Design Report

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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.

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Dr. Alexander Leonessa, Advisor

1. Introduction

You demanded it, we designed it. Extensive cross-market analysis shows customers demand rugged, sleek, and powerful robots built to excel at difficult-to-navigate IGVC (Intelligent Ground Vehicle Competition) courses. The Robotics Lab, a research division of the UCF (University of Central Florida), is proud to introduce Gamblore™ LX 500, the newest line in autonomous ground vehicles. Built and hand-tuned for maximum performance at any IGVC task in rain, shine, or sleet, the Gamblore™ LX 500 sports a specialized, weather resistant chassis capable of handling a wide variety of missions. With its patent-pending technologies, Gamblore's innovative hardware systems and effective software solutions will not fail to disappoint at this year's IGVC.

2. Design Planning Process

Working on a project as complex as a robotic platform, planning is essential to avoid poor or limited designs that result in wasted time and unsatisfied customers. Understanding the importance of proper and unrushed design, all major components were discussed and planned with the whole team present. By bringing together insight from all disciplines, the best high-level design for electrical, mechanical, and software subsystems were developed. Likewise, minor components specific to a subsystem were designed with the corresponding sub-team as long as it met the larger high-level design. Through this approach, each subsystem was constructed individually with the assurance of it integrating as a whole.

2.1. Validation 'V' Design Paradigm

The design paradigm that served as an inspiration to our design planning process is the Validation V [1]. A flexible and iterative design paradigm, the Validation V optimizes the parallel development of a project by various sub-teams or groups. Three groups were formed to handle a specific subsystem of the vehicle: mechanical, electrical, and software. Each group followed the standard design procedure stages: requirements, design, build, test, and ship. Visually represented as a 'V', synchronization between teams forms a 'W' as each group works independently to contribute to the overall design of the project. To further enhance parallelism, the design was purposefully made modular.

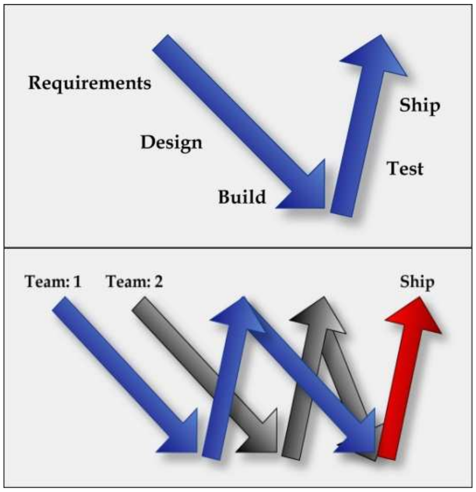

Figure 1: Parallel 'V' groups become a 'W'

2.2. Documenting & Contributing to the Robotics Community

An additional effort to document designs was undertaken, especially software components that may be reusable in a wide variety of applications. The team created a website with a wiki at http://zebulon.sf.net so any member could contribute. Through the design planning process, the team utilized this site to create a resource-laden source of designs, tutorials, solutions to oft-encountered problems, software packages, and documentation. Furthermore, all software programmers on the team use the commenting standard Doxygen so clear and consistent documentation for all software systems can be published. In addition to providing new team members a great place to start learning, this contributes back valuable resources to the robotics community. A testament to its success is the number of other projects (both at UCF and the wider community) that have used the resources available there.

2.3. Gamblore Team Structure

The Gamblore team consists of five volunteer UCF students in computer, electrical, and mechanical engineering disciplines formed into three groups focusing on one of the vehicle's subsystems. Special emphasis was placed on cross-training so team members could easily assist wherever needed most.

Computer		Electrical		Mechanical	
Brian C. Becker	400 hrs	**Daniel Barber**	250 hrs	**Rick Porter**	300 hrs
Daniel Barber	250 hrs	**Brian C. Becker**	25 hrs	**Shane Bell**	200 hrs
Jon Carbone	100 hrs	**Jon Carbone**	25 hrs	**Daniel Barber**	150 hrs

3. *Mechanical Subsystem*

The team spared no effort to ensure customers' satisfaction with the vehicle's mechanical aspects, both aesthetically and functionally. With the aid of a concept artist, several different chassis designs were evaluated before a panel of representative customer analysts. Through their decision, the Gamblore™ LX 500 sports a styled frame with sharp, clean lines trimmed in black to exude confidence and poise.

3.1.1. Frame Design

The first part in creating the chassis was to design a suitable frame. The frame is the core of the structure, serving as a mounting point for all components. A good frame needs to be both lightweight and rugged. The main reason the weight of the vehicle needs to be minimize is to lessen the amount of torque required for the motor to move the vehicle. Reliability is the main

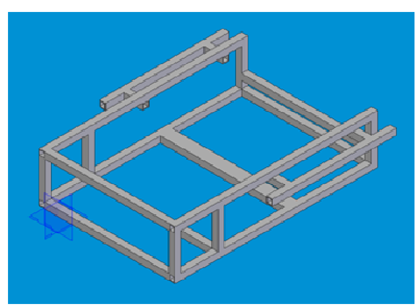

Figure 2: Basic frame CAD

reason for a rugged frame as the frame needs to be able to withstand not only the weight of all the components but the addition of a payload. If the frame is not sturdy enough it will not survive over rough terrain. A basic frame was designed using Solid Works, as seen in Figure 2.

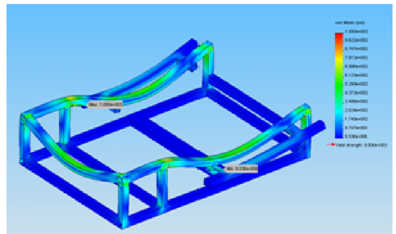

Figure 3: Frame max stress

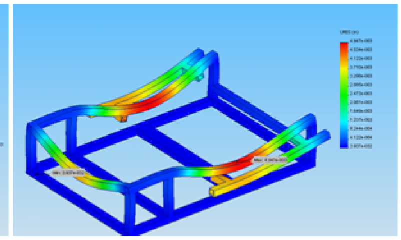

Figure 4: Frame max displacement

Once this initial model was created, a FEM (Finite Element Method) Analysis was performed to see where the max stress and deflection points where, as can be seen in Figure 3 and Figure 4. The frame was restrained from the bottom and a force of 250lbs (the estimated load at that location on the vehicle, with a safety factor of 0.5) was applied to the top. Once the Max Stress/Displacements points where found, it was determined that a redesign was needed. Additional support beams were added to minimize the deflection and stress in the key areas. The new frame can be seen in Figure 5. Once the design of the frame and been completed, it was necessary to find a suitable material that was readily available to construct the frame. A low density metal with a yield strength that meets the requirements found from the analysis was needed. The material best suited was Aluminum 6061.

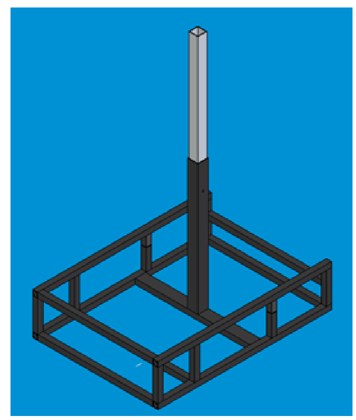

Figure 5: New frame CAD

3.1.2. Drive Train

The next step was to design the drive train for the platform. Two Ranger II power wheelchair motors where used to drive the vehicle. These motors where mounted upright and connected to a ¾'' keyed shaft via a custom mad aluminum coupling. The shaft was then modified to allow a 16" diameter Skyway wheel to be attached. Once the layout had been determined, it was then necessary to test the design, to ensure the shaft would not bend while in use. This was done by once again creating a model in Solid Works. This model was tested, having the restraints placed at the end of the shaft and a load of ½ the vehicle was placed on the coupling end to simulate the weight of the vehicle. The maximum

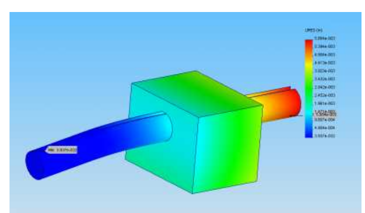

Figure 6: Drive train stress

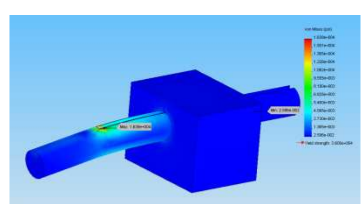

Figure7: Drive train displacement

stress and displacement can be seen in Figure 6 and Figure 7. The material used for the shaft was a high carbon steel that met the Stress and Displacement requirements.

3.1.3. Fabrication

As the design step was completed, it was then necessary to begin the fabrication process. The entire vehicle was constructed from 1/8'' plate, 1'' box and 16 Gage sheet. The core part of the structure was welded while the remaining components were riveted and bolted together. Various platforms to mount key electronic components were created in the back of the vehicle for weather resistance and easy accessibility. In addition to sensor mounting, a caster wheel was placed in the rear of the vehicle. Final CAD drawing can be seen in Figure 8.

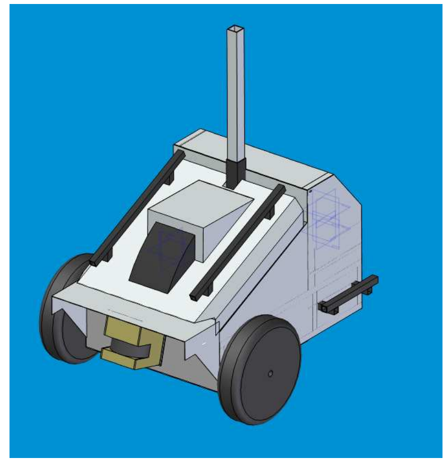

Figure 8: Final CAD

3.1.4. Innovative features

The Gamblore™ LX 500 incorporates many new mechanical innovations for the sole purpose creating a more powerful robot with a simple, yet elegant design. For ease of lifting, carrying, and storage, handles are available on either side of the vehicle. The multi-level drawer system that houses the computer, sensors, and electronics are mounted on sliders for easy access. The back caster wheel has a polymer that acts as a shock absorber to help stabilize the vehicle over rough terrain, thus enhancing image quality and reducing jarring on electronic equipment.

4. Electrical Subsystem

Gamblore's electronics are state-of-the-art and grouped into power distribution, electronics, and sensor.

4.1. Power Distribution

Gamblore's power is provided from two 55 Ah 12 V batteries connected in series to create a 24 V power supply. From this single source, power is routed to the motor controller, DC-to-DC converters, and a DC-to-AC inverter to power all onboard electronics. The 24 V-to-24 V DC-to-DC converter provides regulated power to the SICK LIDAR, and the 24 V-to-12 V DC-to-DC converter is used to power the Mini-Max DGPS and Microstrain

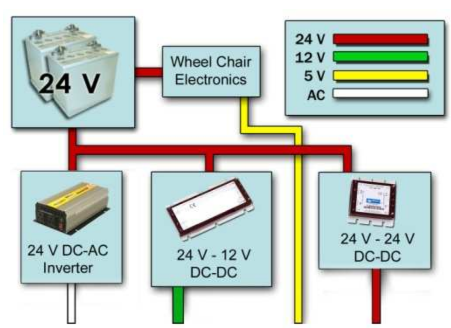

Figure 9: Power distribution

inertial measurement unit (IMU) sensors. The 24 V DC-to-AC inverter is used to provide AC power to the computer, wireless access point, and cameras. The Roboteq AX3500 motor controller is powered directly from the batteries and supplies power to the motors. Main power is engaged using a toggle switch to activate three 24 V 30 A relays. With the relays in place, the manual emergency stop button breaks toggle switch by cutting all power to the vehicle.

4.1.1. Innovative Features

After receiving feedback from previous end-users and customers, easy to use charging capabilities were added to Gamblore. A 24 V charger has been placed on board in addition to new AC power switching capabilities. By plugging in an extension cord to an AC outlet on the side of Gamblore, the battery charger is enabled and all AC devices switch from the DC-to-AC inverter to being powered from the extension cord. This allows the end-user to easily re-charge the vehicle or perform testing of the platform in a way that conserves battery life.

4.2. Electronics

Providing solid closed-loop operation of motors was critical component when constructing the electronics of Gamblore. The AX3500 motor controller board is a COTS product from Roboteq used to achieve this goal. The AX3500 contains an encoder module for closed-loop speed control using 2500 pulses per revolution (PPR) optical encoders, and can provide up to 30 A per motor. Two interfaces are supported for operation of the motors: RC/Analog and RS-232, allowing remote and computer control respectively. Using the serial interface, the onboard computer can set the velocity and rotation rate of the vehicle with high precision. The RC interface to the AX3500 also supports emergency stop operations. This mode is activated using Gamblore's 6-channel Futuba remote control, causing power to the motors to be cut, which also engages a physical brake built into the motors.

On top of Gamblore in clear view of observers is a blue strobe light. A Basic Stamp microcontroller is used to turn it on and off. The computer can send a message to the microcontroller over RS-232 to turn the light on and off. The light is used to display warning or emergency stop information to operators.

The main computing platform for running autonomous behaviors on Gamblore is an Alienware Area-51m 7700 desktop replacement notebook running Microsoft Windows XP Pro. With an Intel Pentium 4, 3.4 GHz Process with Hyper-Threading Technology and 2 Gigabytes of RAM, the computer is more than capable of running path-planning, vision systems, and other software using its RS-232/422, USB, and FireWire interfaces.

4.3. Sensors

For maximum performance, Gamblore is equipped with only the best and most efficient sensors for both obstacle identification and vehicle positioning, including a SICK laser, compass, GPS, and encoders.

4.3.1. Obstacle Identification

A SICK brand LMS-291 LIDAR obtains 2D object placement information up to 30 meters in front of the vehicle in a full 180° sweep. Transmitted to the computer via RS-422 at 500 kbps, the exact placements of obstacles are received in real-time at a rate of 20 Hz. Also extracting object placements are the two Panasonic PV-GS 180 digital video camcorders mounted in the front of the vehicle. Capturing video at 720x480 resolution at 30 Hz, the 3CCD cameras provide high quality color and white balance features for ideal object recognition in a wide range of lighting conditions.

4.3.2. Vehicle Positioning

For locating GPS waypoints, a Hemisphere Mini-Max DGPS connects to the computer over RS-232 and streams back sub-meter accurate differential GPS positions at a rate of 5 Hz. Latitude and Longitude information from the DGPS is converted to Universal Transverse Mercator (UTM) System. UTM provides a cylindrical projection in meters, which is highly accurate for use in waypoint finding. For heading determination, a Microstrain 3DM-GX1 inertial measurement unit (IMU) calculates compass yaw, pitch, and roll at 70 Hz with filtering. Like other sensors in the system, it connects to the computer via RS-232 at 19200 bps. Two EM1 optical encoders with 2500 Pulses Per Revolution (PPR) mounted to the motor shafts connect to the AX3500 Roboteq motor controller for maintaining velocity/steering commands. Since the Roboteq is connected to the computer over RS-232, encoder information can be requested to allow the computer to perform dead-reckoning. From these three sensors and a model of vehicular motion capabilities, a Kalman filter is used to combine and optimize the position of the vehicle. In the event of lost GPS signal, position updates are replaced with the dead-reckoning until the return of GPS.

5. Software Subsystem

The software systems control all aspects of the vehicle under autonomous mode. Through expert programming, intelligence is instilled into Gamblore, allowing it to autonomously perform all tasks of the IGVC. In order to pass on savings to the customer and to increase customer satisfaction at the efficiency of the software, expensive solutions such as LabVIEW and MatLab were rejected in favor of patent-pending technologies developed in-house. After a cost-benefit analysis, the cost of software licenses vs. using free student labor showed the numerous benefits of in-house development.

Furthermore, existing solutions did not afford the team the modularity and low-level control to program a software system of unmatched quality. To reach full potential, all software was implemented in C++ or the powerful programming language BASIC, in the case of the microcontrollers. C++ was chosen because real-time execution is necessary for many of the robotic systems. To avoid some of the typical complexity problems associated with C+++, strict object-oriented development and Doxygen commenting standards were followed, resulting in high quality, reusable, and maintainable software.

If the customer desires to modify the behavior of their Gamblore LX 500 robot, a special C++ API is provided, referred to as Zebulon. What is Zebulon? It is a road in Georgia a few students from the Robotics Lab at the University of Central Florida drove by on the way to a robotics competition. They thought, "What a great name!" and then named next year's code base after it. So in this case it is a set of libraries, tools, and documentation created by the Robotics Laboratory at UCF to aid in the development of different robotics projects. Zebulon provides Gamblore with the default, factory settings suitable for competition in the IGVC. Since Zebulon is an open-source project freely available on SourceForge, a customer may use Zebulon to completely customize how their Gamblore robot behaves.

Figure 10: Zebulon road & codebase

5.1. Modularization

To decrease unnecessary complexity and increase understandability, efforts were made to modularize the software systems. As such, the team used a multi-tiered client/server fan-in approach. Each tier was designed to be independent of the other and could be replaced completely, allowing the end customer flexibility in their choice of sensors and utilizing additional software systems. At the top of the tier, the SICK laser and camera sensors collect high-level information about the environment, such as obstacles locations. This data is served as a continuous stream to the Vehicle Behavior And Motion Control (VBAMC) module at the middle level. VBAMC performs path planning and decides how the vehicle should behave. Behavioral information is subsequently passed to the lowest tier, ARPGUI (Autonomous Robotic Platform Graphical User Interface). ARPGUI consolidates the low-level sensors DGPS, encoders, and the compass and controls the motors to achieve the behavioral motions.

5.2. ARPGUI (Autonomous Robotic Platform Graphical User Interface)

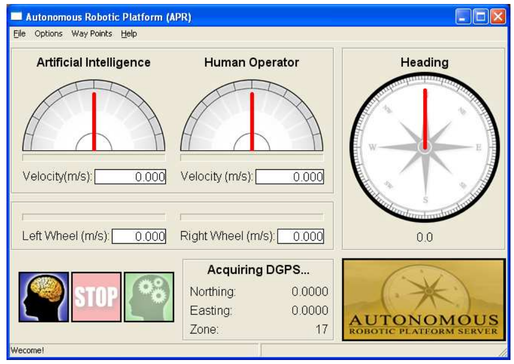

Figure 11: ARPGUI interface

At the lowest level on the lowest tier, ARPGUI performs two main functions. First, it represents a base system for collecting, managing, and displaying general robotic platform control. Secondly, through advanced shared memory technology, it provides an interface for 3rd party expansions to manage the movement and behavior of the vehicle. External programs can send vehicle velocity and steering commands to the ARPGUI without the hassle of interfacing directly with motors or maintain positioning information. To accomplish this, ARPGUI connects to the DGPS, compass, encoders MCU, the BASIC-STAMP microcontroller, and the Roboteq motor controller. Each connection to a sensor runs in a background thread. For ease-of-use and extra reliability you can depend on for critical missions, each sensor has built-in auto-connect in case the connection is lost. All information is communicated through the extremely efficient and swift technique of shared memory.

For precise positioning, a Kalman filter combines localization information from the encoders and the DGPS with a model of vehicular movement. In conjunction with the auto-reconnect features, the Kalman filter allows Gamblore to perform even during periods of intermittent DGPS loss by relying on dead-reckoning. As an added bonus to the customer, ARPGUI displays the current heading, position, and velocity of the vehicle, as well as the mode of operation (Autonomous, Manual, or E-Stop). This allows the user to quickly determine the status of any sensor. Settings for the sensors can be changed through a quick and easy click of the built-in menus. In this, ARPGUI successfully frees the VBAMC from having to directly interface with various low-level sensors and vehicle actuators.

5.2.1. Driver

The driver program is responsible for ensuring the vehicle maintains the correct velocity and steering. Receiving drive commands from the VBAMC as part of ARPGUI, the driver converts velocity commands to RPM values the Roboteq motor controller can understand. Steering is accomplished with a closed-loop feedback PID controller comparing the current compass angle to the desired compass angle. Finally, the driver monitors the movement of the vehicle to determine if the vehicle is stuck. If stuck, one of several strategies is used. If the vehicle cannot rotate, a small forward or backward velocity is added to start the vehicle moving. This is vital when turning in thick grass or loose dirt. If the vehicle cannot travel forward, it will reverse along the previous trajectory and attempt the same path (if clear) at a higher velocity to get through difficult terrain.

5.3. VBAMC (Vehicle Behavior And Motion Control)

At the middle tier handles controlling how the vehicle behaves under autonomous control. Behavior, including motion planning and obstacle avoidance, is performed in the VBAMC (Vehicle Behavior And Motion Control) module. VBAMC uses the high-level tier sensors (SICK laser and cameras) to determine the most appropriate behavior for the current situation. Once VBAMC decides which behavior to use, the corresponding vehicular motions are sent to ARPGUI for execution. VBAMC uses several different path planners based on the environment and goal of the mission. Individual path planners are described in detail later. Through the GUI provided by VBAMC, the current paths and behaviors selected are displayed. Furthermore, configuration settings for individualized path planners can be accessed and set through the GUI.

5.3.1. Cartographer

Gamblore's cartographer map building module is based off the highly acclaimed 3D geometric (non-pixel based) mapping featured found in previous year's line Calculon. By avoiding the time and CPU intensive inefficiencies of storing obstacles as pixels and analyzing maps through image processing techniques, the mapping process becomes much faster. Using a mathematically rich mapping system, each obstacle type is stored symbolically in a partitioned 3D space. During path planning, checks to see if an area is "safe" (i.e. the space is unoccupied by obstacles) are performed in local grid cells of partitioned 3D space by the use of geometric formulas. This approach, combined with ignoring empty cells and cells outside the search area, minimizes search times to a factor of 10X. Both a world and local map can be populated through high-level sensors and made available to the path planning algorithms.

5.3.2. Navigation Challenge Path Planning

While the customer can easily use the Zebulon API to program a path planning algorithm using the existing components and maps automatically generated, Gamblore by default uses potential fields as a method to navigate to GPS waypoints. Destination GPS points are read sequentially from a file and added to the map as strong positive forces (represented in Figure 11 as blue). Obstacles are as weak negative forces (represented in red) with a

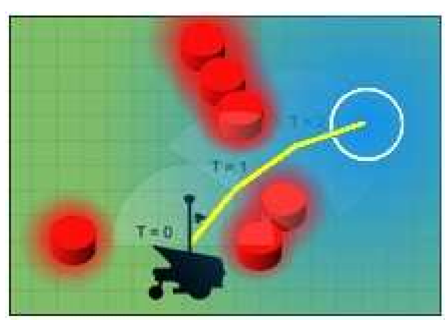

Figure 12: Potential fields (blue is attraction and red is repulsion)

non-linear, piecewise repulsion field that acts weakly at far distances and approaches infinity as the distance between the vehicle and the obstacle approaches zero. The path planning algorithm of potential fields simulates the vehicle as an electron moving through the attractive forces of the GPS waypoints and the repulsive forces of obstacles. As the vehicle travels, it leaves behind small "I've been here" point droppings that are weakly repulsive, discouraging backtracking it in the face of alternative options, yet still allowing this option if necessary. This avoids infinite loops and wavering when a wall is seen. Potential fields path planning is continuous, striking a balance between efficiency and safety based on field strengths, and reacts smoothly to the addition and shifting of objects, making it ideal for path planning to DGPS waypoints.

5.3.3. Autonomous Challenge Path Planning

Because of the different format of Autonomous Challenge and the additional difficulties of lane following, Gamblore utilizes a different path planning algorithm. First, lane lines are identified and stored differently than normal obstacles. They are sorted into right and left lane lines based on the vehicle and line orientation and used to calculate the direction and center of the lane line. These values are updated when lane lines are seen and preserved in the case of dashed lane lines. For path planning, it was found a curve weighted A* path planner was best suited for the unique problems found in Autonomous Challenge. Based on the vehicle's current position, the curve weighted A* path planner incrementally builds a tree of successive curved paths that cover the area in front of the vehicle. Each curved path is evaluated primarily for distance traveled and safety, but also for tendency to travel towards the calculated center of the lane and whether the path crosses over previously traversed areas. Custom weights is used to evaluate all paths and select the path that best balances all these features to stay safely within the lane while cruising at maximum speed. Finally, the safety score associated with the path adjusts the speed of the vehicle to reduce speed when navigating in tight quarters.

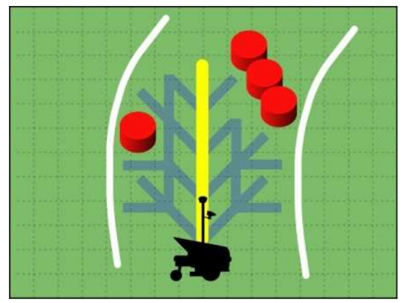

Figure 13: Weighted A*

5.4. High-Level Sensor Servers

Gamblore is equipped with high quality sensors to accurately sense and interpret its surroundings. These high-level sensors form the 1st tier of the software hierarchy. Each sensor has a corresponding server that connects to the sensor, processes the data, and continually streams the data over TCP/IP to VBAMC or any other custom program that may request the data using the sanctioned Zebulon API. Each server has s display GUI and an auto-reconnect features. They are designed to turn on with the computer in an “always on” mode, ready to serve data to any program requesting sensor information.

5.4.1. SICK LIDAR

The SICK LIDAR sensor receives 180° degree scans in ½ increments°, yielding up to 360 individual points where obstacles are located. Most of these points represent the edge of an obstacle and can be clustered together in a line. A specialized split-merge algorithm fits points from the LIDAR to line segments, reducing the number of obstacles to the map by a factor of 3 – 50, improving overall system performance. These line segments are sent as obstacles to the VBAMC module.

5.5. Vision System

The cameras mounted on the front of the vehicle serve as the second high-level sensor that detects obstacles. While the SICK LIDAR excels at detecting solid obstacles, the vision system focuses on lane lines and non-solid obstacles, such as barricades. The key goals in the design of the vision system were to recognize lane lines, recognize color for barrels, segment the colors into objects, and classify them as obstacle or non-obstacle. Many innovations in the vision system include incremental optimizations for better overall system performance. This year, a blend

5.5.1. Color Classification Algorithm

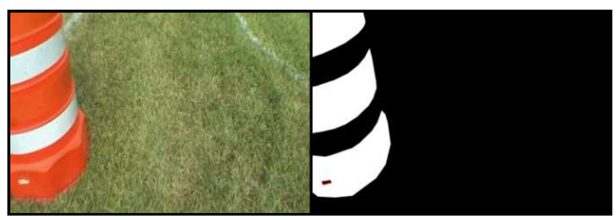

Figure 14: Color classification with mask image

A Gaussian-based skin color classification algorithm [2] was adapted for to recognize colors. By training it using a binary mask and still images (seen in Figure 13), the algorithm fills positive Gaussian spheres in a 3D color cube for colors it is trained on and negative Gaussian spheres for colors it was not trained on. Color recognition is performed by checking if a pixel’s location in the 3D color cube is above some threshold (meaning the color had previously been trained on). This year, additional optimizations in compression and reduction of the 3D color cube have greatly speed up the training and the already fast linear lookup during runtime.

5.5.2. Image Segmentation

With pixels of a particular color identified, image segmentation groups distinct clusters of pixels together to form a segment in the image. Because obstacles at the IGVC are of distinctive colors, color classification works well. A fast line-scanning algorithm [3] was used to group pixels into segments and calculate features such as size, density, aspect ratio, centroid, contour length, compactness, contour bending energy, and mean color.

5.5.3. Obstacle Recognition

Once image segments have been extracted, filtering is performed to separate noise from an image segment representing an actual obstacle. Using the image segment features mentioned earlier, a simple band pass filter performed on the image segments yields decent results. Developing the parameters of the band pass for the various features can be time-consuming, so ARTMAP Neural Networks [4] have proven to be quite successful in achieving nearly the same accuracy as a hand-tweaked model with significantly more automation. This saves the customer valuable time when the vehicle competes in new locations or environments. The ARTMAP can be re-trained for new obstacle types in a matter of minutes, resulting in rapid adaptability when new obstacle types are introduced.

5.5.4. Line Detection

Figure 15: Original image (left), filtered image (middle), classified lines (right).

Line detection is performed by applying a Hough Transform across a segmented filtered image. First, several filters are used to preprocess the image before applying line detection. These filters serve to remove noise and other obstacles that do not represent lines. A Genetic Algorithm (GA) described in 5.6.1 is responsible for the evolved filter sequence used which includes the following filters: sub-sampling, blurring, edge detection, thresholding, and erode. The resulting image is decomposed into a matrix of 5x3 cells and the Hough Transform is applied to each one. Once line segments are identified, an additional step is taken to join adjacent lines together. The benefit of segmenting the image into a matrix before applying the Hough Transform is the ability to find left and right lane-lines and approximate curves in the course.

5.6. Software Innovations

Originally designed to take advantage of the hardware proficiency built into the Gamblore platform, many of the design innovations were introduced in the previous IGVC model Calculon. A geometric 3D mapping system, new machine learning techniques applied to computer vision, and the rapid prototyping tool Discover Vision provide top-of-the-line tools for a competitive edge in IGVC. Ongoing refinements and optimizations to these tools have increased their value without increasing the cost.

For instance, the 3D geometric mapping now performs merging of repeatedly seen obstacles in the world map, increasing its update speed to allow for the faster navigation of the vehicle. In an effort to move to a standardized COTS software system, this year's computer vision algorithms were ported to Intel's popular open source OpenCV library. This also allows wider distribution of our custom, highly efficient code for image segmentation, color classification, and our other image processing techniques developed in the Robotics Lab. Discover Vision, a rapid prototyping vision system builder and one of the key innovations of the Robotics Lab ground team, is being refitted for use with OpenCV. This combines the power and widespread support of OpenCV with the ability to quickly build, test, and deploy robotic vision systems.

5.6.1. Machine Learning

When identifying obstacles, variations in obstacle types, sizes, and poses can make classification difficult. To deal with these problems, a machine learning ARTMAP based Neural Network [4] was investigated. The ARTMAP trains on a representative set of obstacle features (size, aspect ratio, color, density, etc.) to distinguish noise (such as a bright patch of grass) from a true obstacle. When compared to a simple thresholding approach that eliminates noise based on a fixed size or density threshold, the ARTMAP enhances flexibility. If new obstacles or variations are encountered, it only takes a short while to prepare and train the ARTMAP to recognize the new obstacle type, improving the rapid adaptability of the system.

Discovering the correct sequence of image processing filters to clean up and enhance an image for obstacle or line detection is a time consuming process. The solution space is extremely large and processing time can have a major impact on system performance. After researching other efforts to automate the process of evolving filter sequences, a genetic algorithm (GA) was used to create filter sequences for isolating lane-lines and removing background noise from images for line detection. The GA generated filter sequences of different lengths, combinations, and parameters. A filter sequence was evaluated based on how much time was required to process the image and how accurate line detection results were. The GA found solutions superior to previous methods used in both accuracy of line detection and processing time in different lighting conditions. Compared to the best human-determined solution used, the best-evolved solution performed roughly three times faster with double the accuracy. Using this system it is possible to find the best method for lane-line detection within hours based on new training images for different environments. The best solution found for line-detection is described in more detail in section 5.5.4 of this paper.

6. *Vehicle Performance & Analysis*

As a consumer product, the Gamblore™ LX 500 design focused heavily on the safety of operating the vehicle. Electrical connections are clearly labeled and properly wired using standard port interfaces, such as DB9, to allow easy and safe assembly/disassembly. Circuits and exposed electrical components are safely stored in a latched box inside the vehicle and outside the reach of small children. With new Plug-N-Go charging technology, batteries remain inside Gamblore at all times, reducing back strain. In accordance with IGVC rules, Gamblore offers several forms of emergency stopping. The red E-Stop button on the top of the vehicle cuts power to the vehicle, activating the mechanical motor breaks. Wireless E-Stop on the remote control stops the vehicle by cutting power to the motors.

6.1. Performance

Item	Performance & Analysis
Speed	Using the current 16" diameter wheel size, Gamblore can travel a maximum speed of 2.4 m/s, which is limited to the max speed of IGVC (2.2 m/s).
Ramp Climbing	The motors used on Gamblore are wheelchair motors, designed to carry 300 lb Grandma's up and down ramps safely and without fuss.
Reaction Times	Gamblore's internal clock runs at approximately 15 to 20 Hz, leading to a reaction time of no more than a tenth of a second.
Battery Life	The two 55 Ah 12-volt batteries give Gamblore an estimated 3-4 hours of battery life, depending on the intensity of use.
Obstacle Detection Distance	The SICK laser can detect solid objects as far as 8 meters while the camera is limited to 4 meters.
Dead-ends, Traps, Potholes	Dead-ends and traps are dealt with through path history and backtracking. Potholes are treated identically to other obstacles to be avoided.
Waypoint Accuracy	With the Hemisphere DGPS, sub-meter accuracy allows Gamblore to achieve GPS waypoint navigation within the regulated 1 m radius.

6.2. Budget

Item	Company	Cost	Qty.	Total Cost	Our Cost
Ranger II Power Wheel Chair Motors	Inva-Care	$1,000.00	2	$2,000.00	$0.00
SICK LMS LIDAR	SICK-USA	$4,449.00	1	$4,449.00	$4,449.00
PV-GS 180 Digital Video Camcorder	Panasonic	$480.00	2	$960.00	$960.00

Desktop Replacement Computer	Alienware	$3,065.00	1	$3,065.00	$3,065.00
Mini-MAX DGPS	Hemisphere	$2,000.00	1	$2,000.00	$2,000.00
EM1 2500 PPR Optical Encoders	US Digital	$35.50	2	$71.00	$71.00
3DM-GX1 IMU	Microstrin	$1,200.00	1	$1,200.00	$1,200.00
AX 3500	Roboteq	$395.00	1	$395.00	$395.00
Wheels	Skyway	$25	2	$50.00	$50.00
Aluminum	Alro Metals	$500.00	1	$500.00	$500.00
Caster Wheel	Frog Legs	$100.00	1	$100.00	$100.00
Wireless Router	Lynksys	$50.00	1	$50.00	$50.00
Miscellaneous	Various	$1,000.00	Various	$1,000.00	$1,000.00
			Total	$15,840.00	$13,840.00

7. Conclusion

Today you have seen the power, the intelligence, and the sleek elegance of the all new Gamblore™ LX 500. For a time-limited special offer of $24,999*****, you can own a brand new Gamblore model. Whether for play, for work, or just to impress your neighbors with the latest say in autonomous robotic platforms, Gamblore is designed to suit all your needs. From the award-winning software solutions developed in the Robotics Lab to the sturdy frame, Gamblore comes pre-assembled and hand-optimized for speed and endurance. The reliable chassis and sensor suite enable peak performance in IGVC challenges. Even under adverse conditions such as DGPS loss, Gamblore's superior design gracefully handles and corrects for failures. The flexibility of software systems through machine learning configuration GUIs or the more advanced C++ Zebulon API demonstrates the quick and responsive adaptability nature of Gamblore's design. Features such as the Plug-N-Go battery charging, easy-grip handles for moving the vehicle, and the spacious storage room for 3rd party hardware add-ons clearly show that Gamblore rises above its competitors to deliver cost effective solutions to real world problems. As clearly evidenced, it cannot be disputed that Gamblore is ill suited to successfully compete in the 15th annual IGVC competition.

8. References

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* *No assembly required. Batteries sold separately. Only available through UCF's research division, the Robotics Lab.*