University of Alberta

9th Intelligent Ground Vehicle Competition
Bear Cub Research Vehicle
Technical Report 2001

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

Executive Summary

The objective of the Autonomous Robotic Vehicle Project (ARVP) is to design and fabricate a fully autonomous vehicle that satisfies the constraints determined by the Intelligent Ground Vehicle Competition (IGVC). The current platform, henceforth referred to as *Bear Cub*, is the vehicle that the University of Alberta has successfully implemented for the 9th annual IGVC. The *Bear Cub* is an autonomous platform entirely developed by both undergraduate and graduate students from various departments at the University.

In addition to the *Bear Cub*, the University of Alberta is currently developing a new vehicle, called the *Kodiak*, which will be utilized for the 10th annual IGVC. The *Kodiak* will not be discussed in this report, but will be mentioned due to the staggered development design process used by the University of Alberta.

The main objective of the mechanical design team was to develop a platform capable of navigating equally well in both indoors and outdoors environments. Therefore, a relatively small, simple, lightweight and rugged design was developed. This vehicle fits through standard doorways and can be used for testing and further development at any location.

The *Bear Cub*'s electronics systems are designed for reliability and ruggedness. These systems were also designed for ease of replacement and systems integration capabilities with the *Kodiak*. The *Bear Cub* has four independent electric motors, which are used for skid steering maneuverability.

Software, which provides the control of the vehicle, has also been thoroughly considered. This vehicle interprets the surrounding environment through the use of artificial intelligence (AI). In addition to AI, a user interface (UI) was developed to allow for easy control of the vision, SONAR and mechanical systems when testing.

Thorough design, development and implementation have allowed the Bear Cub to be a successful vehicle for the ARVP.

Table of Contents

1.0 Introduction

The primary objective of the 2001 Autonomous Robotic Vehicle Project (ARVP) from the University of Alberta is to develop a simple, reliable and fully autonomous platform, which satisfies the constraints of the Intelligent Ground Vehicle Competition (IGVC). This report summarizes the design process, team organization and the innovation involved with the project. The technical aspect of the project is included in four sections: Mechanical, Electrical, Software (low and high level control) and Systems Integration. The *Bear Cub* is the third vehicle designed by the ARVP since the instigation of the project five years ago, and will be used to compete at the 9th Annual IGVC. The *Bear Cub* was originally designed as an indoor testing platform to be used in conjunction with the *Polar Bear*, which competed last year. However, it is expected that (in the future) the *Bear Cub*'s systems will be integrated into the new robotic platform (called the *Kodiak),* which is currently in production for the 10th annual IGVC.

2.0 Project Overview

2.1 Team Dynamics

The ARVP is a multi-disciplinary team of students aiming to implement an autonomous robotic system in a vehicle. The team consists of students and faculty from various departments at the University of Alberta. Mechanical, electrical and computer engineering students make up the core of the team, however, there is a strong involvement of students from the departments of science, arts and business. Involvement with the ARVP allows students the opportunity to extend the knowledge and tools obtained in the classroom to a real-world application. Most importantly, the ARVP permits students to gain valuable experience and skills.

2.2 Design Strategy and Planning

This year the ARVP has made several major changes regarding project planning and coordination. These changes are essential to the continued success, growth and long term planning of the project. There are approximately 50 students actively involved with the project at any given time of the year. Due to the relatively large number of students, there are both general and team leader meetings on a weekly basis to maintain communication and update critical path deadlines. Over the last twelve months, project participants have volunteered an estimated 5500 hours towards the *Bear Cub* and *Kodiak* platforms.

Staggered design has also been implemented in order to maintain development on two platforms. One existing platform is utilized for optimization and to ultimately enter competition, while the second is in development for the following year. In this manner, a platform would be available for year-round testing purposes. With staggered planning, a more thorough design can be successfully accomplished, as each new platform receives a full year of development and then up to eight months of testing prior to competition. This also allows the software team to function independently of the mechanical team. For example, the *Bear Cub* robot has been available for testing since May 2000 and is competing this year, and the *Kodiak* was started in June 2000 and is currently in production. This new platform will be competing at the IGVC in the summer of 2002.

2.3 Design Process

The initial step when considering any engineering application is to clearly identify the problem and all of the pertinent constraints. In this case, the project constraints and requirements were specifically determined by the rules and regulations set by the 9th annual IGVC. After the constraints were completely identified a series of brain-storming sessions were coordinated among the mechanical, electrical and software teams. These sessions were very useful in that they developed several alternate solutions to the problem. It is also important to note that these alternative solutions were constantly re-evaluated in terms of the pre-specified constraints. This iterative process allowed the design team to identify the optimal preliminary design solution.

The preliminary design solution is further evaluated using technical theory, calculations and various software design analysis programs (see Section 3.3 for further details). After the preliminary design solution was evaluated and approved a simple prototype was fabricated to verify the design's predicted performance in the real world. The final step in the design process emphasized testing, troubleshooting and optimization of the final design. A systematic and methodical design procedure ensured that the team was successful in obtain an reasonable design solution.

2.4 Sponsorship

Significant funding has been obtained this year, which has permitted the ARVP to purchase supplies, tools and all necessary parts to modify existing platforms and to fabricate new vehicles. Approximately $32 300 (CDN) in funding has been obtained from corporate and private sponsors since June 2000. In addition, gifts-in-kind have accumulated to almost $5 500 (CDN). All aspects of the project are entirely funded through corporate and private sponsors.

2.5 Community Outreach

The ARVP also provides learning experiences for students of all ages, from elementary to post-secondary institutions. Involvement in the community is an integral aspect of the project, as it enables the ARVP to interest students in technological development, engineering and science. At least once a month, the outreach team visits Edmonton-area schools with hands-on demonstrations and tutorials. This aspect of the project is of great interest to the University, corporate sponsors and the community.

3.0 Mechanical Engineering Section

In any effective mechanical design, simplicity, reliability and serviceability should be considered. It is these three fundamental design goals that have significantly influenced the design and fabrication of the *Bear Cub*. As a result, the *Bear Cub* has evolved from its initial function as a testing platform for its industrial all-terrain predecessor, *Polar Bear*, into a functional and versatile vehicle. Four Matsushita 24 VDC motors packaged with inline 45:1 gearboxes independently drive each of *Bear Cub*'s wheels. In addition, two 75 Amp hour, 12 VDC sealed gel cell batteries (in series) provide the power necessary to drive the four motors. All components are fastened to a tubular, mild carbon and stainless steel frame for strength and durability. This design provides a simple yet effective platform capable of performing in both an indoor and outdoor environment.

3.1 Frame

In terms of the frame, there are essentially two sections: the base and the roll cage. The base of the *Bear Cub* frame is constructed from mild carbon steel (AISI 1024). This material was primarily selected for its wide availability and relatively low cost. The load bearing members consists of 1" x 1" (0.0254m x 0.0254m) square tubing. This profile was chosen as it was determined to withstand the maximum estimated analytical stresses while maintaining minimum deflection and overall mass. These square tube members (and some minor accessories such as component mount points) were TIG (Tungsten Inert Gas) welded together to form the base. Fastened to the base is a stainless steel (AISI Type 303) roll cage. Stainless steel was selected for this portion of the frame primarily for aesthetics and material availability through a corporate donor. In the event of a collision with an obstacle, the roll cage was designed to protect sensitive onboard electronic hardware. The roll cage was also designed to accommodate appropriate mounting locations for sensors such as the camera, SONAR array and GPS system. The entire vehicle is capable of being disassembled with simple tools allowing for ease of maintenance, transformation and portability.

3.2 Drivetrain

The *Bear Cub* drivetrain consists of four Matsushita GMX-8MCO45A 24 VDC bi-directional motors that are coupled to load-bearing hubs. These hubs are then fixed to 8” diameter by 3” wide wheels. Each motor is capable of producing up to 75 inlb (6.6 Nm) of torque at 100 rpm. Sealed two-channel optical encoders with a resolution of 4550 pulses per output shaft revolution are included in each motor assembly to provide the necessary signals for motion control. These motors were selected for their relatively compact size and performance characteristics. Figure 1 (shown below) displays one of the four custom steel hubs that were designed to alleviate radial loads that may otherwise have been imposed on the motor shafts. Each hub contains an outer assembly, angular contact radial bearing and an internal sleeve. The sleeve was press fit directly onto the motor drive shaft and constrained to the frame by a radial bearing and outer hub assembly. The drive wheel was fixed to the sleeve with an appropriate adaptor plate, where the hybrid tires provided good traction in both indoor and outdoor environments. Finally, the internally pressurized tubes offered adequate vibrational isolation and allowed for minor ground surface variations.

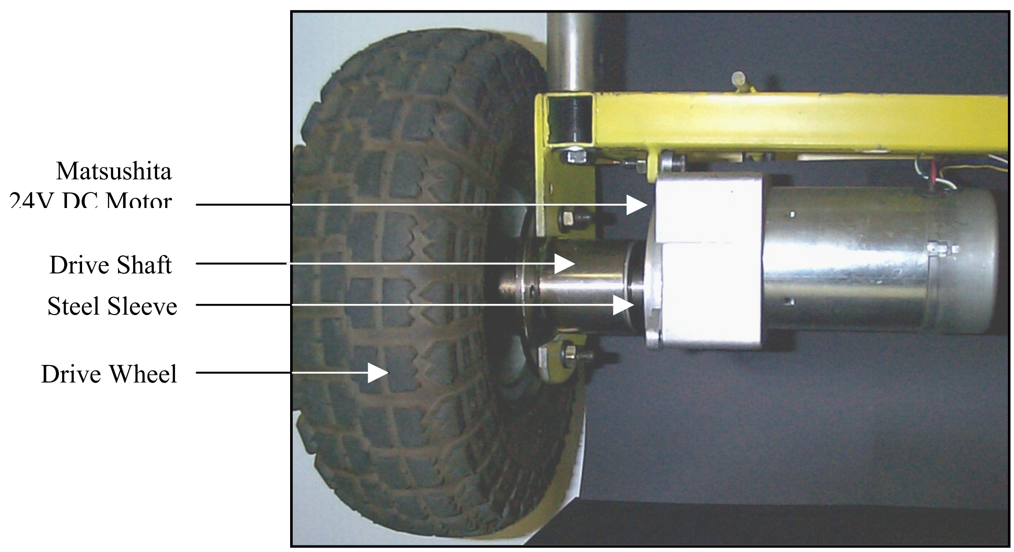

Figure 1: Typical Drive Wheel Assembly

3.3 Design Tools

A variety of analytical and numerical techniques were used throughout the mechanical design of the *Bear Cub*. All materials used in the construction were assumed to behave in a linearly elastic fashion, which allowed for simplified closed form analytical stress solutions to be obtained. Due to the relatively short life span of competition vehicles such as *Bear Cub*, fatigue and stress concentration effects (fracture mechanics) were not considered. The strain energy distortion theorem (Von Misses Stress) and maximum shear stress failure criterions were implemented for simple loading situations. For more complex loading situations where an accurate closed form solution is not easily derived, PRO/Mechanica (a finite element stress analysis software package) was used to determine the maximum stress and deflection. Numerical solutions were compared with simplified analytical models as a method of checking solution convergence. In addition, PRO/Engineer (a three-dimensional solid-modeling computer aided design software package) was implemented to minimize fabrication oversights and construction time. The use of such software packages allowed the design team to optimize critical components, as well as gain detailed and accurate information about the vehicle's mass, inertia, and center of gravity. As a result, the vehicle's ultimate kinematic and dynamic performance could be estimated before the vehicle was physically constructed.

3.4 Performance

With a net mass of 168lb (76kg), overall dimensions of 30.5" wide x 36" long (0.775m x.914m) and a ground clearance of 2.5" (0.064m) the *Bear Cub* is an extremely versatile platform. The robot is small enough to fit through a standard doorway while remaining well suited for use in a variety of outdoor environments. In addition, *Bear Cub* utilizes skid steering (by varying the motor direction); which is easier to control than other forms of steering and allows for a zero turning radius. Sufficient ground clearance and traction were also maintained to allow for predictable ramp climbing ability and sand pit traversing.

Bear Cub is capable of obtaining a maximum speed of 2.4mph (3.8km/h) and a maximum forward acceleration of 0.1G ($1m/s^2$). In addition, the motor torque was sufficient to overcome a 25% grade incline. Heavier components such as the batteries and motors are located as low to the ground as possible in order to minimize the center of gravity. It was determined (using a rudimentary skid pad) that the center of gravity is approximately 10" (0.254m) above the rolling surface. Finally, it was observed that all actual performance specifications were within 15% of those predicted using the CAD software packages. This small discrepancy can be attributed to variables such as excessive friction and other miscellaneous factors.

4.0 Electronic Components

The primary objective of the electrical system was to emphasize reliability while remaining both versatile and inexpensive. The electrical system of the *Bear Cub* consists of a microcontroller, motor controllers, systems for both SONAR and vision, and power supplies for the motors and computer systems.

4.1 Microcontroller

The *Bear Cub* uses a very standard MPC68332 microcontroller (as seen in Figure 2) which is small and versatile, provides ample processing power and a sufficient number of I/O lines. In addition, the MPC68332 microcontroller can be powered from both regulated and unregulated sources and is relatively inexpensive and easy to replace.

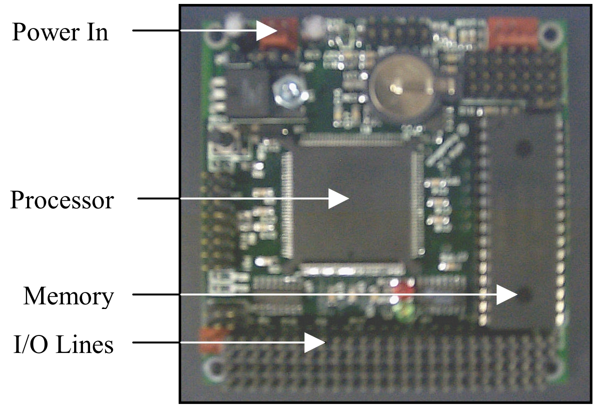

Figure 2: MPC68-332 microcontroller

4.2 Motor Controllers

The *Bear Cub* utilizes four 24 VDC motors (Section 3.2) which are in turn powered by four individual NCC 70 DC motor controllers (manufactured by 4QD). The four motor controllers are capable of outputting a maximum continuous current of 100A, which corresponds to a total of 4800W being delivered to the motors at any one time. Since both the controllers and the motors are extremely efficient, the enclosures do not need to be fan-cooled. Finally, the NCC 70 controllers incorporate a variety of unique features including temperature cut offs, variable ramping functions and variable maximum speed.

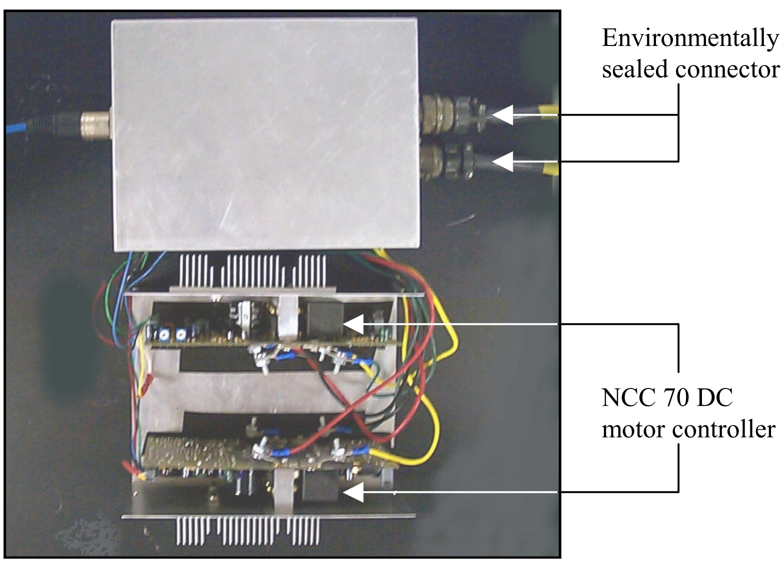

Figure 3: Motor Controller Enclosures

Each of the motor controllers interface with the microcontroller via two lines, where the first line controls the speed using pulse width modulation (PWM) and the other controls the direction. The built-in shaft encoders in each motor allow for easy closed loop control and a more compact design.

4.3 Vision and SONAR

Vision is accomplished with the use of a CCD-TRV87 Sony Handicam, which interfaces directly with the main CPU by utilizing a WinTV video capture card. The Handicam provides excellent resolution, a simple interface and has an adaptable power input: it can be powered by a lithium battery, an AC adapter or directly from the computer power supply.

The custom SONAR array uses six transducers to cover a 60º arc directly in front of the *Bear Cub* and is capable of accurately detecting an object up to 10m away by using digital circuitry (MUX and Logic Gates) to convert echo lines to time of flight. The SONAR array can also be powered directly from the batteries (12V unregulated source) or from the computer power supply. Finally, the SONAR array is connected directly to the microcontroller by an environmentally sealed amphenol connector, which allows the robot to be used in a variety of weather conditions. The specific operation of the vision and SONAR systems is dealt with in Section 5.2.

4.4 Power Usage

The *Bear Cub* is designed to operate with a total of three 12V gel cell batteries; two of which are used to power the motors, where the third is used to power the computer and other delicate electronics. These batteries were chosen because they are able to provide high current, are relatively long lasting (approximately two hours of continuous use) and are air-transport approved. The frame is used as a common ground for all electrical systems. The power structure separates the motor system from the sensitive electronics and ensures a sufficient amount of regulated power for the electronics while adding protection from voltage spikes, brownouts, motor feedback and electromagnetic flux (EMF). Finally, the signal lines (i.e. for the computer and microcontroller) are electromagnetically shielded from the motors, batteries and any of the radio devices.

4.5 Emergency Stop

The emergency stop mechanism of the *Bear Cub* was designed so that the robot could be immediately halted by using a remote control or a large push-button located directly on top of the robot. These are the inputs to a logic circuit that cuts off a bipolar junction transistor (BJT), which switches a relay that cuts off power to the motors. The remote control system allows the robot to be manually stopped from a distance in excess of 150ft.

4.6 Remote Control

A remote control system was constructed in order to facilitate the testing of the mechanical and electrical systems prior to the implementation of the autonomous control systems. This consists of an inexpensive 433 MHz transmitter/receiver pair, two 16F873 MCU microchips and a Sony PlayStation game controller that sends an 8-bit digital signal. This device turned out to be invaluable for troubleshooting the mechanical and electrical systems with an impressive operating range of 75ft (22.86m). As an added safety feature the robot is designed to stop immediately if the signal is lost for longer than 1.5 seconds.

5.0 Computer Systems and Software

5.1 Hardware

The main hardware components of the vision system include a CCD-TRV87 Sony Handicam, a WinTV video capture card and an Intel Celeron 366MHz CPU, which operates with 320MB of RAM. The Sony Handicam offers excellent resolution, improved image stabilization and is remarkably versatile in terms of power requirements. The WinTV video capture card uses open source Linux software in order to provide a 24-bit, 320 x 240 pixel images of the area directly in front of the robot.

5.2 Motion Control

Complex motion control is achieved by using the feedback generated by the motors within a control loop to regulate the motor speed, where in the current application the *Bear Cub* uses a total of three individual control loops. The first two control loops are responsible for ensuring that the wheels all turn at the desired velocity; which is accomplished by determining the difference between the desired and current velocity (an error signal) and multiplying it by a positive (and proportional) constant. Therefore, the *Bear Cub* will speed up or slow down in order to maintain a relatively constant velocity and to account for the external forces that are being applied to the robot.

The final control loop is used to slave the right and left sets of wheels together in order to ensure that they are both turning at a constant rate regardless of external forces, which results in a straight line motion. This is accomplished by creating a third error signal that accounts for the difference between the right and left velocity terms and multiplying it by a bias factor. The bias factor can also be used to keep the vehicle straight (for example, if it were moving over uneven ground) or to implement a right or left turn. In this manner, the sign (positive or negative) of the bias factor determines the direction, while the magnitude determines the sharpness of the maneuver.

5.3 User Interface

In order to assist in the testing of the *Bear Cub*, a user interface (UI) was developed. It allows easy control of the SONAR and motors systems, and can display both the original camera image and the processed image from the vision algorithm. An example of the SONAR screen is shown in Figure 4, where the user has the ability to test any combination of the SONAR and view the results both numerically and graphically.

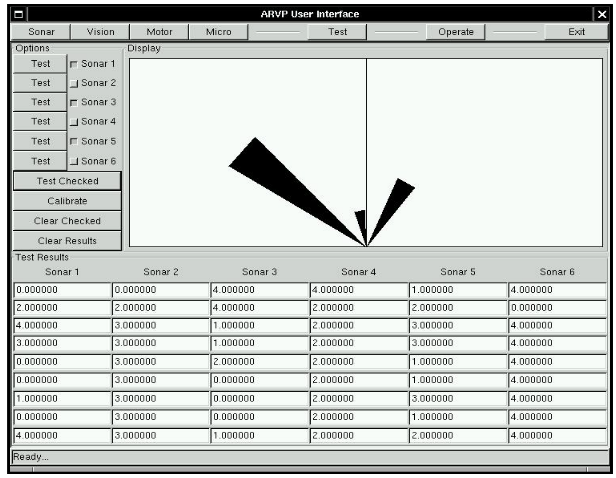

Figure 4. SONAR Screen

This screen can also be used to calibrate the SONAR equipment by performing a sensor test of a known distance in order to determine suitable calibration coefficients. These calibration coefficients can be used to convert the ping time of the SONAR into a very precise distance measurement.

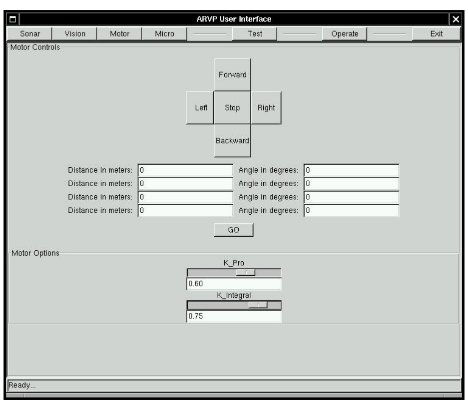

Figure 5. User Interface

In Addition, the UI system can be used to control each of the individual motors by allowing the user to issue several basic commands (forward, reverse, left, right and stop). The user can also specify an exact distance for the robot to drive (or a specific angle that the robot should turn) by using the interface shown in Figure 5. This feature was extremely useful when debugging the closed loop control of the motors and the functionality of the mechanical system.

Finally the UI system can also be used to display both the original image and the image that is obtained using the vision algorithm system. This allows the user to view the effects of the vision algorithm and to fine-tune the algorithm in terms of several parameters related to cropping, threshold values and the number of points on lines. Sample images of a typical tracked outline are shown below where the original image is shown in Figure 6, and the image recognized by the vision algorithm is shown in Figure 7. The vision component was found to be a highly effective and user-friendly way to ensure that the vision algorithm was working correctly.

Figure 6. Original Image

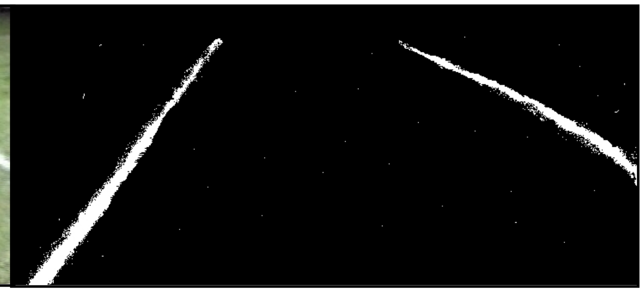

Figure 7. Processed Image

6.0 High Level Control

6.1 Algorithm for the "Follow the Leader" Event

The image from the camera is segmented using an algorithm that is linearly related (in terms of speed) to the number of image pixels; therefore, the system requires less than a second for each gray scale image (on a 366 MHz Intel Celeron processor). The Geometry Analyzer then processes the segmented shapes and sends the corner points of all square-like shapes to the AI as shown by Figure 8.

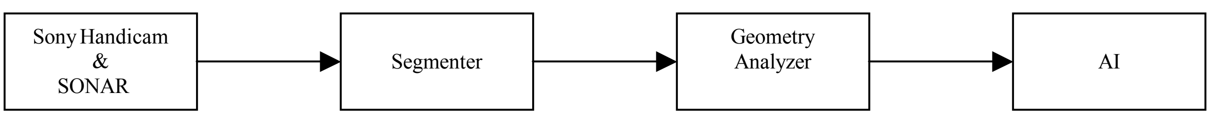

Figure 8. FTL Algorithm Flowchart

The AI uses the perspective three-point algorithm to determine the exact distance to the flag (or target) when the physical locations of certain pixel points (such as corners) are identified. This implementation of the algorithm uses four points and returns two solutions, one of which is always impossible. The distance to the center of the target is then trivially calculated.

Now the AI algorithm uses the flag's last known location and its rate of change to predict its last position; the potential target closest to this position is chosen. The system then uses a simple formula to determine the desired speed of the *Bear Cub* in order to maintain a constant distance of 9.84ft (3m) behind the flag. In addition, the distance to the target and the difference in angle between the trajectory of the robot and the position of the target are used to calculate a curved path between the two points as an arc-angle and length. It is then possible to determine the desired speed for both the right and left pairs of wheels by using the arc length, distance between the right and left wheels (a known constant) and the desired speed.

A complete cycle through the algorithm takes approximately a second on the robot's hardware; therefore, the robot's worst-case reaction time is roughly one second.

At the end of the test the SONAR array is used in conjunction with the Sony Handicam to establish when the flag comes to rest and to determine the exact distance to the target. At this point (when the flag comes to rest) the AI system instructs the robot to move to exactly 9.84ft (3m) toward the target and stop.

6.2 Algorithm for Navigation (GPS)

The main goals that were focused on when implementing the Global Positioning System (GPS) of the *Bear Cub* platform were accuracy, reliability and keeping the system as simple as possible. The GPS data is collected in NMEA-0183 standard format with a Trimble AgGPS-123 system and transferred to the CPU via a standard serial port. The GPS algorithm then uses this data to calculate the bearing and distance to the next waypoint location and to regulate the motor speeds accordingly. Based on this information a control algorithm is able to determine the optimal direction and the overall forward speed. Finally, the distance to the next waypoint is compared to a threshold distance to determine when the robot is to proceed to the next waypoint. The resulting GPS system that has been included with the *Bear Cub* was predicted to be accurate within approximately 8" (0.2032m).

6.3 Algorithm for Obstacle Avoidance

The AI program receives all the information about the obstacles and the sidelines of the road from the Vision and SONAR systems (Figure 1) and stores the physical location of these shapes in terms of individual line segments. In this manner when the AI program determines which direction it should move it examines a large number of headings in front and to the sides of the robot. For each possible heading the AI program determines how far it can travel in any one direction without encountering an obstacle and chooses the heading that moves the robot furthest in the direction it was originally traveling. During each of these steps the *Bear Cub* moves forward a short distance (approximately 3ft or 1m) before the AI program re-evaluates the robot's position and chooses the new optimal heading. The robot currently does not deal with dead ends, traps or potholes. Since the image processing algorithms are heavily color based, the robot also does not identify small road debris.

7.0 System Integration

The overall system layout is shown in Figure 9.

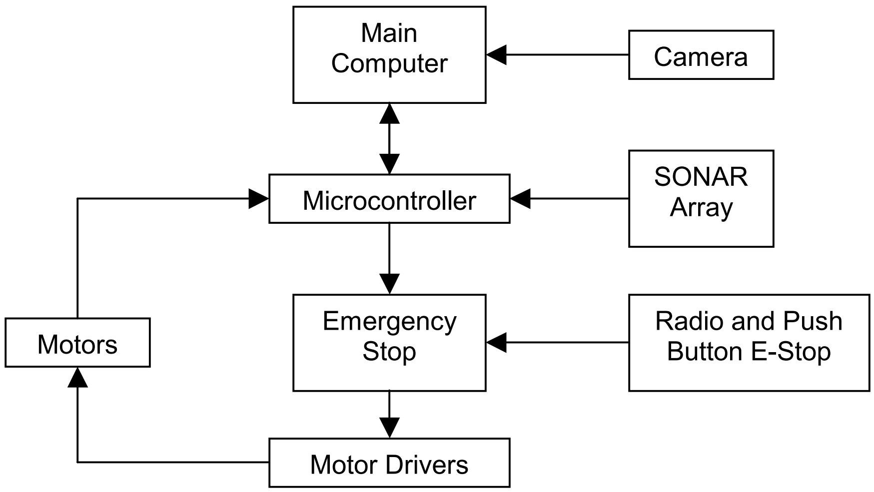

Figure 9. Layout of System Integration

8.0 Conclusion

The *Bear Cub* is a fully autonomous robotic vehicle that was designed, built and manufactured solely by students from the University of Alberta with emphasis placed on keeping the platform portable, reliable and serviceable. The mechanical and electrical systems where built with the intent that the vehicle should operate equally well in both an indoor and outdoor environment and that the robot could be used primarily as a test platform for future applications. The software and high-level control systems were designed specifically so that the algorithms could be incorporated in the pending design platform for the *Kodiak*. The ARVP team has been very fortunate this year in that most major design requirements were met and exceeded by the *Bear Cub* platform, and plans to continue attending IGVC in the future.

9.0 Team Structure and Organization

Mechanical Team			
Mechanical Team Leader	Ryan Chladny	MecE	MSc 1
Mechanical Design Team	Pat Kirchen	MecE	4
	Sean Michealchuk	MecE	4
	Wayne Klaczek	MecE	3
	Jeff T. Woo	MecE	3
	Leah Kaneko	MecE	2
	Robert Knowles	Eng	1
	Dave Kastelan	Eng	1
	Jon Leuke	Eng	1
Electrical Team			
Electrical Team Leaders	Jason McKay	EE	4
	Nick Wrathall	EE	2
Electrical Design Team	James Smith	EE	MSc 2
	Mike Cumming	Math/CS, EE	4
	Kris Johnson	EE	2
	Adrian Pegoraro	EN PH	1
	Chris Ozeroff	EN PH	1
	Chris Bliss	Eng	1
	Mike Riske	Eng	1
	Reid Orsten	EE	3
	Nick Algar	Eng	1
Motor Driver Team	Nick Wrathall	EE	2
	Jason Ng	Eng	1
Power Team	Jody Law	EE	2
	Erica Oberst	EE	2
	Sunil Doshi	Eng	1
Software Team			
Software Team Leaders	Kit Barton	CS	MSc 1
	Chris Steibritz	CS	2
	Andy Hammerlindl	Eng	1
	Andrew Pearse	CS	5
	Chris Cumming	CS	5
	Leendert Van Den Berg	CE	2
	Richard Robinson	CE	2
	Aden Grue	CE	2
	Jason Klaus	CE	2
Follow-the-Leader Team	Doug Kondor	CS	3
	Reid Orsten	EE	3
	Ryan Sanche	CS	2
Navigation Team	Mike Cumming	CS, EE	4
	Jason Gunthorpe	CE	4
SLAM - Sponsorship, Logistics, Administration and Management Team			
Project Coordinator	Jeff T. Woo	MecE	3
Treasurer	Cam Duong	ChemE	4
Community Outreach Team	Kris Johnson	EE	2
	Stephanie Snow	Art	1
	Keith Boyle	EE	2
Sponsorship Team	Melanie Noble	Pol Sci	4
	Jeff T. Woo	MecE	3
	Carolyn Huston	Bio Sci	2
Graphics Design	Kelly Malbeuf	Fine Arts	4
University of Alberta Staff			
Faculty Advisor	Dr. Roger Toogood		
Shop Supervisor	Ian Buttar		

10.0 Research Vehicle Component Cost Summary

General Component Description	Model No.	Quantity	Unit Value (US $D)
Mechanical Components			
Mild Steel Tubing	Maple Leaf Metal Ind.	16	24
Mild Steel Square Tubing	Maple Leaf Metal Ind.	12	14
Electric Motors	Matsushita GMX-8MC045A	4	110
Motor Hubs	Custom	4	
Tires		4	10
		Subtotal	**158**
Electrical Components			
Microcontroller	Motorola MC68-332	1	178
Motor Controller	4QD NCC 70 24	2	205
Sonar Array	Polaroid 9500	6	400
Vision - Sony Handycam	Sony CCD-TRV87	1	500
Batteries	East Penn/Power Battery	3	80
Power Supply	Key Power KP-DX250H	1	342
Computer	Intel Celeron 366 Mhz	1	500
E-Stop	Custom	1	20
Radio E-Stop	Custom	1	40
Remote Control	Custom	1	50
Voltage Monitors	Custom	3	30
		Subtotal	**2345**
		Grand Total	**2503**