University of Massachusetts Lowell

Stark

Team Members
(Alphabetical order)
Alessandro Agnello, Daniel Brooks, Christopher Corcoran, James Dalphond, John Fertitta, Michael McGuinness, Gregg Merlino, Jeff Rousseau, Chad Sweeney, Mike Therrein

Faculty Advisors

Fred Martin, Holly Yanco, David Willis

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1.0) Introduction

The University of Massachusetts Lowell (UML) Robotics Team is proud to present “Stark,” a new robotics platform designed for research as well as competition in the Intelligent Ground Vehicle Competition (IGVC). Stark was designed as a collaborative effort by the Computer Science, Mechanical Engineering, and Electrical Engineering departments at the University of Massachusetts Lowell, marking the first collaborative effort between departments. UML has been competing in the IGVC for the past 5 years, each year learning from previous mistakes. Those years resulted in three significant mechanical and electrical revisions for the previous robots (named the MCP I through III). Although the MCP platform has been tested and was successful in previous competitions, it is not expandable. One of the main design considerations during initial planning was the ability to expand on current sensors and have the ability to add new sensors.

The planning process began in mid-January. Requirements were decided upon and split up in a way that reduced the dependency of one team on another. Because of the modularity of the chassis and components, each system was able to be built and unit tested individually, reducing the chance of problems during integration. Each major mechanical component (chassis, sensor mast, and electronics case) had its electrical system installed separately, integration only required making connectors for each component. Software was also be built in parallel on the existing MCP platform and in a simulation environment that is described later.

2.0) Vehicle Overview

Stark employs a 4-wheel differential drive system for movement. Two motors control the two sides of the robot independently using a chain drive. The outer dimensions of the frame are 28” wide by 37” long. With the mast in the vertical position it stands 57” tall, and only 27” when the mast is collapsed for transport. The weight of the vehicle including payload is approximately 200 lbs.

The electronics are isolated from the rest of the robot in a removable case that sits atop the chassis. Power is provided by two 12 volt, 50 amp-hour batteries, run in series to give 24v. The motors run on 24 volts, and a 24-to-12v DC-DC converter is used to power the computer system and sensors. Under ideal conditions the power system will last approximately 3 hours. The vehicle also has fail-safe and emergency stop (e-stop) systems integrated to keep it safe for operators and spectators. The electrical and mechanical systems are discussed in detail in the following sections.

Stark also includes a comprehensive diagnostic sensor package along with logging software. Possible sensors include temperature, voltage, ammeters, and accelerometers. These sensors, along with the logging software allow the team to track the status of the robot as well as the control programs running on-board. This system is described later.

3) Mechanical Design

This year's entry into the IGVC marks the first interdepartmental robotics effort at the University of Massachusetts Lowell. A team of mechanical engineers were recruited to design a more robust robotics platform than any previous design. The design of the platform also served as a senior year capstone project for the mechanical engineers. The entire robot, including sensors and computer, were modeled in SolidWorks. This allowed the design of the robot to be tested before finalization. The following sections describe the main parts of the robot and their design.

3.1) Motors

Motor selection is critical in designing a robot capable of performing on different surfaces. A careful balance must be reached between efficiency, torque, and speed to optimize battery life while maintaining performance.

Initial assessment began with an energy balance between the mechanical power demands and the power supplied by the batteries. Torque requirements in the various scenarios which the robot will encounter were assessed. The scenarios tested were as follows:

- The robot is traveling in straight line motion: During straight line motion, the robot will have minimum torque requirements, only needing enough torque to keep the robot moving along the terrain. The robot is traveling at maximum speed (5mph), and should have minimum power draw.
- The robot is turning: As the robot corrects for direction, each wheel ‘skids’ while traveling in a circular path about the center of mass. This motion was considered to have the highest torque demand and therefore the highest power demand. Skid steer kinematics were researched to confirm intuitive assumptions about the resistance each tire would encounter to predict load requirements on the motors.

To generate a reasonable approximation on the required torque, focus was shifted to empirical testing of the 2009 MCP III platform. After thorough analysis and considering amp draw, motor speed, and torque, NPC T74 motors were selected from a field of likely candidates. The graph below shows characteristics of motors considered for Stark; The most power motors were chosen.

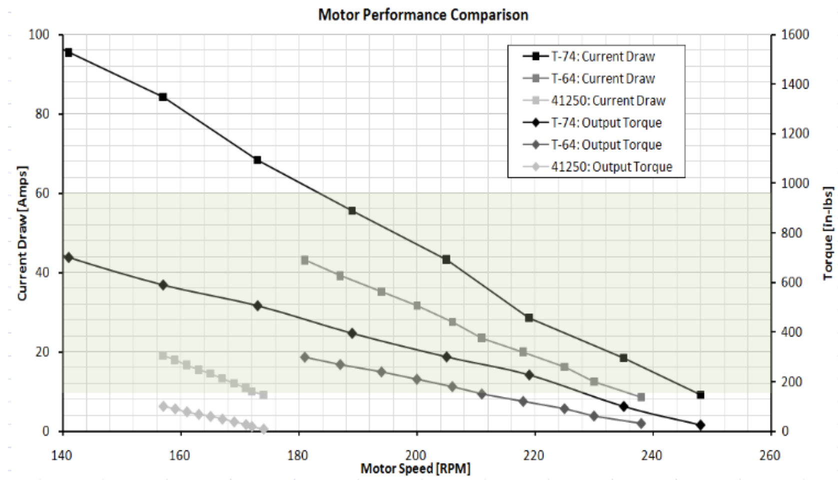


Figure 1: Comparison of Motor Performance

3.2) Chassis / Drive train

As mentioned, a four wheel skid steer design was implemented as the driving mechanism. To cope with the extra forces caused by the wheels skidding to turn, a rigid frame was necessary. Extruded aluminum was used for all structural components due to its strength and light weight characteristics. The diagonal bars of the main frame rails serve a dual purpose. They provide diagonal strength to the frame much like the truss of a bridge. This is a theme that is carried throughout the design to reduce weight and add rigidity. Second, the diagonal bars give a convenient location for a tensioning sprocket for the drive train. A sprocket positioned at an optimal location restricts the idler slide to a single translational degree of freedom, effectively serving the function of removing slack in the chain. This also increases the chains contact on the gears, increasing the strength of the drive-train. Figure 2 depicts the frame rails and idler slider.

Skid steer kinematics were researched thoroughly to determine the optimal wheel base to reduce the amount of power needed to break friction while turning. A wheelbase of 14"L by 24"W was found to give the smoothest turning. The center of mass was placed directly in the center of this wheel base to reduce stress on the system. The drive-train shown in Figure 3 was designed to be used with a chain, but is compatible with a belt drive system. Chain was chosen because of its lower cost.

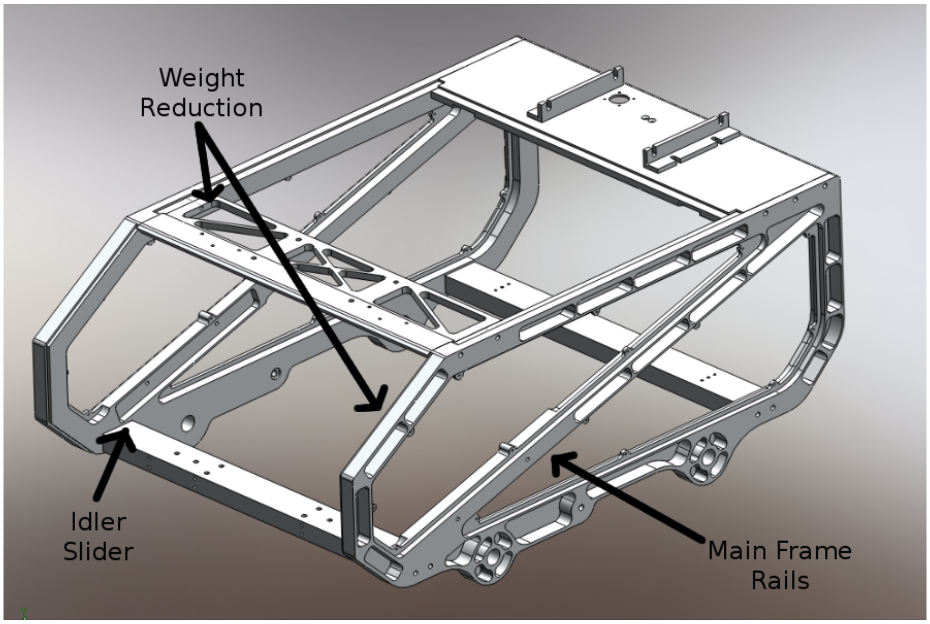


Figure 2: Key Points of Stark's Frame

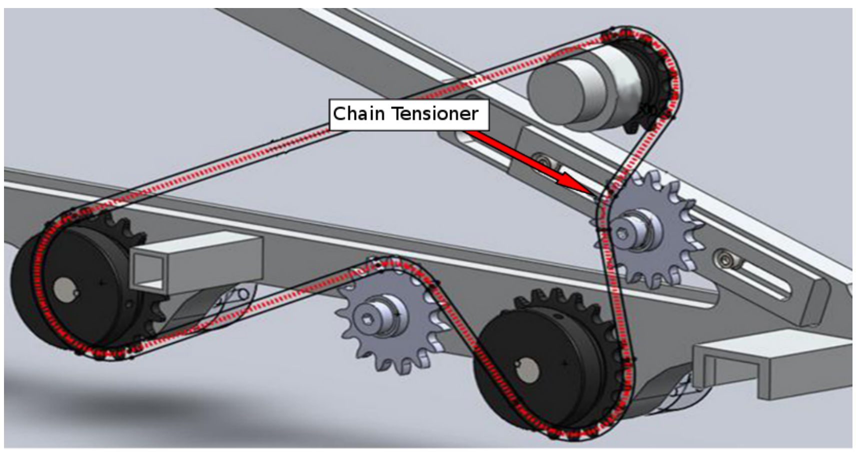


Figure 3: One Side of Stark's Drive-train

All components were placed to keep the robot perfectly balanced around its center of mass and low to the ground. The MCP was not well balanced. When traveling up a hill the weight at the back of the robot would cause it to flip backward. The new chassis has been tested and will remain safe on an incline up to 37 degrees. Batteries, motors, payload, and all other components were modeled in SolidWorks allowing the center of mass to be precisely placed.

After the design was finalized, all heavy parts of the robot were analyzed to determine if weight reduction was possible. Keeping in mind concepts from Solid Mechanics, heavy components were lightened by removing material in the form of pockets shown in Figure 2. The integrity of the lightened components was maintained by staying away from areas of stress concentrations (i.e. holes, abrupt geometric changes, and sharp corners). Also, the remaining geometry did not have a significantly reduced section modulus, again, maintaining its structural integrity.

The chassis also includes a spring dampened front bumper. The bumper serves two purposes. The first is to reduce the stress put on the frame should it hit a stationary object. Second the bumper protects the SICK Laser while remaining out of its field of view, even at its lowest mounting angle. In the future, the spring dampened bumper could contain a push button connected in series with the e-stop circuit. This would give added safety as the robot would come to a stop when the bumper is depressed.

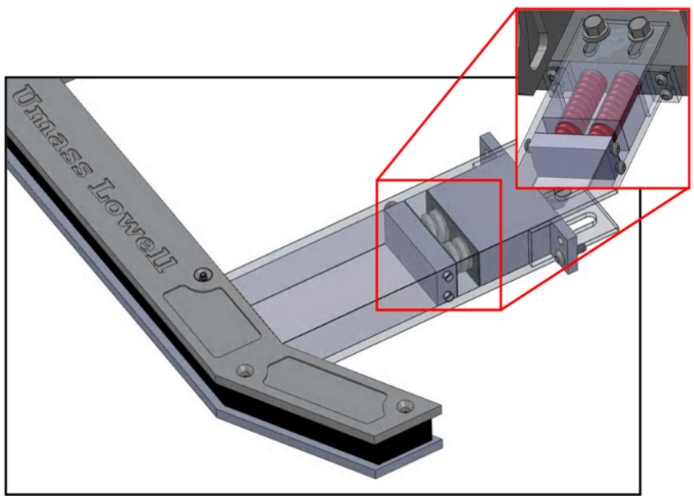


Figure 4: Spring Dampened Bumper

3.3) Sensor Mast

The function of the sensor mast is to position one or more cameras at a high vantage point to maximize the robot's field of view. Minimum functional requirements incorporated into the tower’s design included the need to accommodate one Apple iSight camera being at a minimum height of five feet. On the MCP III platform only a single camera can be mounted. Since Stark was designed to be expandable several mounting points were made for the camera. Two cameras may now be mounted with focal points at known distances allowing for stereo vision capabilities or a single camera to be mounted in the center. The mounting positions are shown in Figure 5.

In addition to housing the cameras, the mast is a convenient place to mount additional sensors such as the two GPS devices and a single compass. Two lightweight mounts were placed on the outside of the mast keeping the two GPS devices at a known distance apart. The reason for two GPS units is explained later. The compass mount in the center of the mast, in addition to the camera mounts, provides increased structural integrity keeping it rigid even during vibration induced by uneven terrain.

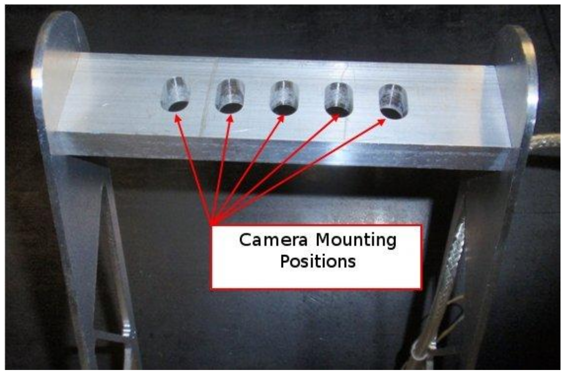


Figure 5: Camera Mounts on Sensor Mast

One of the main problems with the MCP III platform was the fact that it was difficult to transport due to a solid, heavy mast with several wires hanging out the bottom. The electrical and mechanical teams worked together to solve this problem. The first solution was to make the mast fold down. Cam locks were used to allow quick folding of the mast while pins were placed to only let it fold so far in either direction. The cam lock passes through a toggle when it is moved to the locked position; therefore, it will remain secure through intense vibration. Cam locks were also used at the base for quick removal of the tower. The image below shows the sensor mast in both the upright and folded position.

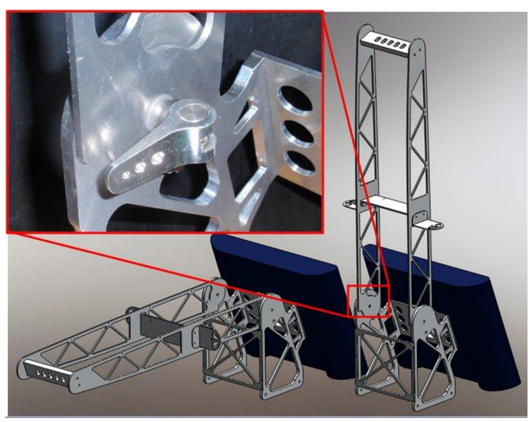


Figure 6: Sensor Mast, Upright and Collapsed

As shown above, the sensor mast was designed to be lightweight. Truss style bridges were the inspiration for the design based on a long history of success. The triangulated geometry throughout the peripheral tower effectively distributes induced stresses to the thin connecting members.

To allow for the quick removal of the mast all wires from sensors, emergency stops, and the monitor needed to be able to disconnect quickly as well. To facilitate this, all wires pass through water tight quick disconnect plugs.

3.4) Electronics Case

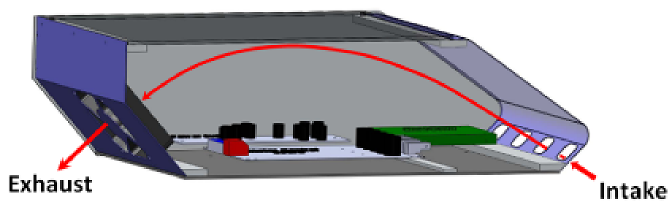
A significant limitation of the MCP III was the manner with which the electronics were integrated. There were two main problems with this that needed to be solved:

- The components must be protected from the elements.
- The electronics must be independent from the chassis so that they can be worked on separately.

Protecting the components from the elements means that the robot must be able to function in a somewhat wet environment. It must be able to withstand light precipitation both while moving and standing still. The obvious solution is to encase all of the components in a box, however many of the components produce heat, and some are heat-sensitive. To address this problem, vents were placed facing downward in the front of the electronics case. To create air flow across the components, downward facing fans were placed at the back of the control case. All of these openings are protected by the shape of the control case allowing it to stay water resistant during light or moderate rain. Thermistors placed in key points within the robot allow us to run the fans only when needed to keep temperatures down, thus conserving battery life.

The electronics cabinet is detachable from the chassis, allowing the electronics to be worked on independently of the robot. Removing the top panel also allows the inside of the robot to be worked on easily. The access panel is attached to the frame using quick release hinges. The hinges allow the panel to be removed yet give a pivot point for the access panel to open. To hold the access panel open, gas shocks were placed within the chassis. Amphenol and Anderson Power Pole connectors are used underneath the panel for quick disconnect of electronics. These connectors are waterproof giving added protection within the chassis. Together, the pneumatic shocks, hinges, and connectors allow the control panel to be completely removed from the robot in under a minute. The rendering below shows the electronics case in its upright and normal positions.

Inside of the electronics cabinet, vibration sensitive components are isolated from the chassis using rubber mounts. The interior of the cabinet is split into two sections to separate power systems from logic systems. These sides are divided by a copper mesh reducing the chances of Electro-Magnetic Interference (EMI) potentially caused by the motor controller or power system.



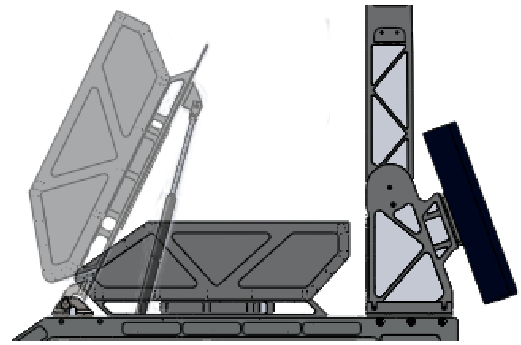


Figure 7: Control Box Air Flow, Control Box Positions

3.5) SICK Mount

Many of the teams at the IGVC use SICK laser range finders for obstacle detection. For Stark, a SICK LMS200 was borrowed from the UMass Lowell Robotics Lab. At last year's competition, the MCP team discovered that the laser was sensitive to angular position. If positioned too low, it would see hills and blades of grass on the field as obstacles to the control software. A solution was attempted in software, but then wooden shims from a nearby hardware store were used to adjust the laser upward.

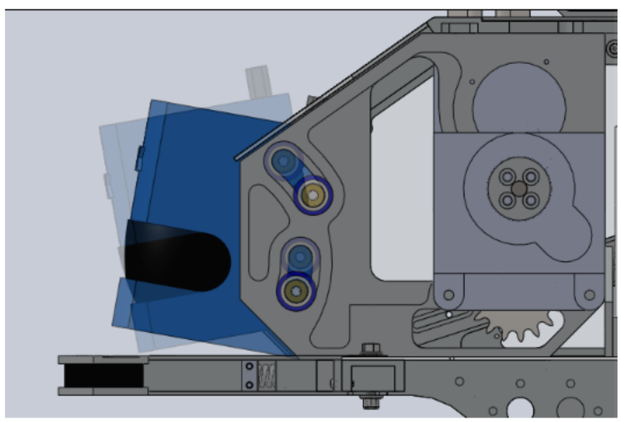


Figure 8: SICK Laser Mount

This adjustment problem was of great concern when designing the Stark platform. The angle of the SICK had to be easily calibrated mechanically. Using the SICK laser's side mounting holes, a pivotal mount was made allowing 30 degrees of adjustment. The pivot point of the laser is centered at about the focal point of the internal lens. In the future, a four-bar linkage could be implemented with a servo to automate movement, which will allow research into three-dimensional mapping. Figure 8 depicts the movement of the device.

4.0) Electrical Design

In the following sections the electronics system of Stark is explained in detail. There are several electronic systems working together to make the robot functional. These include power, computer, sensors, safety, and motor control systems. Figure 9 is a simplified block diagram of how the system is set up.

As shown in the diagram, the safety system gets power directly from the power system as well as from the motor controller. This may seem redundant at first; however, if a wire were to come loose from the direct power, the safety system would stay operational and the robot will not run out of control. If power to the motor controller is interrupted due to a loose wire, the safety system will still be powered. If the whole system loses power, the motors will not be able to run and the system fails safe.

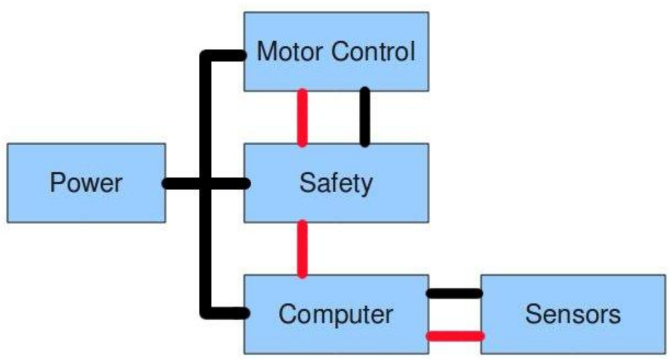


Figure 9: Electrical System Layout (Black = Power, Red = Data)

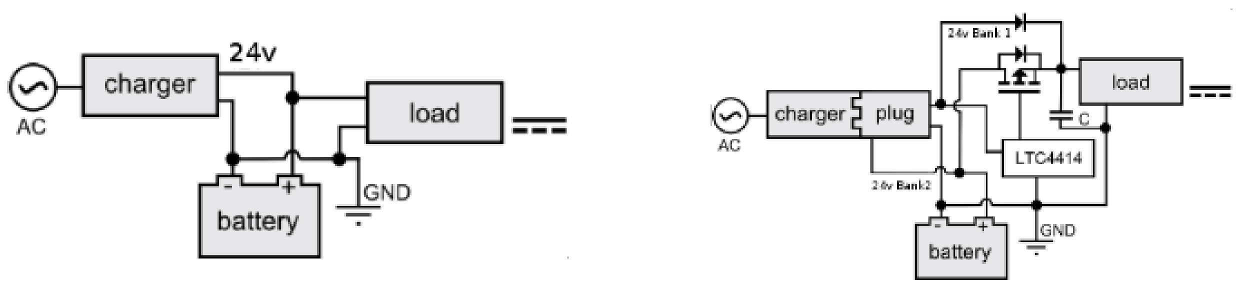
4.1) Power System

One of the main problems with the MCP III is that it is heavy. This is largely due to the fact that it employs two separate power systems, requiring a total of three batteries. Each of the lead acid batteries weigh 33lbs giving the MCP 99lbs of additional weight from batteries. Fitting the batteries into the vehicle also made the chassis taller and back-heavy. With two separate battery systems in use, it was also necessary to have two different chargers, a 24v and a 12v.

To solve these problems the decision was made to have only two batteries. The logic power supplies are generated by high efficiency Vicor Power DC-DC inverters. Rated at 93-95% efficiency, the DC inverters allow us to have smooth power for both systems. The motors run on raw 24v through a Roboteq AX3500, a reliable off-the-shelf motor controller that incorporates closed loop control, emergency shutdown inputs, and multiple signal inputs. The computer, a 3.0 Ghz Dual Core system runs on a 24v-to-12v converter and an automotive optimized power supply. While the original MCP power systems could guarantee only 30 minutes of run time, Stark has been tested for up to 3 hours.

4.2) Charging Circuit

The MCP III was designed to carry its battery chargers on-board directly wired into the system. This allowed it to be plugged or unplugged at any time without shutting down the computer. However, this system was not designed correctly. To charge a sealed lead acid battery takes three steps. The first two steps bring the battery up to nominal current while the third keeps the battery at its nominal charge with floating current. These steps are handled automatically by most chargers. If the computer was running while the charger was plugged in, the charger would see an extra 5 to 7 amps and never leave the second stage of charging, assuming that the battery was still discharged. Figure 10 (left) depicts the MCP III's charging circuit.



Figures 10: Old Charging Circuit and New Charging Circuit (left to right)

The solution to this problem was to design a power switching circuit that would sit between the computer and the two sources of power. To do this a Linear Technologies LTC4414 IC was used to sense when the charger was plugged in. When the charger is sensed, an external power MOSFET is triggered, cutting the batteries off from the load. With the battery cut off from the load, it is possible to charge the batteries with one bank of the charger, and run the computer with the second bank. The charging circuit designed to solve these problems is depicted in Figure 10 (right).

4.3) Motor Controller Interface

The Motor Control Interface (MCI) board is a custom control circuit designed specifically to meet the requirements of the UMass Lowell IGVC robots. The MCI was designed to replace three separate existing systems, combining them into a single reproducible unit which could be used on both robot platforms being fielded for the competition and is the heart of the safety system.

The MCI combines the Motor Controller Communications board, the Wireless Emergency Stop System, and the Main Emergency Stop System into a single unit. This new board acts as a single fail-safe point of contact to the Roboteq Motor Controller, both fulfilling safety requirements and maintaining a flexible interface for controlling the robot.

Having all of these systems combined into one point of failure allows us to make sure that the vehicle will fail-safe should anything happen to the radio controller or computer. If a wire were to come loose from the emergency stop system, or if the MCI board loses power for any reason, the motor controller will immediately be e-stopped and the robot will stop moving.

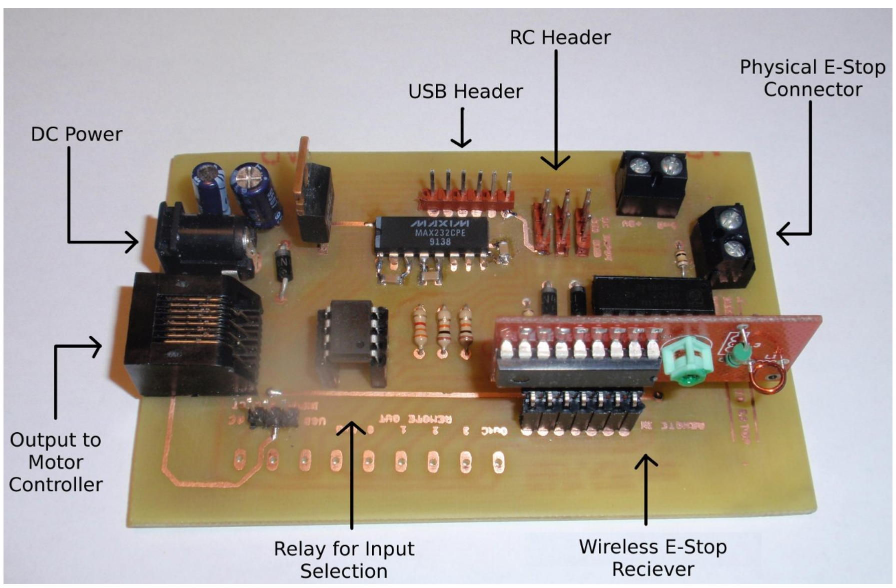


Figure 12: Motor Controller Interface

For physical emergency stops, we are using C&K Rafi-x locking emergency stops which are within regulation for the IGVC. One e-stop is placed at the rear of the robot mounted as part of the monitor. Since the monitor is the part that the operator will most likely be looking at while behind the vehicle, it made sense to put the button within the operator's field of view. A second e-stop is placed atop the electronics case on the front of the robot. This is the easily accessible position for an e-stop if someone is standing in front of the robot. The two e-stops are wired in series in a normally-closed configuration; pressing either e-stop or a wire coming loose will open the circuit, causing an e-stop condition. For the wireless e-stop, a 433Mhz 4 channel transmitter and receiver were chosen. The OEM wireless transmitter is rated at 300 feet, far exceeding the requirements of the IGVC.

4.4) Sensors

Navigating the two courses at the IGVC requires the use of several different sensors. These sensors include cameras for vision, SICK laser for obstacle detection, and GPS receivers for positioning data. Although these are not the only sensors that can be used for the competition, they can be used to provide a good approximation of the world around the robot. In the following sections we discuss each of the sensors and why they were chosen.

4.4.1) SICK laser

The single most expensive part of most IGVC robots is the SICK laser. This sensor allows the robot to "see" 180 degrees in front of itself. As mentioned above, we have borrowed a SICK LMS200 laser ranger from the Robotics Lab at the University, allowing us to create a highly accurate map of the world in front of the robot. With the design of the laser mount, Stark may be expanded to perform three-dimensional mapping in future research.

4.4.2) GPS

In previous years, it was found that the drift from a single GPS receiver can cause problems when trying to find a location. A solution to this problem is to use a Differential GPS (DGPS) system however, these are very expensive and require a lot of power to run. It was hypothesized that given two different GPS chip sets, an average of the readings could be used to determine the position of the robot with higher accuracy. After running several tests with off the shelf components this hypothesis was shown to be true. Stark uses two off the shelf USB receivers from Garmin and USGlobalSat to more precisely navigate. This solution cost $120 whereas DGPS systems used by other teams could cost upwards of $1,000.

Figure 13: Dual GPS Setup

4.4.3) Vision

One of the requirements of the IGVC competition is the ability to detect and avoid white lines on the ground. This task is done using computer vision techniques. In previous years the MCP platform has used a single Apple iSight Firewire camera. The iSight camera has proved to be a powerful camera for its price range. It is capable of streaming 680x420 images at 30 frames per second, and has automatic brightness adjustment to compensate for changing lighting conditions (e.g., clouds). The iSight is low-cost, available for about $80, where comparable cameras could cost upwards of $400. As mentioned previously, the sensor mast will allow the use of two Firewire cameras allowing a low-cost stereo vision setup for research and competition use in the future.

5.0) Software Development Environment

While the mechanical and electrical teams were designing and building the robot, it was necessary to be able to test software. Although the previous year's robot, the MCP, was working, it can be difficult for multiple people to test code on one robot. For the past two years, our robotics team has used an open source development platform to build and test code in a virtual world. This approach allows many people to develop software at the same time as well as keeps people from testing unsafe code on the physical robot. The development environment is explained in the following sections.

5.1) Player

Player is a network interface for developing robot control code that is language- and platform-independent allowing software engineers to develop code in any way that is comfortable for them. Code for previous robots have been written in several languages including C/C++ and Perl. All sensors on the physical robot are networked through Player, allowing control software access to both physical sensors and simulated sensors. For each robot, a single driver is developed that provides an interface to each sensor. This driver is accessed through the Player application programming interface (API), which creates a layer between the control code and the driver. The software team is then able to switch between running in a simulated environment to running on the actual robot without making any changes to code, simply by loading a different configuration file.

5.2) Stage

Stage simulates the physical robot in a 2-dimensional world which contains various sensor models that can communicate with the Player API. The simulated robot performs very close to how the real robot does in the real world. Stage is able to provide simulated position data to the GPS sensors on the simulated robot, making it useful for the navigation team. Test courses were created and the navigation team was able to run the control code when the robot was not available. Stage was most widely used by the navigation team working on the GPS challenge to test A* and open path algorithms, two search algorithms used to find a path to a given point.

5.3) Gazebo

Although Stage provides a great environment for simulation it only provides 2-dimensional world. Obstacles are defined simply as black lines on a white canvas and can only be detected with laser or sonar ranger finders. While this was useful for the navigation challenge, it was not useful for simulating the autonomous challenge, where vision is required. Gazebo provides a three dimensional simulation environment. In this environment, the autonomous team created a course based on the IGVC autonomous course. White lines were drawn on simulated grass, and 3-dimensional barrel obstacles were placed in the path. A model of the robot was created that provided a camera along with the other sensors on Stark. The camera provided images used to test filters and line detection software.

5.4) Logging System

Our logging system is comprised of two components, a client and server. The logging client exposes a single function that a developer can access from their control program, this function is called logMsg(). The function parameters are; robot name, control program, message severity, and a message. The function sends a request to the server which stores the message. The logs are updated to a web service, allowing the team to diagnose problems in real time. All sensor information, including diagnostics sensors, are accessed by low level controls on the robot and logged as well.

6.0) Conclusions

Over the past three months, the Computer Science, Mechanical and Electrical Engineering departments have worked together to make Stark a reality. Utilizing each student's area of expertise, we were able to incorporate everything the robotics team has learned over the past 5 years into a robust robotics platform. It has taken approximately 1500 man hours (conservatively) to complete the project. Thanks to key sponsors we were able to build Stark for under $4,000 out-of-pocket. The tables below break down the budget and team members.

Department	Budget Use	Budget
Computer Science	Computer System, Power System, Sensors	$2,000.00
Mechanical Engineering	Materials, Hardware, Fabrication	$1,500.00
Electrical Engineering	Charging System	$500.00
Sponsor	Items Donated	Estimated Monetary Value
NPC Robotics	3 – T74 Motors	$1,000.00
Vicor Power	2 – DC-DC Inverters	$300.00
C&K Components	Switches, E-Stops, Components	$300.00
Ideas Inc. Fabrication	Fabrication	$3,500.00
Sub-millimeter wave Technology Laboratory	Fabrication	$200.00
UML Robotics Lab	SICK Laser	$5,000.00
Total		$14,300.00

Table 1: Allotment of Resources

	Team Breakdown	
Name	**Department**	**Project Contributions**
Alessandro Agnello	Computer Science	Mapping, Navigation
Daniel Brooks	Computer Science	Electronics, Safety Systems
Christopher Corcoran	Computer Science	Logging System
Alexander Chan	Electrical Engineering	Electronics, Circuit Fabrication
James Dalphond	Computer Science	Project Manager, Electronics, Design Report
John Fertitta	Computer Science	Vision
Gregg Merlino	Mechanical Engineering	Mechanical Design
Jeff Rousseau	Computer Science	Electronics, Charging System
Chad Sweeney	Mechanical Engineering	Mechanical Design, Fabrication
Mike Therrein	Computer Science	Vision
Fred Martin	Computer Science	Advisor
David Willis	Mechanical Engineering	Advisor
Holly Yanco	Computer Science	Advisor

Table 2: Team Breakdown

In addition we would like to thank Don Rhine, Mark Sherman, Abraham Shultz, Karen Volis, Dr. Jie Wang and our sponsors for helping make this project possible.