



STEP - 5



Faculty Advisor Statement:

I, Dr. Ramesh Varahamurti of the Department of Mechanical Engineering, Mechatronic Engineering and Manufacturing Technology at California State University, Chico do certify that the design and implementation of this vehicle has been credited to each team member for their work.

**Dr. Ramesh Varahamurti
Dept. MEM**

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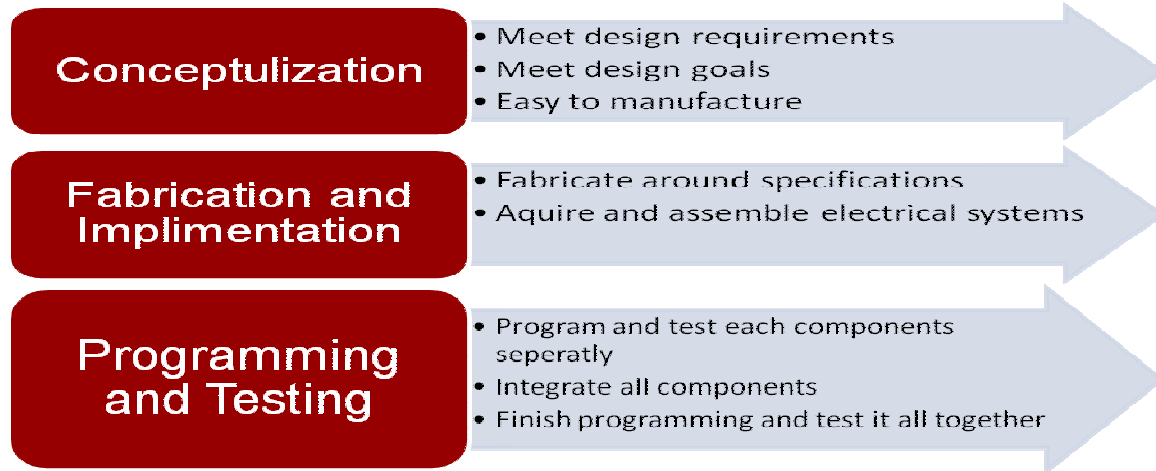
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INTRODUCTION

The California State University, Chico IGVC Team is comprised of different engineering backgrounds including Mechanical, Mechatronic and Electrical. This team and the robot STEP 5 are new to this competition in 2008 and this project has been an entirely extracurricular educational experience.

1. DESIGN PROCESS



1.1 Goals

- Autonomously traverse obstacle course
 - Waypoint Navigation
 - Lane following/ Stay within course boundaries
- Navigate
 - Potholes, Ramps, Objects in Path, Switchbacks
- Compact Design
 - Lightweight
 - Carry Payload
- Stay within Budget

1.2 Design Requirements

- GPS within 1 meter accuracy
- Max speed 5 mph
- Height: 3ft min, 7ft max
- Width: 2 ft min, 5ft max
- Length: 6ft max

1.3 Features

GPS, Sonar, Machine Vision, Compass, Electric Motors, Speed Limiter/ Monitor, E- Stop

2. MECHANICAL

In an effort to maintain California State University Chico's sustainability goals, as many materials as possible were acquired through scrap recycling and donations. The mechanical design is divided into three parts: Chassis, Drive System and E-Stop.

2.1 Chassis

The chassis was built from 6061 aluminum scrap of a local house boat builder. The chassis was intended to have a zero radius turning capability in order to avoid back up situations, and to allow for center pivot of the vision system. This was accomplished by utilizing two drive wheels and two rear pivoting castors, Figure 1.



Figure 1: Chassis Design



Figure 2: "Brain"

The vehicle was initially estimated to weigh 200 lb or less after completion. Wheelchair motors were used due to the built-in gearing, a high start torque, low power consumption and ease of maintenance. The motor mounts were reversed in order to facilitate greater travel in the suspension system. An effort was also made to design all motor mounting brackets to be of the same shape to allow for easy manufacturability. The shocks were custom fabricated from off the shelf springs which were Tool Dipped in rubber for aesthetic reasons.

One innovation of the chassis system is the modular attribute of the "brain", and its ability to be removed and placed into any other chassis. The "brain" is a rack system containing all sensor hardware, motion control systems, and our operating system, as seen in Figure 2. The "brain" is easily removed by unplugging three quick connect sockets, one for the power system, and one each for the motors.

The entire chassis was modeled in Solid Works design software before fabrication which allowed for placement of the center of gravity, as well as interference detection.

The final chassis was powder coated because this process has less environmental impact and air pollution when compared to traditional spray painting. The bottom of the chassis as well as the cargo bed were both coated with Rhino Liner bed lining to provide impact and abrasion resistance.

2.2 Drive System

The vehicle is driven by two brushed servo motors with worm gear right angle gear reductions. The motors are each powered by separate Advanced Motion Controls 50A8 PWM servo motor amplifier, which can supply 25A continuous and 50A peak current. The amplifiers are run in a closed loop system controlled by a Galil Motion Control DMC-2183 8-axis motion controller. The motion controller receives incremental encoder feedback from the motor and uses it to command a $\pm 10V$ signal to the amplifiers. The main computer sends commands and receives information from the controller through a RS-232 serial port. The motion controller was donated by Galil Motion Control, the amplifiers were donated by Advanced Motion Controls, and the motors and gearheads salvaged from a wheelchair which was donated by a private party.

2.3 E-Stop

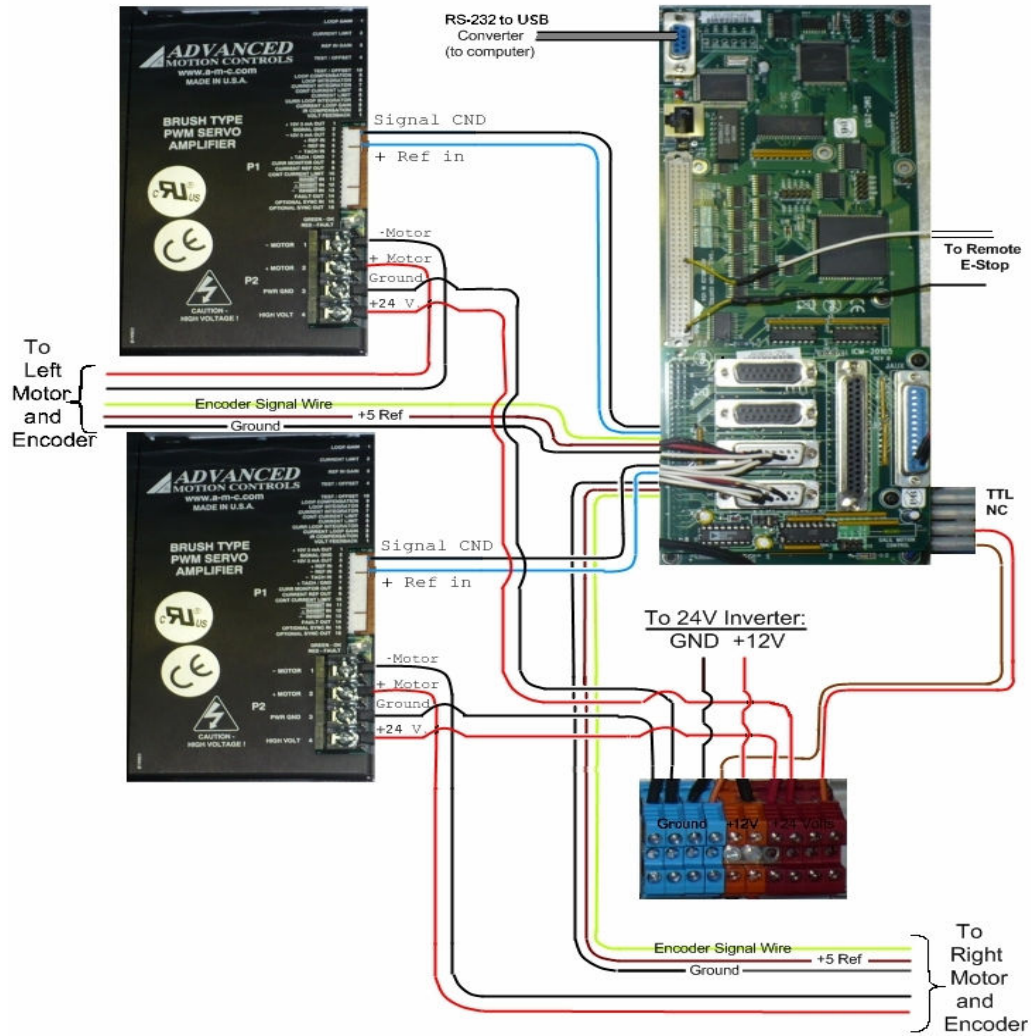
STEP 5 is equipped with both manual and wireless E-stops. When either E-stop is engaged an abort signal stops the execution of the controller program and turns off the $\pm 10V$ control signal to the amplifiers. Additionally, mechanical relays disconnect the motor power wiring from the amplifiers and apply a regenerative power dissipation resistor across the motor leads, which help slow the vehicle to a quick stop.

3. ELECTRICAL

3.1 Power Supply

Electrical energy is stored inside two sealed gel-type 12V batteries. The batteries are wired in series to supply the 24V required by the motion controller and motor amplifiers. An additional 12V supply is taken from a single battery to power the computer and other electronics.

Wiring Diagram for STEP 5:



3.2 Power Delivery and Control

The batteries are stored in a compartment beneath the main electronics cab. The 24V supply can be disconnected from the electronics by a switch, however there is no switch for turning off the 12V supply to the computer. This is a safety feature that ensures that the computer is not accidentally turned off.

3.3 Power Monitoring

The power supply is monitored through the use of a PIC18F452 microcontroller. This device reads the battery voltage from the digital voltage sensors and sends it to a display. It also monitors the temperature inside the cab and controls the fans to help keep the electronics cool.

4. SENSORS

4.1 Digital Video Camera

Our vehicle is equipped with an IEEE-1394 (FireWire) camera. It is interfaced with the system main controller to capture video information. The captured image is then processed in the system controller using custom built image processing functions.

4.2 Digital Compass

The digital compass is used to sense vehicle heading relative to magnetic North. A fully integrated Honeywell HMC6352 compass module is used for this purpose. It has 2-axis magneto-resistive sensors with the required analog and digital support circuits, a microprocessor, and algorithms for heading computation. It works on 3.3VDC and is interfaced with the sensor controller through I²C bus. The compass plays an important role in the navigation challenge in order to successfully execute the most optimized path.

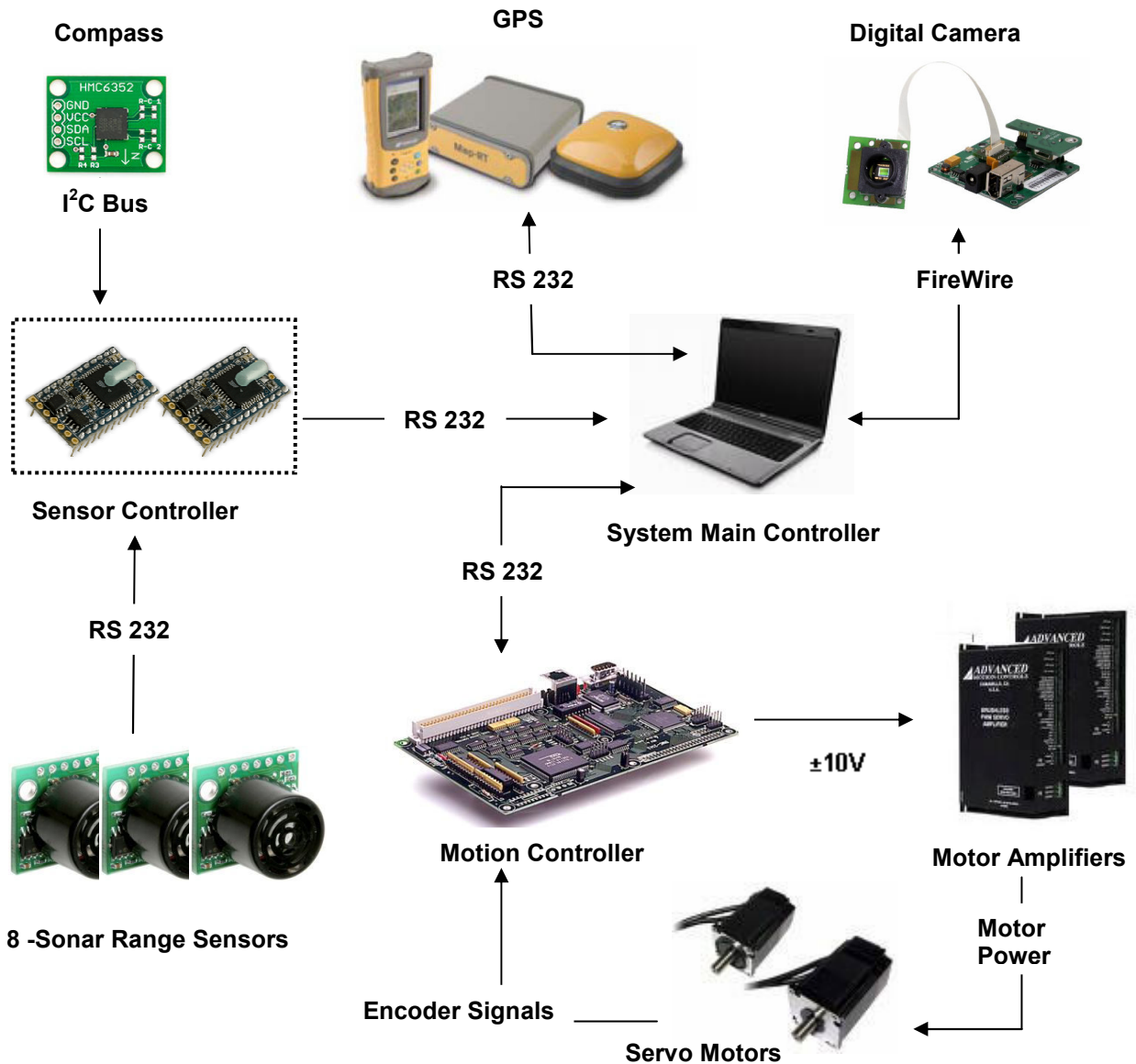
4.3 Sonar Range Finder

A low cost ultrasonic range finding solution for obstacle detection was used. Each sensor has an effective range of 6.45 meters with a 26 degree conical coverage beam. The vehicle utilizes eight such sensors to increase the obstacle detection field angle. The sensors are arranged with 4 facing forward, one facing to either side, and two facing towards the back. They are powered by 5 VDC source and are interfaced with the sensor controller through an RS232 interface. The sensor controller reads the range from each sensor and creates a single ASCII string which is sent to the main system controller by RS232. Each sensor has a refresh rate of 50 milliseconds and opposite facing sensors are read at the same time to reduce the overall scan time.

4.4 GPS

The Global Positioning System (GPS) is used to determine the position of the vehicle on the field. The vehicle uses Topcon's GMS-110 GPS receiver. The GMS-110 uses GPS and GLONASS satellites with differential and beacon correction signals to achieve sub-meter, real time accuracy. This device is interfaced with the main system controller via an RS232 serial interface. Data received through the GPS module plays a critical role as the vehicle position detector for the navigation challenge.

5. SYSTEM COMPONENTS INTEGRATION



This vehicle uses two controllers for data processing:

- System main controller
- Sensor Controller

5.1 System Main Controller

The HP Pavilion ze4805us notebook is ideal for its onboard power source and display as well as its simple configuration and variety of ports to interface with the motion controller, sensor controller and GPS module through RS232 serial links and to the digital Camera through a FireWire port. USB to serial converters are used to interface these RS232 devices. All data acquisition and processing (except data acquisition from the compass and sonar sensors, see section 5.2 Sensor Controller) is performed through the system main controller. It performs the following functions to achieve end results.

- Image processing algorithms
- GPS data extraction
- Decision making algorithms
- Peripheral communications

5.2 Sensor Controller

The sensor controller uses two BasicX-24p microcontroller modules. These modules are based on ATMEL microcontroller and work on 5V supply. They have serial, digital and analog interfaces which make them the right device to use as a data acquisition module for sensor interfaces. These two modules are interfaced with the digital compass through an I²C bus and the eight sonar range sensors through a RS232 serial interface. Acquired sensor data is communicated to the system main controller through RS232 links.

6. PLAN FOR PATH AND CONTROL DECISIONS

In the navigation challenge, the heading and distance to the target waypoint are calculated based on the current and target GPS locations. In the autonomous challenge, the heading to be traveled is likewise calculated from the machine control thread. In either case, the target heading and distance are used as inputs in the machine to determine the behavior of STEP 5. The machine vision further assists the sonar in the detection of obstacles, lanes and boundaries. The process is described in Figure 3.

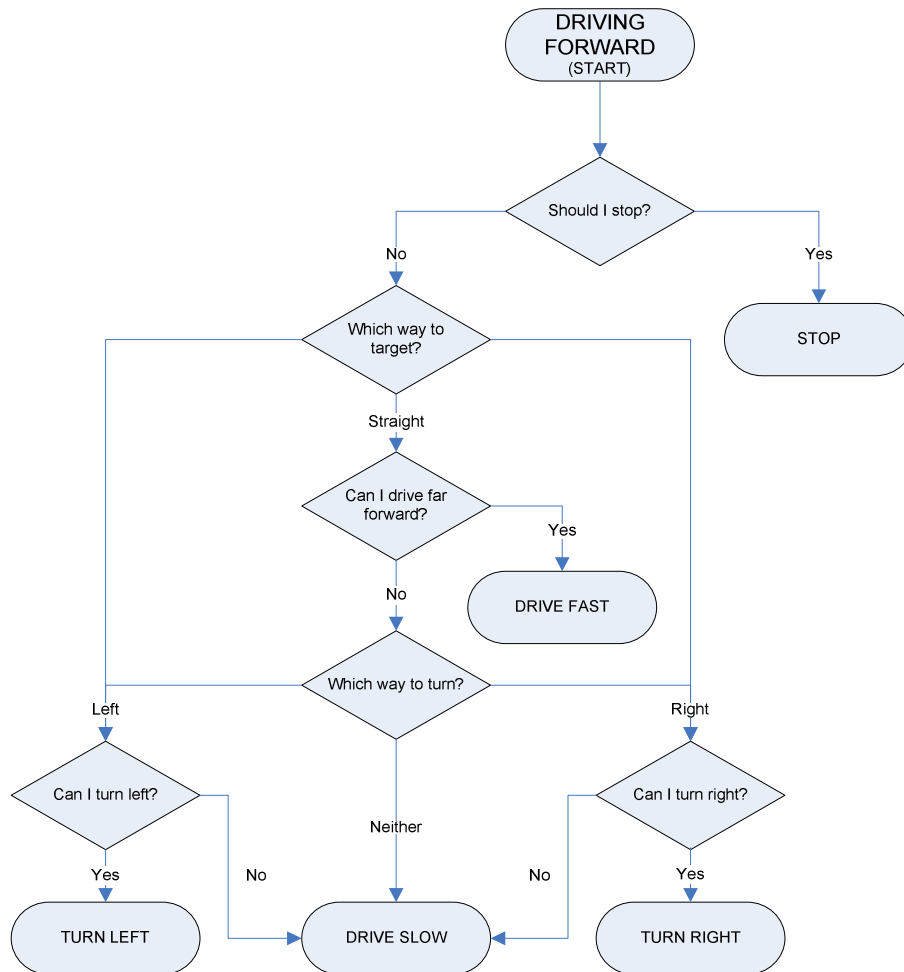


Figure 3: The flowchart for the Driving Forward state.

7. SIGNAL PROCESSING

7.1 Image Processing

Images from the digital camera are received by the system main controller and then sent to the image processing algorithm. The image processing algorithm is based on custom built functions and OpenCV library functions. Once the image is captured, it is processed in three different stages.

- Image pre-processing
- Line detection
- Vehicle command computation

7.2 Image Pre-Processing

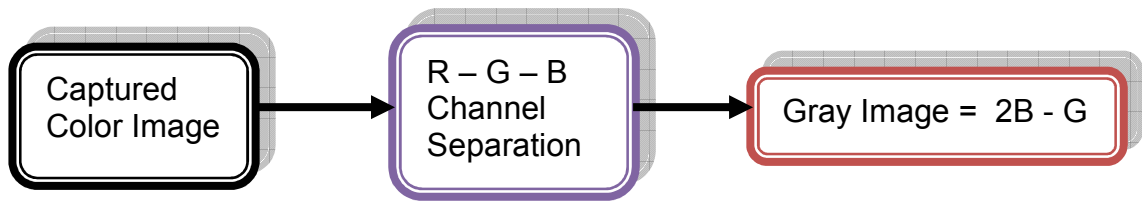


Figure 4: Image pre-processing flowchart

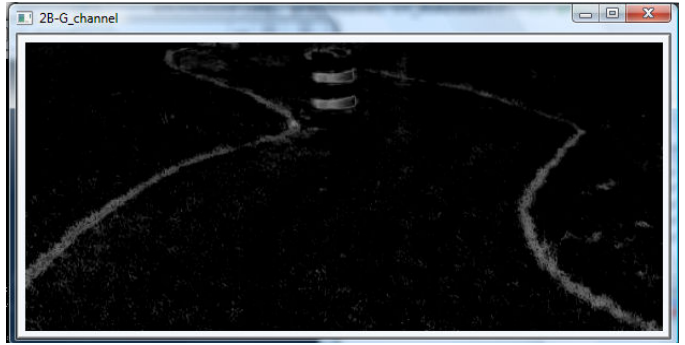
As shown in Figure 4, Red, Green and Blue channels of the captured image are separated and a gray image is generated using a specified combination of the green and blue channels.

7.3 Line Detection

At this stage the gray image is split into two images: a left and right part. The major aim is to find one line in each image part which represents the left and right side track on the ground. In order to detect a proper line through these two image parts, brightest row pixel detection is applied on both images. Edge detection and a Hough transform are then used to detect a straight line passing through active pixels in the images as shown.



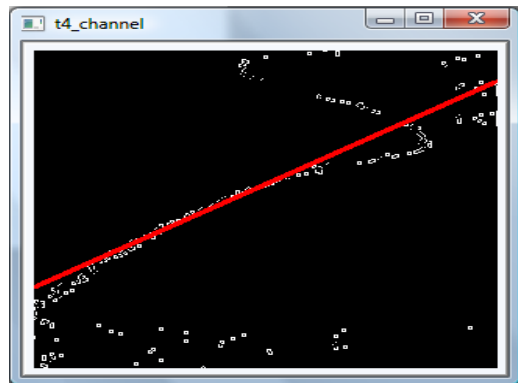
Source Image



Gray Image = $2B-G$



Brightest Row Pixel Image



Hough Transform

7.4 Vehicle Command Computation

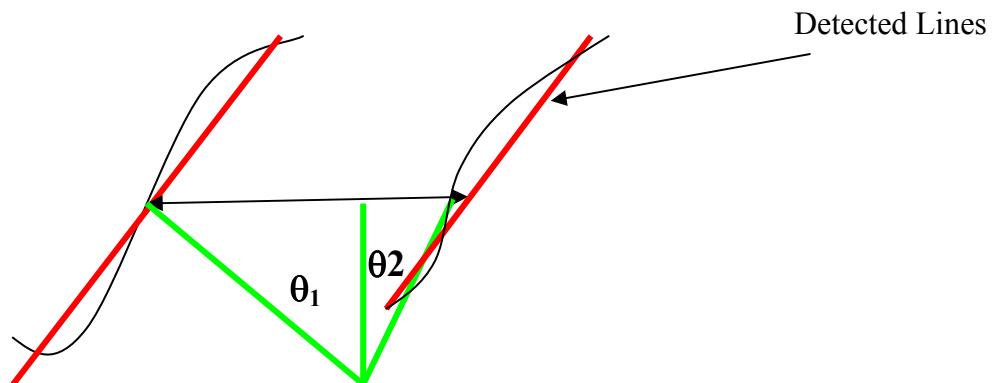


Figure 4: Heading command computation

After the line detection through Hough transform an image is extracted as shown in Figure 4 (above). The vehicle heading angle is then calculated based on values of θ_1 and θ_2 and then passed to the motion control thread for use in the path planning decision making process.

8. SOFTWARE STRATEGY

The software underlying STEP 5 was designed with reusability and portability as chief considerations. Since “the brain” can be easily moved from one chassis to another, the code was developed to match the same level of portability. The program was written in C++, using entirely standard functions and libraries. Serial communications were programmed using Windows API functions. The code acts as its own serial communications library, which will run on any Windows system and can be easily adapted to work on virtually any hardware configuration. With only slight modification, it could easily be recompiled POSIX compliant and ported over to Linux, Mac OSX, or any number of other operating systems.

The program itself is multithreaded, with sensor threads running in the background to provide the latest sensor data to the main program. As the threads receive a new set of data from their respective sensors, the latest extracted data is then posted to a global semaphore. These semaphores are used as inputs to the main program which is modeled as a Mealy machine, based on a motion state, a navigation state, and the current sensor data.

Modular functions are used to evaluate the current inputs and base the decisions accordingly. These functions are defined by the geometry of the sonar arrangement, the current state, and the current sensor inputs, and are reused in each of the states' respective operations.

9. ANALYSIS

9.1 Obstacle Detection and Avoidance

STEP 5 was built with certain specifications and performance factors which included speed, obstacle detection and avoidance along with ramp climbing ability and reaction times. With the integration of GPS, Sonar, and Machine Vision components as well as its physical factors of being compact with a small turning radius, STEP 5 has no problems turning about its axis in an efficient manner in order to avoid obstacles. The computational analysis for this process takes on an average of 200 milliseconds to read all the peripherals, make a decision and execute it. It has the ability to detect obstacles and potential traps at a maximum distance of 5 meters but is set at about 2 meters, with line detection verification being calculated several times per second.

STEP 5's processes for ramps are treated the same as the rest of the obstacle course; the largest area of interference free zones is calculated and driven toward. Ramp limitations include inclines over a 25 degree angle.

9.2 Speed

With the compact ability of the chassis and the power of the motors, STEP 5's max speed is approximated at about 9 mph, but for this competition it will be set and limited to less than 5mph. This is accomplished by using an electrical hardware circuit to monitor the speed of each wheel and deactivate the amplifier enable pin when the max speed is reached, effectively cutting power to the motors.

9.3 Battery Life

When constructed and tested, two optima batteries were utilized to provide the sufficient power to the robot and all its components. Running at constant speed while fully loaded, battery life is estimated at about an hour, and standby time at about 5 hours.

Table 1: Cost of STEP 5

Component	Total Cost	Team Cost	Donated by
Optima deep cycle batteries	\$300	\$300	
Wheel chair outdoor tires	\$60	\$60	
Pivoting castors	\$40	\$40	
Integrated compass	\$70	\$70	
Aluminum and parts	\$300	\$300	
Fire Wire enabled 400Mbps camera	\$150	\$150	
Emergency stop remote w/ receiver board	\$70	\$70	
Fans	\$20	\$20	
FireWire card for PC	\$25	\$25	
Sonar modules	\$200	\$200	
Microcontrollers	\$120	\$120	
Voltage sensor	\$20	\$20	
Temperature sensor	\$10	\$10	
GPS unit	\$5,495	\$750	<i>Topcon</i>
Servo Amplifiers	\$1,050	\$0	<i>Advanced Motion Controls</i>
Motion Controller	\$1,595	\$0	<i>Galil</i>
Expansion board w/ interconnecting module	\$195	\$0	<i>Galil</i>
4-Axis amplifier	\$795	\$0	<i>Galil</i>
Complete electric wheelchair	\$1,699	\$0	Private Party
HP ze4805us	\$1,045	\$0	Team Member
USB to serial converter	\$20	\$0	Team Member
TOTAL	\$13,279	\$2,155	

TEAM MEMBERS:

- Rob Marsden- President (EE)
- Brian DeWilde-Vice President (MECA)
- Ross Huber-Vice President of Mechanics (ME)
- Wilfred Ghonsalves- Vice President of Embedded Systems (EE)
- Matt Montgomery- Vice President of Motion Control (MECA/ME)
- Teresa Muir- Secretary and Treasurer (ME)
- George Wing- Member (MECA)
- Alex Scharf- Member (ME)
- Sam Ferguson-Member (MECA)

Total Man-Hours Spent: over 5120 hrs

