4 Safety Devices

The Culture Shock II platform is potentially capable of inflicting serious injury in the event of malfunction or carelessness. To minimize the chances of such an occurrence, the platform incorporates additional safety features beyond the emergency stop functionality required by IGVC rules. Specifically, the platform incorporates warning devices to alert persons near the platform of its presence and potential for movement.

A USB-controlled relay board, the JSB-280-04 from J-Works, Inc. provides the means by which these warning devices are activated. These relays switch power to the GPS unit, the electronic compass, and the warning devices, all under software control.

5. Platform Software

The following paragraphs describe the software execution environment, the software development process, and the operation of the IGVC challenge software.

5.1 Processing Resource

The main computer is housed in a narrow-profile Micro-ATX computer chassis. The 2.4GHz quad-core processor provides ample processing power to handle the sensor data acquisition, sensor fusion (such as stereo image processing), planning, execution, and control functions of the platform with 100% room for growth. Robust I/O expansion cards (and associated drivers) provide high-reliability communications with peripherals. An 800x600 resolution touch screen provides the primary user interface for the platform.

A 40GB solid-state hard drive is new for 2010. This innovation provides improved vibration-resistance, with the added benefits of faster boot time and lower power consumption.

5.2 Operating System

The main computer uses Microsoft Windows XP Professional™ as its operating system. This choice was made due to its stability, the availability of device drivers for all sensor peripherals, and its support for multi-core processors. Both Windows Vista™ and Linux were considered as alternatives; neither choice was supported by all sensor manufacturers.

5.3 Programming Language

Where possible, the Java programming language is used for all new software development on the Culture Shock II platform. Other languages considered included 'C', 'C++', and 'C#'. Some of the considerations in Java's favor included portability, ease of use, rich development environments, and native support for threading and synchronization constructs. Concerns that Java would not be able to keep up with the processing requirements have shown to be unfounded.

5.4 Development Process

Before the original Culture Shock platform sensor suite was finalized, certain aspects of the software were already known. Primitive classes representing scalar measures (LatLong, Distance, Angle, etc.) were developed and tested. During this period of time, through past experience and a little trial and error, a development process took shape. It was recognized early on that this project had similar characteristics to open-source projects involving many individuals at multiple geographic locations; we looked to these projects for examples, both good and bad.

To begin with, we standardized our development environment amongst the team. The Eclipse platform was chosen for the interactive development environment (IDE), due to its many features and available extensions. Subversion was chosen as the source code version management tool due mainly to ease with which it can be incorporated into the Eclipse platform (via Subclipse – the Eclipse 'plug-in' for Subversion). For those pieces requiring an interface between Java and C++, the Microsoft Visual C++ 'Express Version' was used, primarily because it has no associated license fees.

As sensor selection progressed, acquisition software for those sensors were designed and coded. The software architect designed the interfaces, and handed these off to developers for subsequent coding and testing.

The Culture Shock II software takes advantage of the primitive and sensor-related classes developed on the Culture Shock project. For Culture Shock II software development, the software development tasks were broken into largely independent pieces. Interfaces between these pieces were defined as 'contractual' interfaces, requiring agreement among all stakeholders if changes were to be made subsequently. Implementation largely followed information flow through the system, beginning with interpreting and processing sensor inputs, and progressing through the various processing stages. This facilitated a ‘code-a-little, test-a-little’ approach, where each piece was integrated into the working system as it was developed, avoiding costly rework if an algorithm or approach was found to be deficient.

For Culture Shock II development, an ‘agile’ development paradigm was followed. Regular, short meetings were held to 1) track schedule, and 2) discuss project-related issues. Where development on a particular piece lagged schedule, the reasons for the slip were identified, and additional resources provided where necessary.

5.5 Simulated Platform

The robotic platform simulator developed for the 2007 IGVC competition was used during development of the original Culture Shock platform software. For the Culture Shock II effort, the simulator was largely unused, due to the platform being highly available coupled with the small team size.

5.6 User Interface

The Culture Shock II platform incorporates an 8” diagonal touch screen with 800x600 screen resolution. The Culture Shock II user interface software incorporates a new and innovative tabbed interface that allows the various functions of the platform to be logically grouped and presented independently. This is particularly useful for functions such as calibration that do not need to be performed often.

5.7 Challenge Software Design

Figure 3 shows a conceptual block diagram for the challenge-related software, with primary flows of data throughout the system represented as arrows with data processing and storage functions shown as boxes. The following paragraphs describe the various software components in detail, presented roughly in order of data flow from sensor acquisition to control outputs.

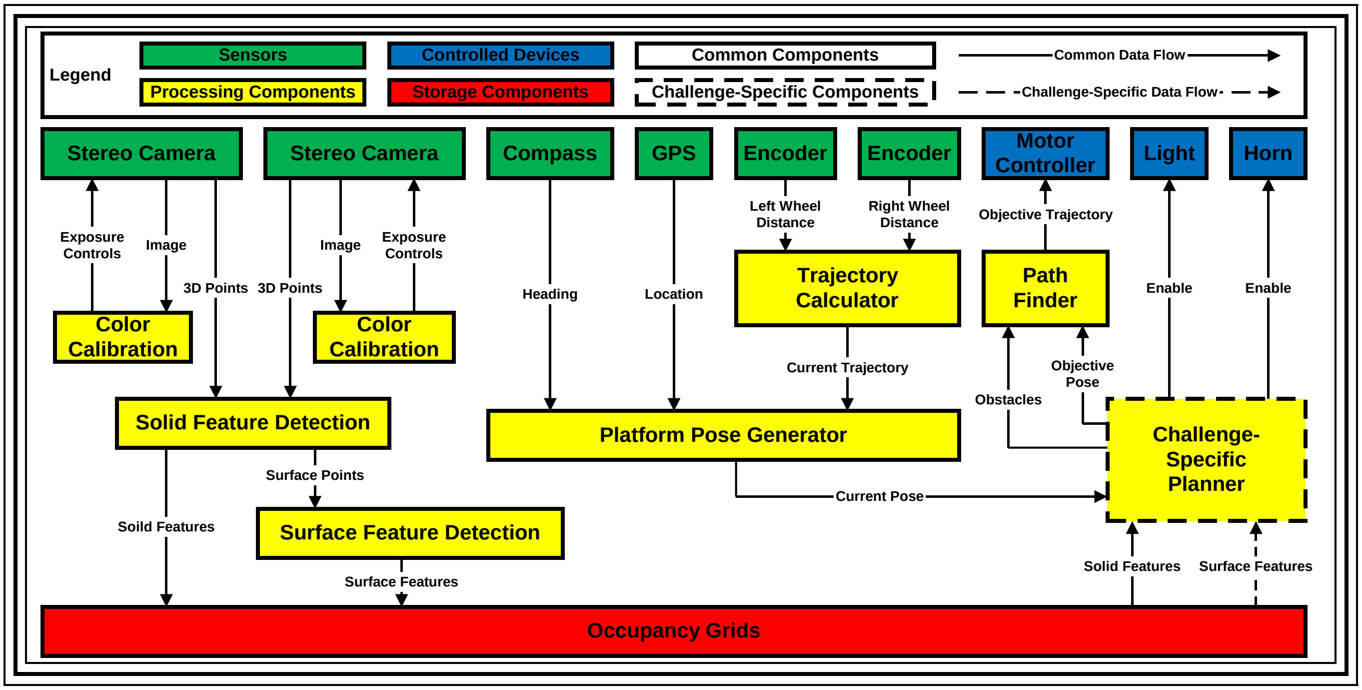


Figure 3 –Challenge Software Block Diagram

5.7.1 Stereo Camera Sensors

This component provides the low-level interface to the stereo cameras. Responsibilities include the acquisition of raw camera images and the correlation of these images into 3D points. Problems experienced in the 2009 Culture Shock platform were traced back to multiple software threads accessing the stereo cameras via the same stereo vision library DLL instance. A 2010 Culture Shock II platform innovation moves the acquisition algorithms into separate processes, avoiding the reentrancy issues.

The stereo vision library performs correlation on stereo image pairs. For those points that can be correlated between the images, 3D coordinates (in the camera coordinate system) for those points are derived. **(Figure 4** demonstrates the correlation process, using a false-color image to depict the distance of each correlated point from the camera.) These points are then transformed (via multiplication with an appropriate transformation matrix) into the platform coordinate system. The transformation matrix used is unique to each stereo camera and is determined during platform sensor calibration. Point data derived from any number of stereo cameras can be combined to form a detailed representation of the platform environment using this approach. The output of this component is the set of points as derived from the stereo camera. Each point includes the RGB color of that point in addition to the 3D platform coordinate.

Figure 4 – Correlation of Points in Image Pairs

5.7.2 Color Calibration

A new innovation for the 2010 Culture Shock II platform, reference color bars have been added to the platform structure such that they will occupy fixed areas in the camera images. During the calibration process these areas are identified to the color calibration component, which adjusts the camera exposure, gain, brightness, and color balance settings in an attempt to maintain constant color values in these areas. As a result, the images provided to the feature detection software are color-corrected, which in turn allows color-based discrimination of similar features.

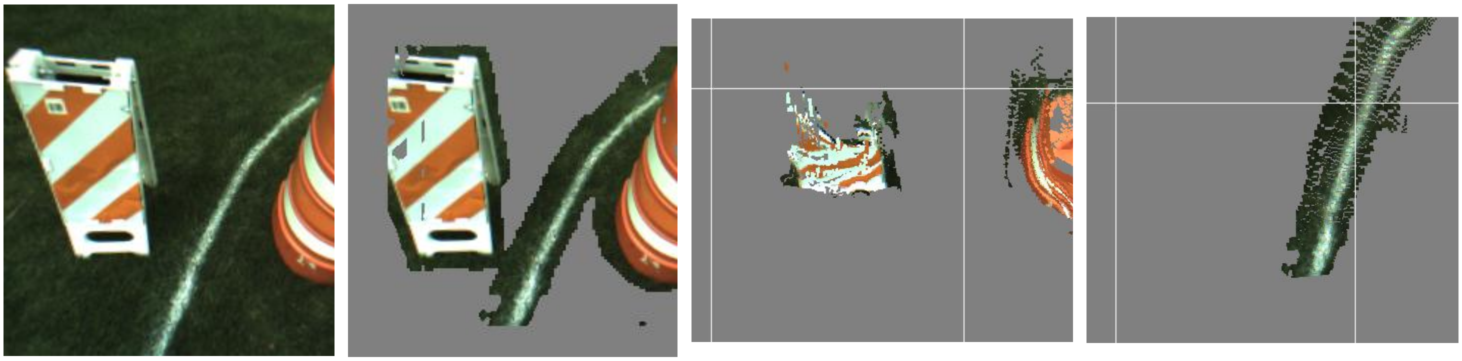
Note that cylindrical structures were selected for the color reference bars to minimize the possible effects of glare from reflected sunlight. Any such glare will occupy only a small portion of the color reference area in the image, and so will have minimal impact on the color correction algorithm.

5.7.3 Solid Feature Detection

The individual points received from the Stereo Vision Processing component are examined. Points with ‘z’ coordinate values above a configurable threshold value are classified as belonging to solid obstacles and are culled from the data set. Proximal points at surface level with similar color are considered to be part of the obstacle and are culled as well.

The output of this component is the points representing solid obstacles, and the set of points that do not represent solid obstacles.

This approach is depicted in **Figure 6**. Panel **a** shows the original image. Panel **b** shows the set of correlated points in the image (as seen from the camera). Panel **c** shows the overhead (x-y) view of the points identified as obstacles (the relatively high distortion of these points is due to the nature of the reflective surfaces of the obstacles – when using reflective tape, a single point can present different colors or intensities depending on the viewing angle, skewing the correlation results slightly. Panel **d** shows the points remaining after removing the solid obstacles from the point cloud. These points belong to surface features.



a b c d

Figure 5 – Extraction of Solid Obstacles from Point Cloud

5.7.4 Surface Feature Detection

The points that remain after solid feature culling are classified by color and grouping characteristics. The points representing features that exhibit obstacle characteristics (such as lanes or simulated potholes) are provided as output from this component. This component has been made more configurable to accommodate the introduction of new obstacles (and non-obstacles) into the competition.

5.7.5 Occupancy Grids

Two occupancy grids are maintained. Occupancy grids accumulate the information provided by the feature detection components, reducing the data to a form manageable by the challenge-specific planning components. Essentially, the platform X-Y plane is divided into squares, typically 4 to 6 inches on a side. The points obtained from feature detection algorithms are examined, and cause a counter associated with the corresponding square to be incremented. Squares with counters that exceed some threshold value are considered to be occupied by an obstacle, and therefore unavailable for occupation by the platform.

5.7.6 Compass Sensor

The compass sensor acquisition software underwent a complete rewrite due to the change in electronic compass. The new compass uses a binary-encoded message-based data stream with error detection, whereas the old compass used an ASCII-based data stream. The new format represents data values more densely, supporting the higher sample rates of which the new compass is capable.

5.7.7 GPS Sensor

The GPS sensor component acquires latitude and longitude information at regular intervals.

5.7.8 Encoder Sensors

The motors have integrated encoders that are connected into the motor controller. The encoder sensor software component queries the motor controller periodically to obtain cumulative motor rotational information, and by extension total distance traveled by each wheel.

5.7.9 Trajectory Calculator

Information derived from the encoders is used to derive the current speed and angular velocity of the platform, which we refer to as the platform trajectory.

5.7.10 Platform Pose Generator

This component monitors the GPS location and compass heading data to determine platform pose. During GPS dropout a best guess of platform pose is derived from compass heading data and current trajectory information.

5.7.11 Challenge-Specific Planners

Each IGVC challenge has a challenge-specific code component, as described in the following sub-paragraphs.

5.7.11.1 Autonomous Challenge Planner

To recognize lanes, the surface feature occupancy grid is examined for occupancy groups that have line-like characteristics. These groups are analyzed to determine their orientation, and the objective pose is set at some relatively distant point along this line. This objective pose, along with solid and surface features is passed to the path finder for execution.

5.7.11.2 Navigation Challenge Planner

This component maintains a list of waypoints and analyzes them repeatedly to determine the next waypoint to attempt to visit. This next waypoint is transformed to platform coordinates and provided to the path finder component as the objective pose. The starting waypoint location and the area immediately around it are provided as obstacles to the path finder component. The challenge boundaries are provided as obstacles to the path finder component. Surface features are not provided to the path finder component.

5.7.11.3 JAUS Challenge Planner

This component advertises its presence to the Common Operating Picture (COP), and then waits for commands from the COP until interrupted via the user interface. A transform is maintained that converts ‘local pose’ information into corresponding latitude and longitude information. Local waypoints provided to the Local Waypoint list driver are translated into latitude and longitude using this transform, and from there into platform coordinates, which are provided as the objective pose to the path finder component. Solid features are provided as obstacles to the path finder component.

5.7.12 Path Finder

This component works in the X-Y platform coordinate system. Obstacles that are provided from the challenge-specific planner are in the form of points as obtained from an occupancy grid. The path planner constructs a virtual 'buffer zone' around each of these points with a radius of slightly greater than two feet (the distance at which Culture Shock II can be guaranteed not intersect the point). The area inside each of these buffer zones is considered off-limits for path planning purposes. Given these constraints, the path finder then looks for a path that can best approach the objective pose as provided by the challenge-specific planner. In the event that no path can be found that makes progress toward the objective, the path planner enters a wall-following mode. In this mode, the outline of solid obstacles is followed until either significant progress can be made toward the objective, or a lane feature is encountered, in which case the direction of the wall-following mode is reversed (from left-handed to right-handed, or vice versa). **Figure 6** demonstrates normal path finder operation. The objective pose is represented by the yellow X, and the chosen path is represented by the blue arc.

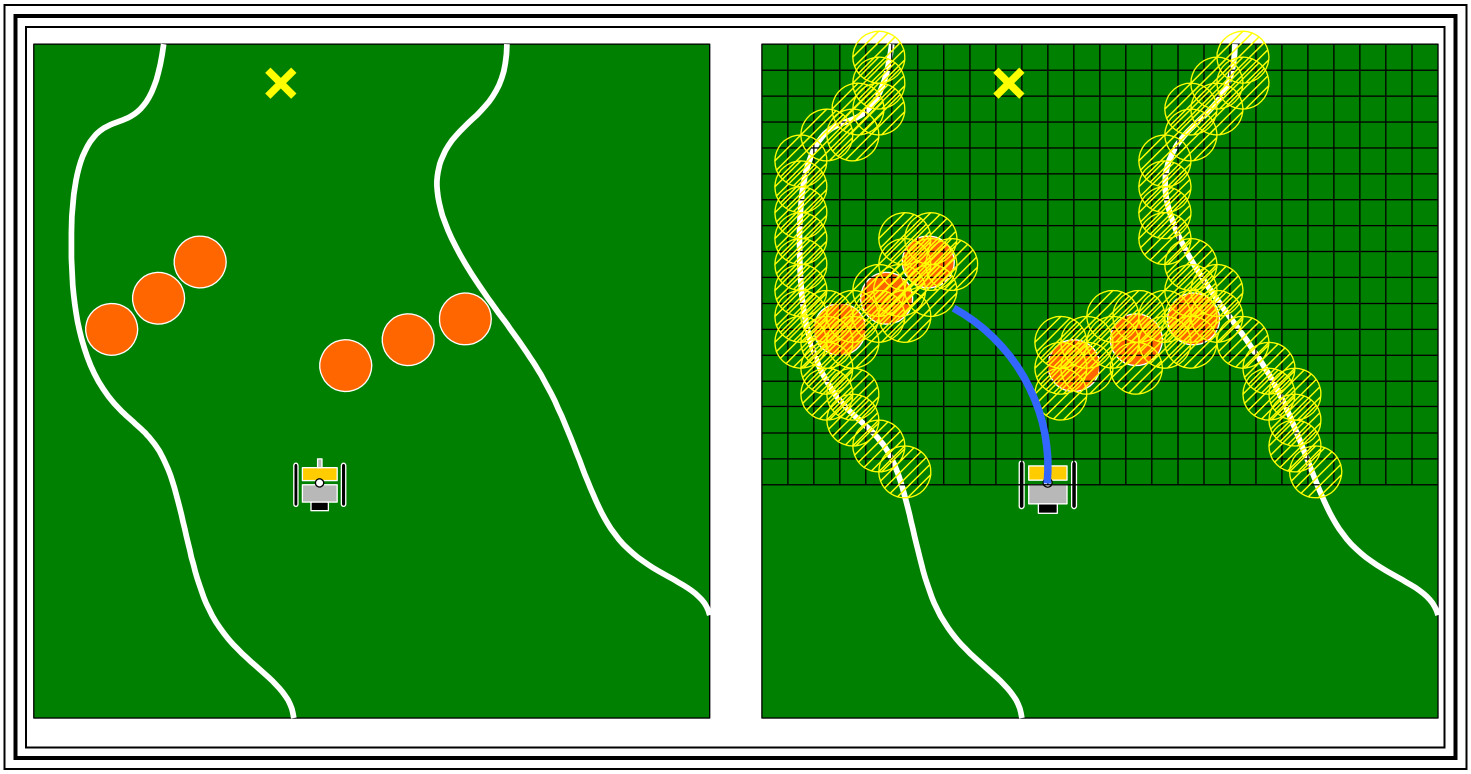


Figure 6 – Path Finder Operation

5.7.13 Motor Controller Device

This component communicates with the motor controller, sending rate commands to control motor speeds. The motor controller is configured via an external setup program to run in PID feedback mode and to limit motor speed to the maximum allowed for the competition. In this configuration, the motor controller limits the motor speed automatically.

6. Predicted Performance

The following points describe predicted performance and the methods used to determine these numbers.

- **Speed –** Propulsion system design and component selection were undertaken with a goal of achieving the maximum allowed speed of 5 miles per hour under load. This top speed is enforced by setting the motor controller into a PID feedback loop configuration, and by adjusting the encoder scaling parameters appropriately.
- **Ramp climbing –** Propulsion system design and component selection were undertaken with a goal of performing at top speed on a 15% gradient, the specified maximum under IGVC rules. Performance to this goal has been verified in trials.
- **Reaction times –** The vision system achieves a sustained throughput of 15 frames per second for each camera. Based on an analysis of latency in acquisition, processing, and communications paths, it is estimated that an obstacle presented within the field of effect will affect motor speed in 90 +/- 25 milliseconds.
- **Battery Life –** Battery life is highly dependent upon the operational environment. In a quiescent state with failsafe brake disabled, the 24V battery life is estimated at 10 hours. Under continuous load, the 24V battery life is estimated at 2 hours. The 12V battery life is estimated at 3 hours under full processing and sensor load.
- **Obstacle Detection Distance –** This is configurable via parameters to the stereo vision processing software. Detection is presently limited to 6 meters.
- **Complex Obstacle Negotiation –** Switchbacks will be handled inherently by the path finding algorithm, described in the software design section. In the case of traps, the path planning algorithms switch to a wall following mode, reversing direction when a lane feature is encountered.
- **Navigational Accuracy –** The geolocation equipment used is capable of sub-meter accuracy when used with satellite- or earth-based augmentation. Culture Shock II employs satellite-based augmentation and is presently configured to use the OmniSTAR service for differential corrections, which after settling typically achieves a standard deviation of 0.3 meters or less.

7. Cost Data (in dollars)

Mechanical / Propulsion		Sensors		Processing / Electrical	
Unicycles	1,070	Stereo Cameras	1,755	Computer System	1,000
Chain & Sprockets	110	GPS System	1,760	Power Supply	250
Aluminum/Steel Stock	1,150	Compass	775	E-Stop System	100
Miscellaneous Hardware	250	Motor Controller	410	LED Beacon	55
Batteries	265			Touch Screen	315
Motors	1,790			Laser Diodes	85
Shocks & Casters	120			Misc. Electrical	200
				TOTAL	11,460

8. Labor Data (in man hours)

Mechanical		Electrical		Software	
Design	120	Design	80	Device Interfaces	160
Fabrication	200	Component Selection	40	JAUS-Specific	320
		Integration	60	Algorithm Development	480
				Administrative	200
				TOTAL	1660