HARDCORE III – IGVC Design Report

IGVC Team Leader

Iheanyi Umez-Eronini

Hardcore Design Team	**IGVC Team Members**
Josh Karpoff	Alex Sojda
Micheal Duke	David Longo
Nick Valerio	Jose Torres
Nathan Pendleton	

TABLE OF CONTENTS

1. Introduction

HARDCORE is a recursive acronym standing for Hardcore Autonomous Robot Designed to Cover Outdoor Regions Efficiently. The robot is of a modular design that compartmentalizes the mechanical elements from the computing elements. The brains of hardcore are meant to be interchangeable depending on its task. Hardcore was designed by members of RIT MDRC (Multi Disciplinary Robotics Club) as a multipurpose rugged outdoor robotic test-bed which could travel from GPS waypoint to waypoint avoiding obstacles along its path. When MDRC made the decision to enter the IGVC, HARDCORE was the logical choice as a starting platform. As a result, this document will both detail the design process used and issues faced in the development of the HARDCORE platform, as well as those involved in preparing HARDCORE for the IGVC.

Each team's goal in the IGVC is to design a professionally packaged autonomous robot that is rugged, serviceable, safe, and able to traverse outdoor regions and navigate to various targets while avoiding obstacles. Since HARDCORE met most of these requirements, the bulk of the work done on HARDCORE in the past five months has mainly been to implement a more advanced suspension system for HARDCORE's base and to create a sensor/decision suite that would allow the base robot to successfully compete in the IGVC.

Participation in MDRC is a voluntary and extracurricular activity; all the student members of both the HARDCORE design and IGVC teams were either taking full course loads or working full time (to satisfy RIT's coop requirements), in addition to participating in the other projects and activities that MDRC operates. Since MDRC funds its operations with little aid from the university or outside sources, resources to develop a next generation HARDCORE were limited both financially, and in terms of student time to work on the project. As a result, many decisions the IGVC team made in our design process were focused on optimizing the use of those resources while maintaining a sufficient level of sophistication that would allow HARDCORE to be competitive.

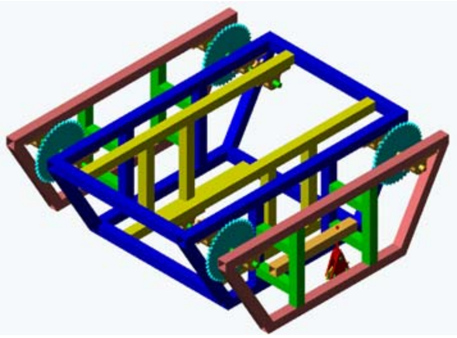
2. Mechanical Design

2.1 Overview:

HARDCORE was designed based on the past experiences of its design team with previous robots. Its trapezoidal tank-like design allows it to traverse uneven outdoor terrain easily while giving it the ability to climb over rocks and small curbs. It is easily serviceable; HARDCORE is essentially in two parts, the base which houses the drive motors and drive batteries, and the top box, which mates to the base, allowing changing the sensors and computing devices attached to HARDCORE depending on its current goals. The top box also houses a power distribution system for HARDCORE which isolates the motor and electronics power and provides a means to halt the movement of HARDCORE with an emergency kill switch.

2.2 Chassis

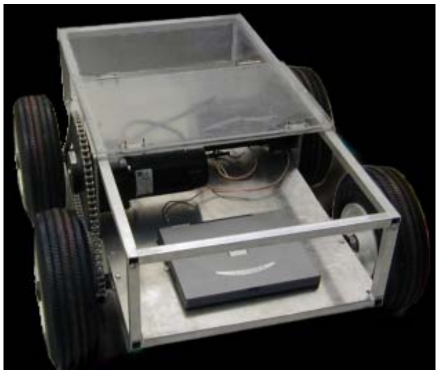
The mechanical elements incorporate a well balanced design, keeping the bulk of the weight, the motors and batteries, in the lower compartment. This maintains a low center of gravity. The geometry of the treads is very similar to that of a tank; they have a ramped trapezoidal shape which is more robust than a linear tread path. The area of the base is square to aid in turning which occurs on a central axis. Building on previous design experience on other robots, and previous versions of HARDCORE, the current design uses steel tubing, rather than solid aluminum, which is much stronger and able to withstand HARDCORE's drive forces.



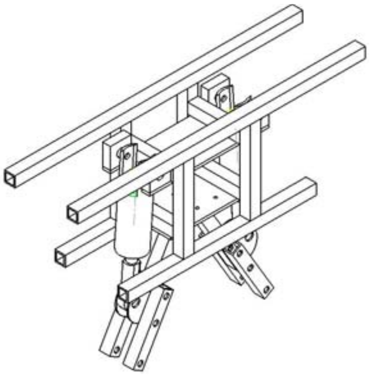
2.3 Power Distribution

In keeping with the rest of the robot, the electrical system is designed to be modular and expandable. Using standard twist-lock connectors, the two compartments easily separate, allowing for both easy access and expansion. The motors run on 24 Volts, which is provided by two 12 Volt batteries in series. Charging of these batteries can only be done with 12 Volts, so through the use of a switch, the system can be changed from 24 Volts to 12 Volts, with the battery configuration changing from series to parallel. When the switch is changed from operational mode to charging mode, the entire control system is isolated, which protects the sensitive electronics from any transient voltages during charging. A secondary 12 Volt system is currently located in the electronics compartment to provide power for various electronic systems. The electronics compartment currently houses the emergency shut off system, the motor controllers, the USB device bus, the main computer, and sensors.

2.4 Suspension and Locomotion



The original HARDCORE ran on pneumatic wheels, rather than tracks. While this was sufficient for the initial indoor testing of the robot and outdoor testing on concrete or paved surfaces, it was immediately obvious that that method of locomotion would be insufficient for HARDCORE on grassy and other off-road surfaces. Research showed that treads would cover a wider range of surfaces and while supporting HARDCORE's frame and motive components. Metal tracks and a simple manually adjustable chain tensioner were used. However, we found that this system transmitted too much vibration to HARDCORE's components and in some cases could cause bolts and nuts to slowly vibrate apart.



A redesign of the suspensions system uses a spring-loaded piston to absorb the shock and relies on HARDCORE's own weight to dampen remaining vibrations. This design raises HARDCORE's center of gravity(COG) by almost a foot, however, its COG is still very low; and we expect HARDCORE will remain stable. Additionally, HARDCORE now has greater ground clearance which would allow it to climb over larger objects and make the E-Stop button a little easier for people of average height to reach.

2.5 Safety

HARDCORE by design utilizes an emergency kill switch already located in the IGVC suggested position. Additionally, since RIT is home to the National Technical Institute for the Deaf (NTID), HARDCORE makes use of a strobe light which constantly runs when powered on. The internals of HARDCORE are protected from curious fingers (or perhaps it's the fingers that are protected) by the use of plastic side panels which can be quickly removed for servicing. We purposefully don't paint these panels since our view of HARDCORE's internal workings while its in motion serves as a troubleshooting and debug tool.

The design of the top-box was also motivated by a desire to maintain safety. It too is covered by plastic panels and has a latching door when access to the electronics is required. Removing the top box of HARDCORE, or the top box somehow getting disconnected from the base, will disconnect power to a normally open relay, which supplies power to the motors. Additionally, we operate the Victor motor controllers with the brake jumper set. This ensures that whenever the controllers are not receiving a valid control signal, their internal circuitry will brake HARDCORE's motors. Additionally, the Victors default to brake-mode when no jumper is present. This ensures that even if the jumpers were to somehow vibrate out of position, HARDCORE will remain safe.

The output of HARDCORE's motors are 270 in-lbs of torque and a maximum speed of 42rpm. The motors directly run a 60tooth sprocket that drives a 15tooth one. This 15tooth sprocket is on the same axle as a 6.25" diameter 24tooth sprocket which drives the treads of HARDCORE. This places HARDCORE's max speed at 3.12374 mph, well below the IGVC limit of 5mph.

2.6 Modifications for IGVC

HARDCORE II's dimensions did not meet the length requirement for IGVC. A new top box was created to meet this requirement, as well as provide a mounting area for much of the sensors, while still maintaining protection of electronics from the environment. Additionally, quadrature encoding of HARDCORE's main drive sprockets was implemented using an encoder wheel and Infrared (IR) break/beam sensors to allow for closed loop control of HARDCORE's speed, position, and heading. Additional batteries were added to the top box to ensure available power for the additional sensors and computing equipment used for IGVC. The IGVC's safety requirements mandate both a wireless and onboard E-Stop for all robots that must be independent of the control software. A wireless E-Stop controller was created to meet this requirement in addition to the hardwired one already built into HARDCORE.

3. Electrical System

3.1 Overview

At a minimum, to compete in both the IGVC Autonomous and Navigation Challenges, a robot must posses distance measuring sensors, a camera, or some other sensor that can detect lane markers, and some means of odometry. With the proper algorithms, the sensors will allow the robot to travel along the Autonomous Challenge course without lane excursions or colliding into obstacles and travel to the waypoints in the navigation challenge by keeping accurate track of its position. However, the algorithms to do these tasks with great accuracy using only the most basic of the sensor types described are still under research. The solution is to use sensors which can provide more data, higher accuracy, or higher precision. Often, this can make up for deficiencies in an algorithm. Since it was our goal to optimize the use of our financial and time resources, we chose sensors which we felt provided an adequate balance of effectiveness to cost, while still allowing the control logic to stay simplified.

3.2 Sensors

3.2.1 Cmucams

Lane following based on image analysis is not a trivial task. In most implementations, a Hough transform is required to extract the lines of interest, then more code is necessary to localize that line relative to the robot. The Cmucam is an integrated system which can track one or more color channels. It works best when tracking one color against the background of another. The white lanes on a sea of green grass found in the IGVC are a great example of the situations that the Cmucam was designed to handle. By offloading most of the image processing into our camera module, we drastically cut the lane following algorithm development time for similar cost to teams using a digital camcorder. Since the Cmucam's behavior can be updated dynamically, it can be switched from tracking lanes to tracking orange color obstacles. In this manner, the Cmucam not only serves its primary purpose as a lane detector, it is also a redundant obstacle detection sensors in the case of a failure. In fact, one forward looking Cmucam behaves as an obstacle sensor as it's purpose is to detect potholes. The IGVC rules states under light rain, robots will still have to compete. While the placement of the other sensors in/on HARDCORE aids in waterproofing them, this is not the case for the cameras. We've decided that by mounting the camera's inside of project boxes with holes cut for the lens and wiring, we can sufficiently waterproof the camera modules by sealing the wiring holes and lens holes once the cameras are in the final positions.

3.2.2 Ultrasonics

In most instances, HARDCORE will always be driving forward and would only require a forward looking sensor, the primary of those being the lidar unit. However, there are cases where HARDCORE will need to pass between obstacles. While the lidar would see this opening and a path could be planned between them, the ultrasonics serve as redundant obstacle detection sensors in the case of failure of the lidar unit. Since our distance threshold for locating obstacles falls within the range of the ultrasonics, they can act as primary obstacle avoidance sensors in the case of an emergency.

3.2.3 Lidar

The lidar is a staple sensor for most teams in the IGVC for a good reason, it is a highly precise distance measuring sensor which communicates over standard serial connections. Most teams use units manufactured by SICK, which provide up to 180 degree coverage of the zone ahead of the robot. This sensor serves as our primary obstacle avoidance sensor. Unlike the ultrasonics which have a narrow beam width, the lidar can detect all obstacles ahead of the robot which allows for efficient path planning to go around (or between) them. Another club affiliated with MDRC generously donated to us the use of their lidar unit, allowing us to gain this valuable sensor without any financial cost.

3.2.4 Odometry

Hardcore has been outfitted with IR break/beam sensors which effect quadrature encoding of the movement of encoder wheels affixed to HARDCORE’s main drive sprockets. This allows closed loop control of HARDCORE’s speed, position, and orientation. In addition to being useful for regulating HARDCORE’s speed as it travels through “free” areas and those with obstacles, in the navigation challenge, the odometry allows HARDCORE to independently travel to the waypoints. However, the inaccuracies inherent in most odometry systems require that they be systematically corrected by an independent source of positioning information.

3.2.5 GPS

The GPS unit provides this independent correction to the odometry while simultaneous acting as the primary sensor for localizing HARDCORE between waypoints. Again, a club affiliated with MDRC has generously donated a differential GPS system for our use in this competition. The accuracy of differential GPS allows us to use it as a full correction to the odometry, rather than having to employ a probabilistic model to determine HARDCORE’s true position based on data from both sensor technologies.

3.2.6 Digital Compass

While both the odometry and GPS sensors are able to provide heading information for HARDCORE, they both require HARDCORE to be in motion and are subject to errors such as a loss of GPS signal or accumulated error in the odometry due to sensors missing readings and representation errors in the variables that track heading. As a result, a digital compass is necessary as a primary source of heading information.

3.3 Motor Control

Closed loop control of HARDCORE’s speed, position, and orientation is achieved using feedback from the quadrature encoders and a PID loop running on a PIC microcontroller. The PID loop is used to guarantee HARDCORE’s speed, while the true speed data collected by the quadrature encoders are fed to a set of functions which describe how HARDCORE’s position and orientation changes as a function of the speed of its drive motors and their distance apart. The main controller is able to issue speed, distance, or position commands to the PIC which then ensures that HARDCORE complies with those orders exactly. Additionally, a command can be sent to immediately halt HARDCORE if an obstacle was suddenly detected in the direction of motion, a lane excursion was eminent, or a software E-Stop executed. The PIC is a very low cost device, capable of being programmed in C, and supports the use of the trigonometric functions necessary to maintain an estimate of HARDCORE’s position and heading. In addition, we are able to clock this device at a high enough rate so that it can perform all of these functions in reasonable time, allowing for fast responsiveness, in spite of the architectural limitations of the processor.

Victor 883 motor controllers are used to drive HARDCORE’s motors. The controllers have a jumper which can select between letting the motors coast when the speed control signal is in a neutral position, or electromagnetically braking the motors when in neutral. HARDCORE is always operated with the brake jumper enabled. This way, if control was every lost from the PIC or when a software E-Stop is executed, HARDCORE will immediately halt. Additionally, the Victor defaults to brake mode if no jumper is installed, maintaining safety in the unlikely scenario that a jumper pops out.

3.4 System Integration

The overall system controller is a Pentium III machine with a 1GHz processor running Matlab inside of Windows XP. All devices ultimately communicate to the PC over serial. Using USB to Serial converters, the PC is able to support multiple independent serial ports. The cameras, GPS unit, and Lidar all communicate over serial. The ultrasonics and digital compass utilize I2C, transmitting their data to the PIC which uses its free processor cycles to route that data, as well as HARDCORE position data back to the PC over serial.

Matlab was chosen as the development platform for IGVC due to the availability of many built in math, graphical, and analysis functions. Additionally, programming in Matlab is a relatively simple task which would allow rapid development of control algorithms and their subsequent debugging. Additionally, graphical user interfaces (GUIs) are easily created in Matlab which can support further debugging of the system.

The main downside of using Matlab is the relative slowness with which code is interpreted, versus the execution of similar code that is compiled in another language. However, once modules have been coded, tested, and fully debugged in Matlab, more experienced C programmers can port the code to C/C++ and using the Matlab libraries, create an interface that allows efficient passing of data between a compiled DLL (Dynamic Linked Library) and a Matlab function, allowing us to gain the speed of native C/C++ code while enjoying the ease of development with Matlab.

4. Vehicle Intelligence

HARDCORE’s planner’s primary task is to generate paths for the robot to take to goal points while avoiding obstacles and staying within lane boundaries (if present). In the Navigation Challenge, the goal points are the waypoints themselves; the planner will only deviate from driving HADRCORE directly to goal points whenever obstacles are detected ahead. In those cases, it will temporarily replace the goal point with one that takes HARDCORE out of the path of the obstacle, once there, the waypoint is resumed as the primary goal point.

In the Autonomous Challenge, another function generates goal points for HARDCORE. This is done by classifying the operating regimes for HARDCORE into these four categories:

a. Cmucam sees a line, no obstacle(s) detected.
b. Cmucan sees a line, obstacle(s) detected.
c. No lines seen, no obstacle(s) detected.
d. No lines seen, obstacle(s) detected.

When the Cmucam sees a line, goal points are chosen to make HARDCORE follow the lane, as if it were a wall following robot and the lane, a virtual wall. If an obstacle is detected near the current line being followed, a new goal point will be chosen that will take HARDCORE to the opposite lane and allow it to follow that one. If HARDCORE approaches an obstacle in one direction, it will turn and attempt to approach the line opposite that obstacle.

At the very worst, this would have HARDCORE zigzagging as it travels between obstacles. Since the goal point is always placed ahead of HARDCORE's current position, HARDCORE should not get trapped between an obstacle and a line. However, to ensure HARDCORE can escape from those situations, a trap handler function will take over to backup HARDCORE and reorient it so that it can go around the obstacle. In the Navigation Challenge, HARDCORE should have an easier time planning smooth paths around obstacles since it doesn't have to deal with the lane restriction. The full frontal view of the Lidar unit ensures that HARDCORE's planners will never get it trapped in a corner, a situation in which robot's with simple obstacle avoidance behaviors are easily trapped.

Throughout the competition, there are instances where a sensor can fail. In most instances, there are backups for primary sensors. If HARDCORE looses GPS reception, it can navigate based on odometry alone. If the Lidar unit stops functioning, HARDCORE can fall back on the forward looking ultrasonic sensor. The digital compass is backed up by both the odometry and GPS. Also, failure of both the Lidar and ultrasonics can be compensated by employing the Cmucam's to detect obstacles.

However, while loss of one side looking Cmucam may be compensated by setting always having goal points that move HARDCORE towards the line on the working camera's side, or if both side looking camera's fail, the forward looking camera can be used by driving HARDCORE towards a line, determining its direction, and driving HARDCORE forward some distance before repeating this operation, loss of all the camera inputs could be devastating. As a result, we will attempt to develop code that can take advantage of the placement of obstacles and memory of where the lane markers were last seen, to guide the robot in the Autonomous Challenge.

As described earlier, the Navigation Challenge mode would not require a goal placer but instead make use of the waypoints. Once the list of waypoints is given to the team, it would be entered into a function which determines the order in which to traverse the waypoints. The function will, starting from the start position, guide HARDCORE to the closest waypoint. From there, it will travel to the next closest waypoint and repeat those steps until all are covered, then return to the start position. Since the odometry is subject to accumulating errors, once HARDCORE determines it has reached its destination, if it does not have GPS confirmation of this event, it will wait a predetermined amount of time, before attempting to navigate to the next waypoint. If there is time available after visiting the remaining points, it will attempt to revisit those points that it is unsure it crossed before returning to its start position.

5. Cost Analysis

Part	Vendor	Part Number	Quantity	Total Cost	IGVC Cost
HARDCORE II*	RIT MDRC	II	1	$1500	$0
Suspension	Various	None	2	$?	$0
Rubber Bumper	McMaster-Carr	9540K61	12 packs	$67.44	$0
18-8 Rivets	McMaster-Carr	97525A473	9 packs	$82.80	$0
Roller Chain Holder	McMaster-Carr	6052K14	1	$17.56	$0
Grooved Clevis Pin w/ Retaining Ring	McMaster-Carr	92735A140	2 packs	$11.36	$11.36
12V Batteries **	?	?	2	$120	$0
Cmucam v2+	Acroname	R245-	2	$338	$338

		CMUCAM2-PLUS			
Cmucam v2	Acroname	v2	1	$199	$0 -
Devantech Sonar Ranger	Acroname	R145-SRF08	2	$119.00	$119.00
Devantech Sonar Ranger	Acroname	R241-SRF10	1	$59.50	$0 -
PIC	Microchip		12	$0 -	$0
DGPS	RIT GCART	?	1	$?	$0
Lidar	SICK->RIT GCART	LMS	1	$5000	$0 -
USB/Serial Converter	Acroname	S19-USB-SERIAL-INT-CONN	5	$110.00	$110.00
Proto Board	RadioShack	?	2	$6 -	$0
4 Pin Headers	Mouser	571-874997	20	$10.40	$10.40
3 Pin Headers	Mouser	571-874995	10	$5.90	$5.90
Crimp Connectors	Mouser and Others	?	> 100	>$17.00	>$17.00
Wire (all types)	Various	Various	Too many to count	$? -	$0
Pentium III PC	IBM	Thinkpad x24	1	$385 -	$0
Project Box (for Cmucam v2+)	Mouser	546-1593KBK	4	$8.80	$8.80
Project Box (for Cmucam v2)	Mouser	546-1598BBK	2	$22.44	$22.44
IR Break/Beam Sensors	?	?	8	$16.00	$16.00
Totals				>$8096.20	> $658.90

* HARDCORE II comes complete with two 12V drive motor batteries and a single 12V battery for the electronics box, Victor 883 motor controllers, power distribution circuits, e-stop, track, chain, sprockets, and frame.

** HARDCORE III required more batteries to guarantee power to the IGVC sensor/computing suite.

+ RIT MDRC received this item free of charge and did not incur this cost in the past.

- These items were either donated to the club, belong to club members, or are being borrowed by the club.

6. Conclusion

The HARDCORE platform was a great starting point for RIT MDRC's entry into this competition. Based on our previous experience operating HARDCORE as a GPS guided obstacle avoiding robot, as well as other experiences with smaller robots, some designed solely to research GPS guidance methods, others which focused on obstacle avoidance techniques, we feel that HARDCORE III is ready to perform competitively in the Navigation Challenge and will place within the top six.

The Autonomous challenge adds a lane following element which must be integrated with our current obstacle avoidance and guidance techniques. We feel that our design choice of using the Cmucam's to track the lane markers, a proven system (on smaller robots), will make a great difference between the usual choice of other teams – using webcams or camcorders as vision sensors and writing their own image analysis and processing code. By simplifying the vehicle intelligence system to work with smarter sensors, we can devote more time to developing control algorithms – which all teams would have to do anyway. Based on the past performance of other teams in IGVC, we are confident in stating that HARDCORE III will also place within the top six in the Autonomous Challenge.

Part of our design objectives is to optimize our available time and resources. Where most other team's participation in IGVC is part of a senior design course, MDRC is an all volunteer team of students who work on their spare time. Our design was driven by a desire to show that by appropriate selection of sensors, a good base, and fast development platform, we can still produce a robot with equal or greater performance to the other participating teams.

7. Acknowledgements

The IGVC team would like to thank the HARDCORE design team, including many former members not listed who participated in HARDCORE's design, construction, testing, and previous programming. We'd also like to thank the members of the RIT MDRC who contributed time, knowledge, code, and other valuable help to the team. We'd also like to recognize the help from RIT GCART and the College of Engineering. We say thanks to:

Dr. Ferat Sahin (EE Assistant Prof and Advisor of MDRC, RIT)
Dr. Harvey Palmer (Dean of the Kate Gleason College of Engineering, RIT)

RIT Student Government
RIT GCART
Gumstix Inc

Chris Armenio, Sean Croteau, James Dawson, April Diak, Mike Duke, Mike Egan, Kevin Egan, John Floren, Eric Hammerle, Patricia Heneka, Josh Karpoff, Alejandro Lam, Mark Mckann, Nathan Pendleton, Steve Pomeroy, Zac Poncheri, Andrew Snodgrass, Jason Stanislawski, Aleksy Tentler, Nick Valerio, and everyone else who has contributed significantly to HARDCORE and IGVC at RIT whose names I cannot find or remember.