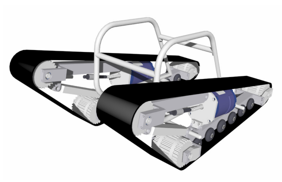

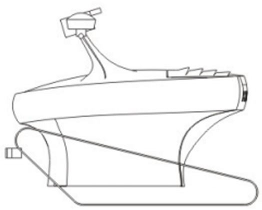

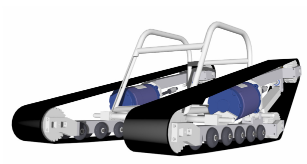

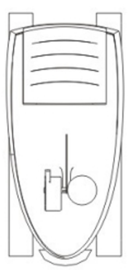

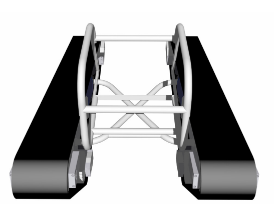

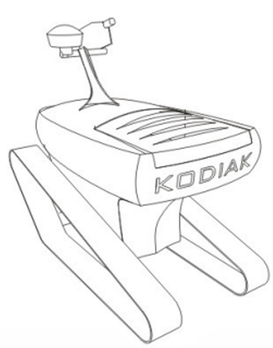

autonomous robotic vehicle project

2002 Kodiak Design Report

10th annual intelligent ground vehicle competition

Presented to:
William G. Agnew
Chair of Design Judging Panel

autonomous robotic vehicle project

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1.0 Introduction

The Autonomous Robotic Vehicle Project (ARVP) is a task-oriented endeavour. Its primary mission statement is, "to annually design, test and implement an autonomous robotic vehicle system suitable for participation internationally at the Intelligent Ground Vehicle Competition (IGVC)." The team structure reflects the practical necessities of creating such a robot. Additionally, the team dynamics are also influenced by our secondary mission statement, "the ARVP will also strive to foster strong ties with, and garner positive public relations for, both the University of Alberta and surrounding communities." This report aims to outline the team organization, design process, and technology implemented to create the ARVP's fourth vehicle and 10^{th} Annual IGVC entry, *Kodiak*. *Kodiak* builds on the successes and addresses some of the shortcomings of its predecessor and test platform, *Bear Cub*. *Kodiak* was designed with safety, reliability, and durability in mind. At the same time, it is a very versatile platform with abilities and constraints extending beyond IGVC guidelines such as the capacity to navigate rough terrain, stairs and steep slopes while remaining useable indoors. These qualities and its modular design make it both an excellent experimental vehicle and marketable commercial platform.

2.0 Team Organization

To address the goals of the ARVP, the project has several teams operating semi-independently to complete their allocated tasks. The overseeing body is an executive comprised of elected leaders chosen from each of the sub-teams. The sub-teams include the Sponsorship, Logistics, Administration and Marketing (SLAM) Team, the Mechanical Team, the Electrical Team, the Computer and Software Development Team, the Community Outreach Team, and the recently developed Features and Applications Team (FAT).

On an annual basis following the IGVC, an election decides the members of the executive. The Project Coordinator can be elected from among the team leaders or from the general team roster. The Faculty Advisor is the only non-elected position on the executive and is held by a professor provided by the Faculty of Engineering.

The executive meets on a regular basis to discuss the status of the project in order to set goals and allocate funds. In addition to the council meetings, there are weekly general meetings that all members are encouraged to attend. These meetings are intended to inform members of the ARVP about upcoming plans and events and to provide a forum for general input and feedback. Updates from the each of the sub-teams encourages all members to participate in any portion of the project that may be of interest.

Each of the sub-teams has a specific role in the creation of the robot for competition. The SLAM team is responsible for the various business aspects such as liaising with the University, procuring sponsorship, creating an annual budget, organizing events, purchasing the materials necessary to build the robot, and making travel and accommodation arrangements to reach the IGVC.

The main technical aspects of the project are carried out by the Mechanical, Electrical, and Computer and Software teams. The Mechanical team both designs and builds the robot, keeping in mind the needs of the Electrical and Computer and Software Development teams. The Electrical team designs, tests, and installs all of the electrical systems necessary the robot to function. The Computer and Software team chooses appropriate computer hardware for the robot and writes the code necessary for both the sensory systems of the robot and its locomotion.

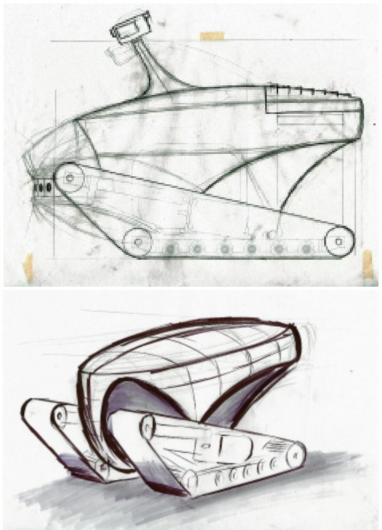
Instituted last year, the Community Outreach team continues to provide public education regarding technology and robotics. Events have included speaking at schools, participating in science fairs, and running summer day camps. The Outreach team has also expanded the scope of its activities to include a more mature audience through presentation to retired alumni at the University.

The Features and Applications Team (FAT) was created this year to assure the robot a professional appearance. It also develops potential uses for autonomous vehicle technology. This past year, the FAT designed a device that could be attached to the robot and used to collect soil samples in hazardous areas such as mine tailings ponds. This creative idea allowed the FAT to compete successfully in both the Western (Canadian) Engineering Competition and Conference (WECC), and the Canadian Engineering Competition (CEC).

3.0 DESIGN PROCESS

To maximize the time available for development, the ARVP employs a staggered design process. Following the fall semester of classes, the team leaders of the ARVP meet to discuss IGVC rules and regulations, goals and abilities of the current team, and new ideas and technologies that could be implemented in the next generation vehicle.

The concept vehicle resulting from this meeting is then researched to determine its feasibility. Drawing from the wide range of backgrounds, ideas, and experiences of the ARVP's thirty members, the efficiency and overall technical practicality of the design is explored using technical theory,



Early artist conceptions of *Kodiak*

calculations, and various software design analysis programs (see 4.3). At the same time, financial constraints are considered and marketing methods of the new design are suggested to best attract attention and sponsorship from the public and industry. It is here that the aforementioned Features and Applications Team contributes with a vested interest in the creation of a saleable product.

Due to the public nature of the project, safety and reliability are paramount design factors. Emergency equipment such as the remote stop and mechanical guards are discussed to ensure that team members and the general public are not endangered at publicity events, outreach school visits, or tradeshows when the robot is demonstrated. Also, hot-swappable and interchangeable parts as well as diagnostic tools are considered to reduce downtime and increase reliability.

After much research and design modifications, a functional vehicle concept has been established and the ARVP returns its focus to completing the vehicle that will attend the current year's IGVC.

Following the competition, the concept vehicle is revisited and design enhancements are made reflecting competition results and the desired performance. By this point, each sub-team of the ARVP has specific and task-oriented goals that lead to the creation of the vehicle. In the final design stages, an industrial design student is consulted to finalize dimensional constraints and create a body for the vehicle to provide protection for the sensitive electronics onboard and mechanical fixtures that make up the robot.

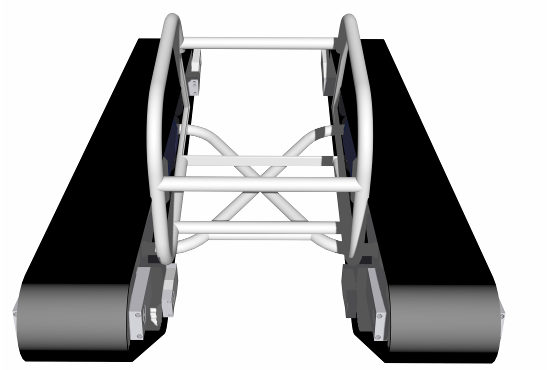
The final step in the design consists of testing, troubleshooting, optimization, and component packaging to prepare the robot for demonstrations and the competition.

4.0 MECHANICAL SYSTEMS

The mechanical design of *Kodiak* focuses on simplicity, flexibility, durability, and most importantly, safety. A modular construction approach allows for a versatile platform that is able to compete in the IGVC while remaining adaptable to other tasks. Two identical and interchangeable track subassemblies contain the drive motors and worm gear reduction drivetrain components. These subassemblies are mounted to a subframe which in turn connects to the frame housing the computer, electronics, and power supply. This design makes for quick on-site assembly and permits substantial modification of key components without major overall design changes.

4.1 Frame and Subframe

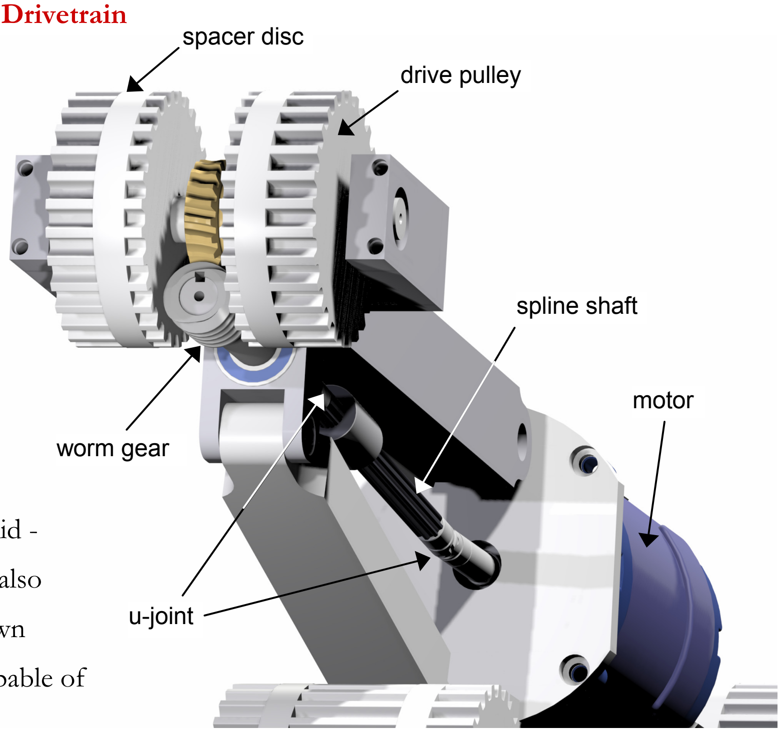
Both the frame and subframe are constructed from mild carbon steel (AISI 1024) due to its desirable functional properties, workability, and availability. The load bearing members consist of Tungsten Inert Gas (TIG) welded 1" (25.4mm) diameter round tubing. To minimize deflection, wall thickness of 0.09" (2.29mm) was chosen. In the event a collision or loss of control, the frame is designed to protect sensitive onboard electronic hardware by encompassing the components within a cage. Additionally, the rear of the frame is sloped to facilitate battery access and prevent terminal shorting when swapping units. The frame is mounted to the subframe using rubber shockmounts to reduce vibration and allow for a small degree of lateral motion. The subframe is designed to connect the frame to the two track subassemblies and permit easy assembly of the robot without the use of tools.



Kodiak front view featuring frame and subframe

4.2 Track Subassembly and Drivetrain

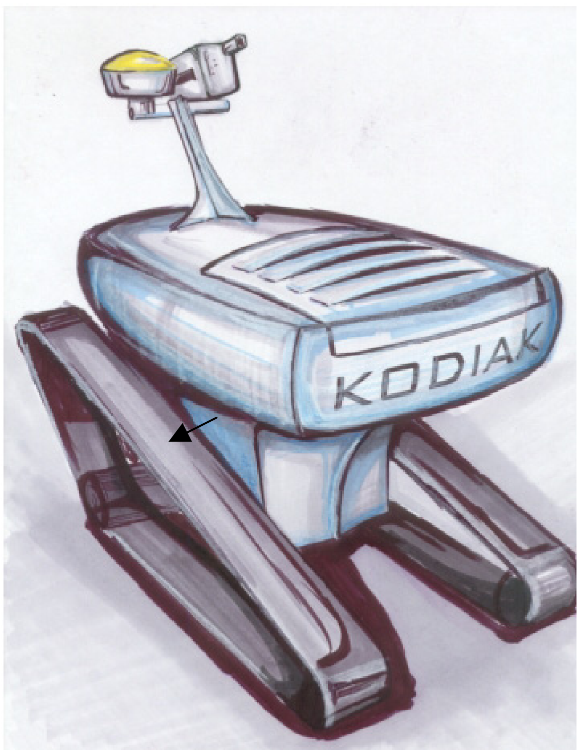
In order to achieve a modular construction for *Kodiak*, the entire drivetrain is packaged within the two track subassemblies. At the heart of subassemblies are two Leeson Canada C4D17NK9C 24V DC motors. Each motor is rated at 1/3 HP at 1800 RPM. These motors provide the torque necessary for skid - steering in close quarters and have also enabled the ARVP to achieve its own design goal of creating a vehicle capable of



Kodiak drivetrain

climbing stairs and navigating hazardous terrain. A u-joint connects the motor shaft in each subassembly to a telescoping drive shaft to compensate for misalignment. A second u-joint on the opposite end of the drive shaft transfers power to the worm shaft which in turn drives the worm gear at a reduction of ten to one. The track is powered via the front drive pulley and is aligned by discs mounted within each pulley. These discs and twelve bogey wheels per subassembly run in channels in the belt that prevent the track from walking.

4.3 Vehicle Body



Artist rendering of *Kodiak* complete with body

Kodiak's fibreglass body is designed with form and function in mind. This shell gives the vehicle a pleasant appearance for public demonstrations and provides area for displaying project decals and sponsor logos. The body is also functional as it protects all components from direct sunlight and moisture while housing the onboard notebook computer at a useable height. The shell also features mounts for the video camera and GPS antenna. With the humidity and heat present in Florida's climate, active cooling of the vehicle is necessary. The shell fulfills this requirement with embedded fans that draw cool air from the base of *Kodiak*, cycle it through the vehicle, and eject it through vents at the upper rear of the body.

4.4 Design Tools

The mechanical design of *Kodiak* was accomplished using a combination of software packages. Parametric Technology Corporation's (PTC) Pro/Engineer was used to design parts for *Kodiak* and assemble them in a 3D virtual space on computer workstations. However, Pro/Engineer proved to be difficult to work with when optimizing the design of the linkages on the track subassemblies. For this purpose the Solidworks application was utilized for its speed and ease. In addition, PTC's Pro/Mechanica was used for component stress analysis and optimization via Finite Element Methods (FEM). The use of these computer aided design packages minimized costly fabrication errors and virtually eliminated laborious prototyping.

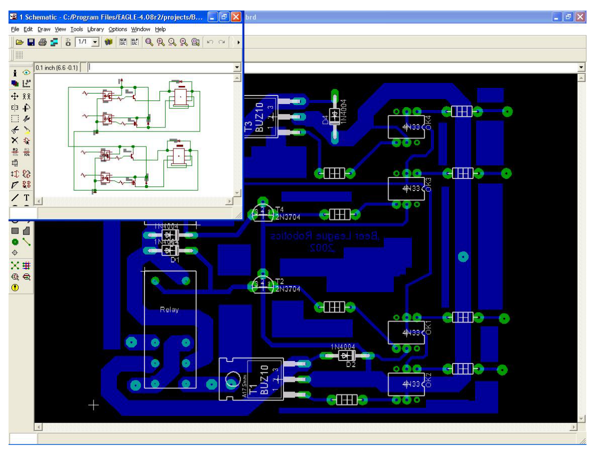
4.5 Performance

Kodiak is quite a manoeuvrable vehicle. Its skid method of steering gives it the ability to turn on the spot in dead-end or trap situations, while a ground clearance of 3.8" (96.5mm) is sufficient for most applications. Being only 27.75" (704.8mm) wide, *Kodiak* is also able to pass through all standard door sizes to allow for indoor testing. To provide stability and prevent rolling in extreme circumstances, the length of *Kodiak* was chosen to be 50.1" (1272.5mm).

Given the front-heavy nature of the track subassemblies, the batteries and cargo space were positioned as near to the rear of the frame as possible. As a result, the center of gravity is located approximately 9" (229mm) from the ground and just rearward of the front bogey wheels. With a net mass of 278lb (126kg), *Kodiak* is capable of attaining a maximum speed of 4.4mph (7.2 kph) and a maximum forward acceleration of 0.1G (1m/s2). Motor torque is sufficient to overcome a 30° incline. Following testing, it was discovered that all actual performance specifications agreed with those predicted to within 15%. This small variance can be accounted for by imprecise belt tension and excessive friction.

5.0 Electrical Systems

Electrical systems on *Kodiak* were designed to fulfill four tasks: data acquisition, low-level control, motion control, and power.



Computer-aided electronics design facilitates planning, fabrication, and testing

5.1 Data Acquisition

Sensor data is collected using three main systems: a Sound Navigation And Ranging (SONAR) array to gather physical object detection information, camera vision for line, pothole, and obstacle detection, and motor shaft encoders to gather velocity feedback from each track on the vehicle.

5.1.1 SONAR

The SONAR array consists of 6 high frequency transducers that are placed in an arc formation for maximum object detection capabilities. Each transducer has a conical region of coverage of 13 degrees that slightly overlaps to create a total detection range of 60 degrees. The individual transducers are accurate to +- 3 cm in air temperatures ranging from –30 ºC to 70 ºC and humidity ranging from 5% to 95% with a range of approximately 10m. Failures of the SONAR array due to particulates are eliminated using a custom designed array enclosure, which houses the circuitry of the transducers as well as the custom built circuitry designed to relay information from the transducers to the microprocessing unit.

5.1.2 Vision

The vision system consists of a Sony Handicam (DCR-TR7000) positioned to capture images of the area in a 3 m field of view in front of the vehicle. This camera was chosen for its low cost, high resolution, simple interface, self-contained power supply, and the ability to record video for later analysis and testing. The images obtained are transferred for processing via the Firewire (IEEE-1394) protocol.

5.1.3 Motor Feedback

Custom made optical shaft encoders connected directly to the motor output shafts provide real-time feedback and closed-loop control of the drive system. They consist of a spinning perforated disk that interrupts a beam of light at regular intervals. The encoders send a square wave corresponding to the resulting light pulses that the software converts into speed and acceleration information.

5.2 Low-Level Control

5.2.1 Microprocessor

The low-level control of *Kodiak* is accomplished with a Motorola 68332 microcontroller. This microcontroller was chosen for its low cost, ample processing power, and sufficient number of I/O lines. The 68332 handles redundant tasks that would otherwise slow down the higher-level artificial intelligence such as motor and SONAR control. With this year's addition of a custom daughter board for all microcontroller connections, protection, maintenance and reliability have been greatly improved. Another microcontroller enhancement is an LCD display. This simple interface will help with operation and troubleshooting.

5.3 Motion Control

5.3.1 Motor Drivers

The motor in each track subassembly is controlled by a NCC70 motor driver manufactured by Q4D. Each NCC70 controller is capable of outputting 100A of continuous current at 24V for a maximum continuous power transfer of 2400W. This controller was chosen for its excellent efficiency (negating need for active cooling) as well as numerous useful built-in features such as temperature cut offs, variable ramping, variable maximum speed, and regenerative braking.

5.3.2 Emergency Stop

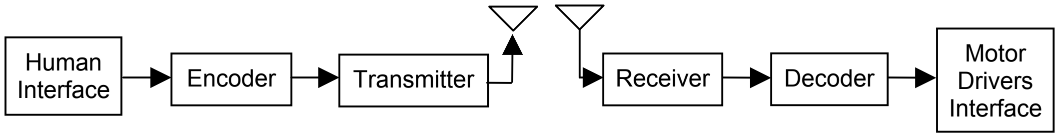
The emergency stop on *Kodiak* is controlled using a 2-button key-ring UHF transmitter. By pressing one of the two buttons, a signal is sent to activate a receiving circuit board equipped with two relays. The key chain transmitter operates from 300 to 375 MHz and has a tested range of up to 40 meters away.

The receiver circuit board, powered by 12V-15V, processes a signal via a bandpass filter, amplifier and Schmitt trigger. Its output delivers a digital pulse train to the input of a decoder IC. When the decoder IC receives data with valid information, one of the two relays is toggled corresponding to the button pressed on the transmitter.

To protect against dangerous situations and to prevent failures at competition, false triggering of the system has been avoided using flip-flops in an RC network. Protection diodes have been connected across each relay to limit the back-EMF when the relay is de-energized.

5.3.3 Remote (Manual) Operation

A radio frequency remote control was developed to provide a means of controlling the robot manually. The remote control systems block diagram is below. It consists of a human interface, encoder, transmitter, receiver, decoder, and the motor control circuitry. The human interface is a simple arcade style game pad with 4 - directional buttons and 4 levels of speed control. This information is then encoded into a binary serial stream (which contains error correction and device addressing) using a Holtek 640 – 8 bit encoder. The transmitter block uses amplitude modulation (AM) which modulates the carrier signal with the encoded data and amplifies it for transmission through free space. The transmitter used was the TWS-434 transmitter module. Now that the signal has reached the robot, the receiver demodulates the incoming radio wave at 433MHz using the RWS-434 receiver module. The original serial information is then fed into the Holtek 648 – 8 bit decoder, where the data integrity is verified. Upon verification the decoder outputs the correct speed and directional information to the motor control circuitry that in turn drives the robot. The remote control has been tested successfully at a range of approximately 200 feet.



Kodiak's Remote control process diagram

5.4 Power Requirements

Two 12V 75 Amp-hour gel cell batteries (Power Battery EG24) connected in series supply power to *Kodiak*'s drive motors. These batteries are easily swapped for recharging and were chosen for their high current output, air-transport approval, and endurance that allows the vehicle to operate for approximately two hours under regular use. To isolate the motor system from other sensitive electronics, a separate small 24V battery with a custom regulator and filter is used to power these components. This battery is long lasting, accessible, and is easily recharged. Further protection of the electronics is achieved by shielding the motors and radio frequency (RF) devices to prevent interference. The video camera and onboard notebook computer both contain individual power supplies consisting of either a rechargeable lithium ion battery or an AC adapter used during stationary testing.

6.0 COMPUTER AND SOFTWARE SYSTEMS

6.1 Hardware

Kodiak's onboard notebook computer is a Fujitsu Lifebook with a 500MHz Intel Celeron CPU, 128 MB RAM, and Debian Linux as its operating system. This product was chosen for its adequate processing power, available drivers, and low cost. The only significant addition to the computer is a PCMCIA Firewire (IEEE-1394) adapter that interfaces with the video camera.

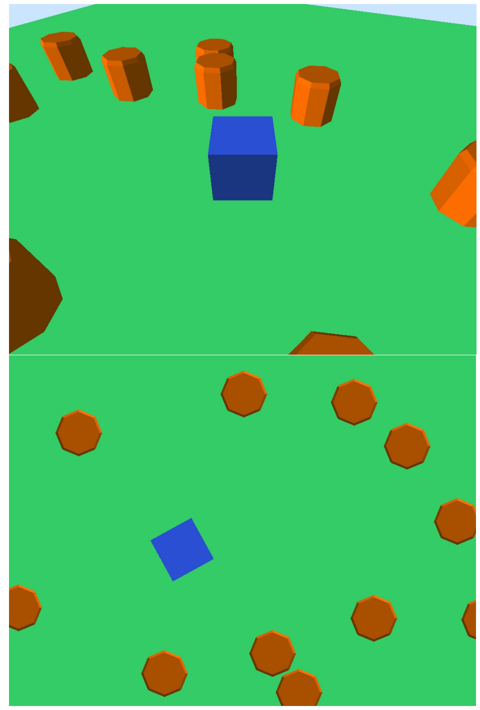
6.2 Map Representation

The two main sensors (SONAR array and camera vision) act with a range of 3 m to construct a map of the robot's environment in order to make path decisions. The operation, input sensors, and software interfaces of the *Bear Cub* test platform are quite different from *Kodiak* in some aspects. As a result, an abstract method of sensory data representation is needed to allow for a single path-finding algorithm that behaves identically on both machines. Map representation accomplishes this task.

Any obstacle that the robot interacts with can be represented by a group of line segments. To avoid this obstacle, the algorithm determines a path that does not cross any of its representative lines. Thus, the resulting motor commands are issued based on a two-step process:

1. All sensory data is converted into line segments in real world coordinates.
2. The map of line segments is used to ascertain the best direction of travel.

In the context of IGVC events, this process combines the sensory data involved in lane following and obstacle detection into something visually understandable to the user and useful for Artificial Intelligence path decisions.

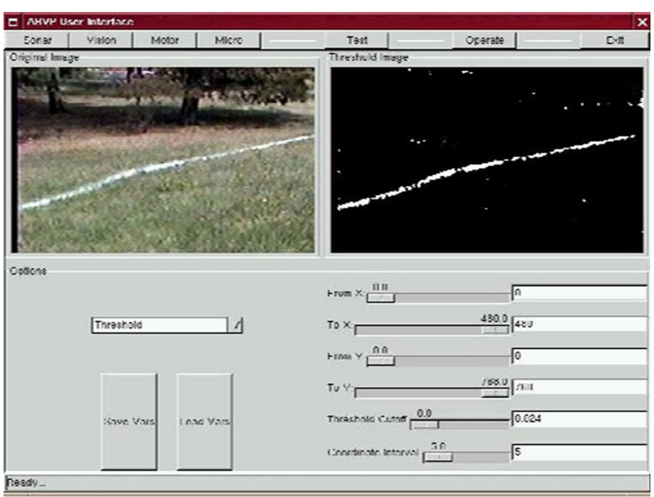


Map representations generated for testing *Kodiak*'s software algorithms

6.3 Sensor Data Conversion

6.3.1 Vision Data

The images received from the video camera by the software are processed using a histogram threshold algorithm to extract white shapes and convert them into a list of pixel coordinates. A parallel process is used to detect bright orange and extracts additional information from the image about the location of construction barrels on the course.



The User Interface was developed to calibrate SONAR and video equipment and issue motor commands for mechanical testing and debugging. Here, it displays a pre- and post-processed image of a painted line during testing.

It is essential that the same coordinate system be used to represent all points in this map. Therefore, the software uses an algorithm to convert the pixel coordinates into world coordinates that are then joined to construct a line.

If it were left at this point, the robot would know not to cross the portion of the line that was visible to the camera. However by approximating each line as maintaining its direction beyond the edge of the camera's view, the robot is able to avoid an upcoming line. Consequently, the robot may be less reactive and may plan a better "long-term" heading.

Pothole detection is achieved using an algorithm that scans each camera image to find large white elliptical regions. This algorithm serves a dual purpose as it also detects white pails that will be present on the competition course. However, through testing it has been found that lines and bright regions of grass are wrongly interpreted as obstacles to avoid when using this algorithm. Based on current testing, our team may or may not use this algorithm at competition depending on its reliability. If it is used, the corners of the regions will be converted to world space coordinates and a roughly circular polygon will be used in the map to represent the pothole.

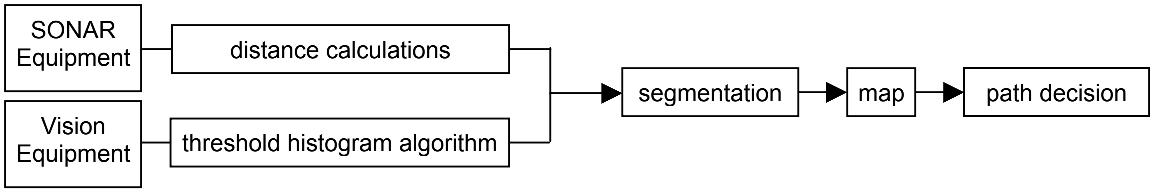
6.3.2 SONAR Array Data

When the computer receives information from a valid SONAR ping, it converts that ping into a distance. To account for the width of the SONAR transducer cone, the software conservatively estimates the obstacle responsible for the ping as an arc at the measured distance that sweeps out the angle of the cone. This arc is put into the map as an obstacle to avoid.
Obstacles detected in this fashion may be larger in the map than in reality. This uncertainty ensures that the robot avoids them. As the robot approaches an obstacle, the resolution provided by each SONAR cone in the array improves enabling the software to continuously make better path decisions.

6.4 Path Decisions

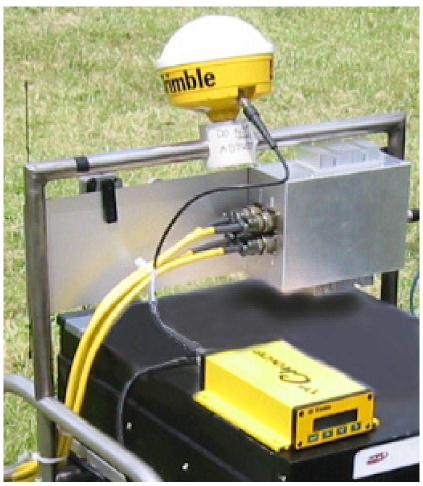
Once all of the sensor readings are converted into the map, the software has a good representation of the field in front of it and can go about finding the best path. To find the optimal heading, the software determines how far the robot can travel in a given direction before encountering an obstacle. It tests headings at a resolution of about one degree in a range of 90 degrees left and right from its current heading.

From this sampling of angles, it chooses the angle that will safely take it the greatest distance. If this angle represents only a small deviation from the current path, it will continue in its current direction. If the angle is greater, it will try to turn in an arc towards that heading. However, if the angle is too large or if there is an obstacle immediately in front of the robot it will stop immediately and turn on the spot to move to the new heading. These path decisions occur several times per second, allowing the robot to advance through the course while avoiding obstacles.



Kodiak's interpretation of sensor data to make path decisions

6.5 GPS Navigation

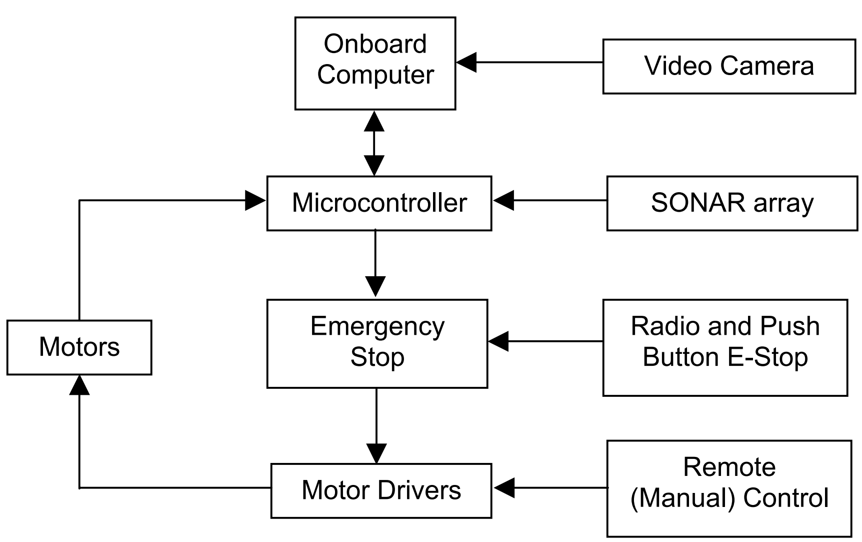


The Trimble AgGPS 132 GPS receiver on the *Bear Cub* test platform

At the heart of any successful GPS navigation is the GPS unit itself. *Kodiak* uses the Trimble AgGPS 132, a high performance GPS receiver supporting OmniSTAR, Racal-LandStar or Coast Guard Beacon Tower real-time differential GPS. With as few as 6 well-positioned satellites, the receiver is capable of sub-meter accuracy on all position information, and it supports up to twelve satellites for even further accuracy. This positional information is communicated over a serial port to the *Kodiak*'s onboard computer which decodes and interprets it.

The waypoints are visited in the order determined by a pre-computed shortest path algorithm which also takes into account the time limit imposed by the event. As obstacles are encountered and detected by SONAR, the robot modifies its course to avoid obstacles while continuing toward the next waypoint. *Kodiak* also attempts to keep moving throughout the event to improve the GPS directional information and increase the chances of reaching more waypoints in the allotted time.

7.0 System Integration Diagram



8.0 Conclusion

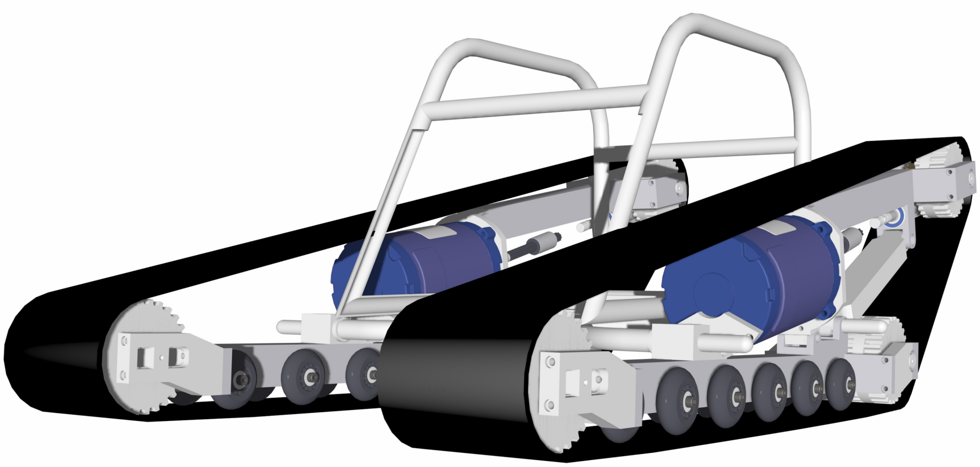
Kodiak is a fully autonomous robotic vehicle that was designed, built, and manufactured by students from the University of Alberta's Autonomous Robotic Vehicle Project. The platform was designed with safety, reliability, durability, and versatility in mind. The mechanical and electrical systems were created with the intent of both indoor and outdoor operation in a variety of environments. The software and high-level control systems were designed for lane following, obstacle detection and avoidance, and GPS navigation challenges at the 10th annual Intelligent Ground Vehicle Competition. The ARVP team has been very fortunate this year that most major design requirements were met and exceeded by the Kodiak platform, and plans to continue attending the IGVC in the future.

9.0 Team Members

Name	Sub-Team	Discipline	Year
Barton, Kit	Computer Team Leader	MSc Computing Science	2
Buksa, Graham	FAT Team Leader	BSc Electrical Engineering	3
Cooke, Terry	FAT	B.A. Industrial Design	4
Fan, Dorothy	Software Team	BSc Computer Engineering	2
Flanders, Megan	Electrical Team	BSc Electrical Engineering Coop	4
Hammerlindl, Andy	Software Team	BSc Engineering Physics	2
Huston, Carolyn	ARVP Team Leader	BSc Biology	4
Jabakhanji, Duha	FAT	BSc Computer Engineering	4
Johnson, Kris	FAT	BSc Electrical Engineering	3
Kachurowski,Allen	Outreach Team Leader, FAT	BSc Electrical Engineering	3
Kastelan, David	Mechanical Team, FAT	BSc Engineering Physics	2
Kimaru, Jeremiah	Software Team	BSc Computer Engineering	4
Klaus, Jason	Software Team	BSc Computer Engineering Coop	3
Klippenstein, Jon	Electrical Team	BSc Engineering Physics	2
Knowles, Robert	Mechanical Team Leader	BSc Computer Engineering Coop	2
Korus, Roger	Electrical Team	BSc Engineering	1
Kwan, Andrew	Mechanical Team	BSc Mechanical Engineering	2
Law, Jody	Electrical Team, FAT	BSc Electrical Engineering	3
Marcos, Joseph	Mechanical Team	BSc Mechanical Engineering	2
Ng, Jason	Electrical Team	BSc Engineering Physics	2
Ozeroff, Chris	Electrical Team	BSc Engineering Physics	2
Pegoraro, Adrian	Electrical Team	BSc Engineering Physics	2
Rashid, Samir	FAT	BSc Electrical Engineering	3
Sieben, Vincent J.	Electrical Team	BSc Electrical Engineering	4
Tutscheck, Monte	Mechanical Team	BSc Mechanical Engineering	2
Wong, Bryant	Electrical Team	BSc Electrical Engineering	2
Woo, Randy	Electrical Team	BSc Electrical Engineering	3
Wrathall, Nicolas	Electrical Team Leader	BSc Electrical Engineering Coop	3
Yuen, Stacey	SLAM	BSc Engineering	1
Toogood, Roger	Faculty Advisor		

10.0 Component Cost Summary

Component	Model	Quantity	Unit Price	Subtotal
Mechanical Components				
Mild Steel Tubing	AISI 1024	1	$23	$23
Aluminum stock	AISI 6061	1	$911	$911
steel bar stock	AISI 4041	1	$72	$72
Motors	Leeson Canada C4D17NK9C 24V DC	2	$391	$781
Tracks	single-sided timing belt	2	$325	$651
bearings	NSK-6004 20 mm	16	$7	$115
rollerblade wheels		24	$5	$125
rollerblade bearings	ABEC-5	24	$4	$94
worm gear assembly		2	$59	$118
spline shafts		2	$42	$84
u-joints		4	$24	$96
Shell	Fiberglass cloth, Resin, Gelcoat	1	$325	$325
Electrical/Computer Components				
Micro	Motorola MC 68-332	1	$99	$99
LCD		1	$12	$12
Motor Controllers	Q4D NCC 70 24	2	$261	$522
Remote Control	Custom	1	$35	$35
E-Stop	Custom	1	$35	$35
Batteries	Power Battery EG24	4	$120	$482
GPS	Trimble AgGPS 132	1	$5,077	$5,077
SONAR array	Custom	1	$195	$195
Video Camera	Sony DCR-TR7000	1	$521	$521
Shaft encoders	Custom	2	$33	$65
Notebook	Fujitsu Lifebook	1	$423	$423
PCMCIA Firewire	Evergreen Technologies Fireline	1	$78	$78
		TOTAL ($USD)		**$10,940**



Kodiak