Project Proposal for Autonomous Vehicle

Group Members:
Ramona Cone
Erin Cundiff

Project Advisors:
Dr. Huggins
Dr. Irwin
Mr. Schmidt

12/12/02

Project Summary

The autonomous vehicle uses an EMAC based system that will autonomously navigate the vehicle through the Jobst-Baker quad to the destinations entered by the user. This vehicle operates under the following conditions:

- The sidewalks in the quad are clear of debris.
- The vehicle starts from the same position at the Northeast door of Jobst and is oriented in the same direction pointing South.

The vehicle navigates from point to point using a table of coordinates stored in EMAC memory that maps the quad. This table of coordinates is based on the various sidewalk intersections located in the quad. Large obstacles, such as people, are detected and the vehicle motion is halted until the obstacle is cleared.

Functional Description

Objectives

The objective of this project is to create an EMAC based system that will autonomously navigate a vehicle through the Jobst-Baker quad to the destinations entered by the user. This vehicle operates under the following conditions:

- The sidewalks in the quad are clear of debris.
- The vehicle starts from the same position at the Northeast door of Jobst and is oriented in the same direction pointing South.

The vehicle navigates from point to point using an internal map of the quad stored in the EMAC memory. Large obstacles, such as people, are detected and the vehicle motion is halted until the obstacle is cleared.

Modes of Operation

This system has three modes of operation: query mode, maneuver mode, and obstacle mode. They are described in detail below.

- Query Mode:
  The vehicle is stationary, and the user has the opportunity to enter the destination or destinations of the vehicle. First, the user enters the number of destinations, and then the user enters the destinations in sequential order.
- Maneuver Mode:
  Straight:
  The vehicle uses the signals from the sensors to stay on the sidewalk with motion parallel to the edge of the sidewalk. In this mode, no turns are expected and no intersections are detected.
  Intersection /Lost Edge:
  The sensors do not detect the edge of the sidewalk, so the vehicle first stops and then determines from the internal map and the distance input if it is at an intersection. If it is at an intersection, it then enters Turn Mode or re-enters Straight Mode depending on the desired destination. If it is not at an intersection, it searches for the sidewalk edge and re-enters the Straight Mode.
  Turn:
  If upon entering an intersection, the vehicle needs to turn to reach the destination entered by the user, it then enters the Turn Mode from the Intersection /Lost Edge mode. During this mode, the sensors are used to detect when the vehicle has turned onto the new sidewalk. Once the vehicle is on the intersecting sidewalk, the system steers the vehicle into a straight path parallel to the edge of the sidewalk and enters the Straight Mode. Since the turn radius on the vehicle is large, the vehicle might have to briefly leave the sidewalk while turning.
- Obstacle Mode:

The vehicle stops when the obstacle detection sensor detects an object within a specified range. The vehicle waits until the object is no longer detected and then continues in its previous mode of operation. Obviously, if the obstacle is stationary, the vehicle will remain stopped, and an information signal will be displayed.

System Block Diagram

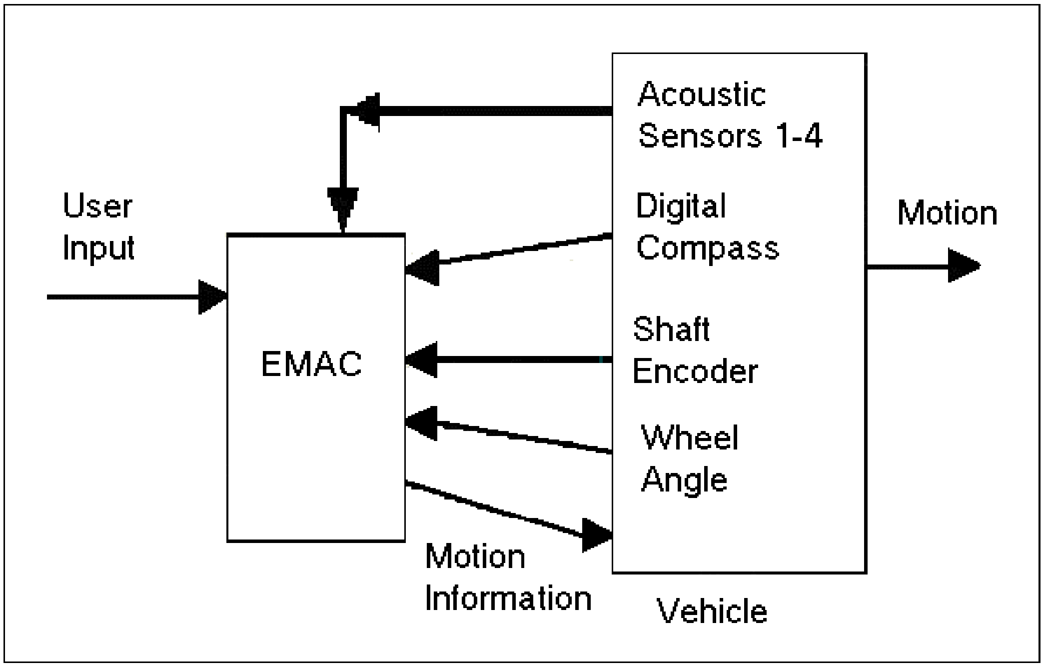

Figure 1 – Block Diagram

Inputs to EMAC based system:

- User Input:
  The user picks the final destination and enters the waypoints the vehicle should take. The intersections are identified by number. The user specifies if the trip should be one-way or round trip. This information is entered on the EMAC keypad.
- Acoustic sensors 1-4 Inputs:
  Sensors 1, 2, and 3 (see Fig. 2) are mounted on the vehicle pointing towards the ground for sidewalk detection inputs. Sensor 4 points straight forward (parallel to the ground) for an obstacle detection input. Sensors 1, 2, and 3 send signals to the EMAC regarding the surface texture and density. The acoustic sensors 1-3 may also be able to send speed information via Doppler shift. Sensor 4 sends a signal to the EMAC if an object is detected within a specified range in front of the vehicle.

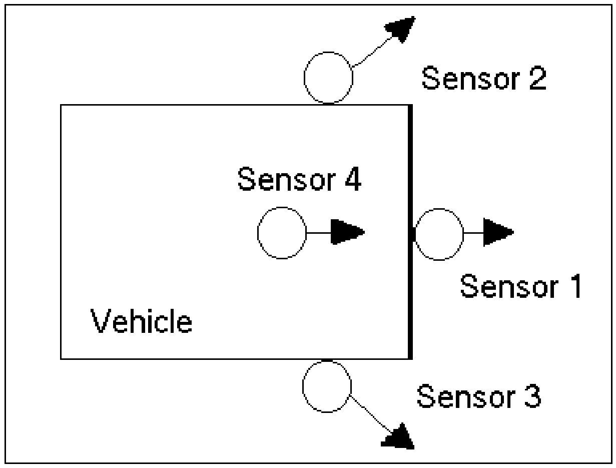

Figure 2 – Sensor Diagram on vehicle

- Shaft encoder:
  This input is a pulse wave proportional to speed and is used by the system to determine where the vehicle is located on the internal map.
- Linear Actuator:
  This input sends varying signals according to wheel direction and is used by the EMAC based system to know whether the vehicle is going straight, turning right, or turning left. This information also aids the EMAC based system in determining the vehicle's location on the internal map of the quad.
- Digital Electronic Compass:
  This input sends a signal to the EMAC based system indicating which direction the vehicle is headed. This information helps the system determine where the vehicle is located on the internal map of the quad.

Output from EMAC based system:

- The output of the system is the movement of the vehicle. Either the vehicle is stopped, or it is moving toward the waypoint specified by the user. The vehicle's motion towards the waypoint can be seen in three ways: turning right, turning left, or going straight. The motion output depends on the various inputs to the EMAC based system.

Input/Output	**Mode**		
	Query	Maneuver	Obstacle
Acoustic Sensors 1-3	N/A	signals vary in amplitude according to surface, Doppler shift for speed	N/A
Acoustic Sensor 4	N/A	N/A	varying amplitude signal if obstacle is detected in the designed range
Linear Actuator	N/A	varying signal determining wheel angle	N/A
Shaft Encoder	N/A	varying frequency square wave proportional to speed	N/A
Digital Electronic Compass	N/A	sends signal according to direction vehicle is facing	N/A
User Input	destinations and waypoints	N/A	N/A
Vehicle Movement	stopped	vehicle turns left, right, or continues forward	vehicle stops and waits for obstacle to move

Table 1 - System Inputs and Outputs

System Level Block Diagram for Autonomous Vehicle

Hardware:

Hardware System Level Block Diagram

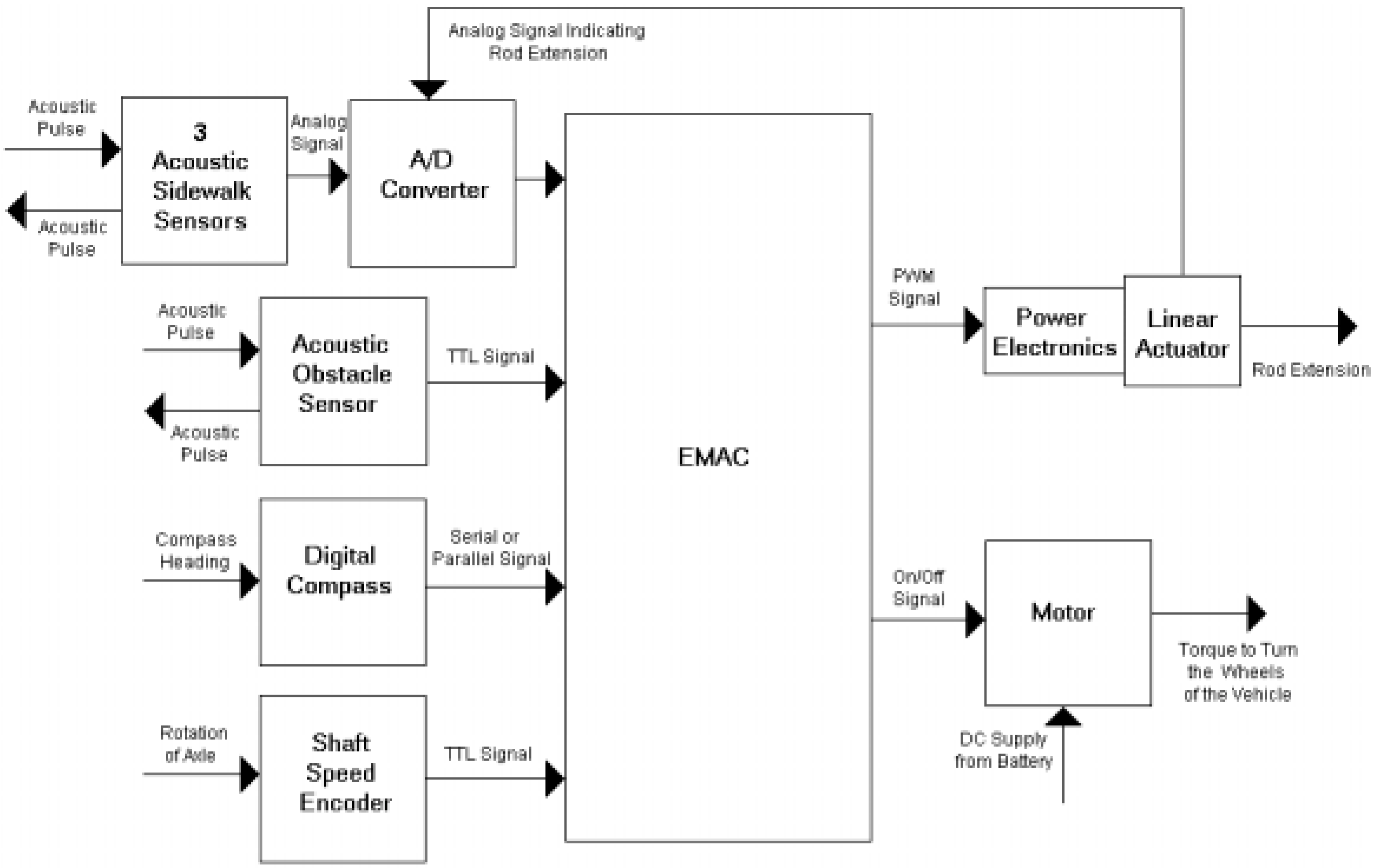

Figure 3 – Hardware System Level Block Diagram

Each hardware subsystem can be seen in the Hardware System Level Block Diagram above in Figure 3. This block diagram shows all of the inputs and outputs of each subsystem and how they relate to the overall system. Each of the subsystems is discussed in more detail below.

Acoustic Sidewalk Sensor Subsystem

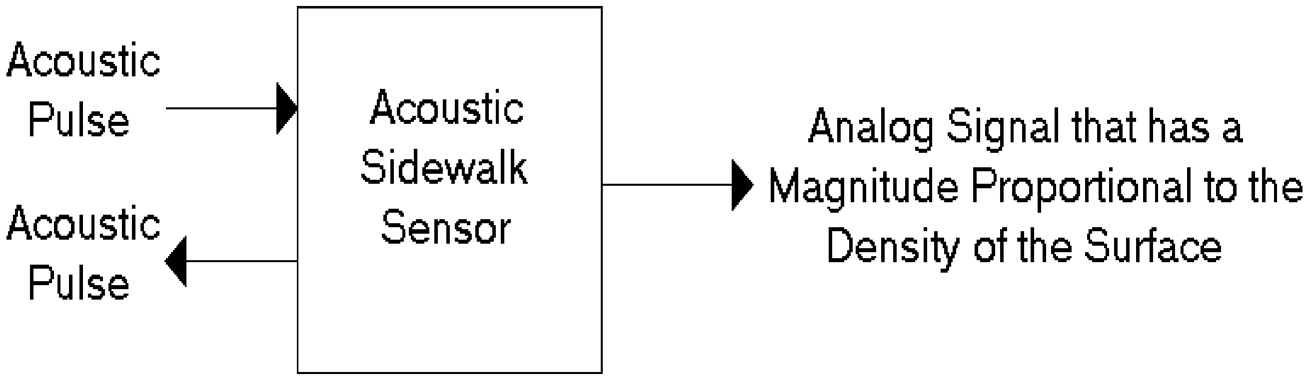

Figure 4 – Acoustic Sidewalk Sensor

Acoustic Pulse Input and Output:
The acoustic sensor transmits an acoustic pulse. If it hits an object, the acoustic pulse reflects off the object, and a portion of the reflected energy propagates back to the sensor where it is detected.

Analog Signal Output:
The acoustic sensor has two outputs: an analog signal output and a digital output. For this application, only the analog signal output is used. The analog output has a magnitude that is dependent on the reflected acoustic energy received by the sensor. This energy depends on the angle of the surface to the sensor bore sight, the distance of the surface to the sensor, the density of the surface, and the texture of the surface. The acoustic sidewalk sensor is mounted on a boom, pointing so that the sensor bore sight is perpendicular to the ground, so the acoustic pulse is normally incident on the surface. Also, the distance of the sensor to the surface is fixed because it is mounted at a certain height. Therefore, when comparing different output analog signals from the acoustic sidewalk sensor, the differences in the magnitude of the analog output signal can be attributed to different surface densities or different surface textures since the distance and angle of incidence is fixed. If there is not a returned acoustic pulse received by the acoustic sensor, then there are no objects within a specified distance, or the object absorbs the incident acoustic energy.

Three acoustic sidewalk sensors are used in this EMAC based system. They are all pointing towards the ground. These sensors are used to differentiate the sidewalk from the grass. The analog signal output is sent to the A/D converter on the EMAC board. This signal provides the appropriate information for determining if the vehicle is on the sidewalk, off of the sidewalk, or on the sidewalk at an intersection. From this information, the EMAC software determines if the vehicle needs to continue in its current mode of operation, or switch to a new mode of operation.

Acoustic Obstacle Sensor Subsystem

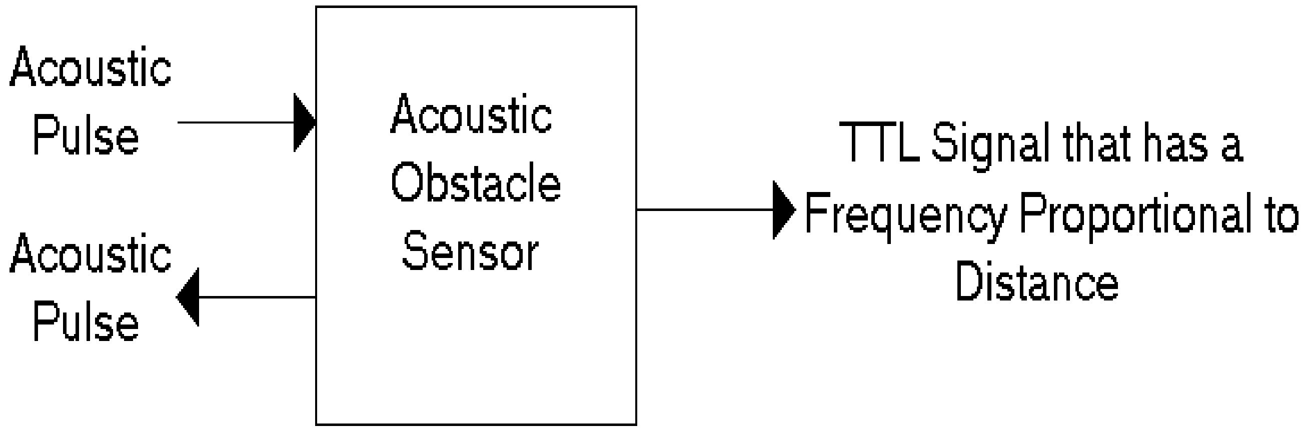

Figure 5 – Acoustic Obstacle Sensor

Acoustic Pulse Input and Output:
The acoustic sensor transmits an acoustic pulse. If it hits an object, the acoustic pulse reflects off the object, and a portion of the reflected energy propagates back to the sensor where it is detected.

TTL Signal Output:
The acoustic sensor has two outputs: an analog signal output and a digital output. For this application, only the digital signal output is used. The digital output is generated if a return pulse is detected. If detected, the time delay of the pulse relative to transmission time is proportional to the distance of the object to the sensor. The detection of the acoustic pulse depends on the angle of the surface to the sensor bore sight, the distance of the surface to the sensor, the density of the surface, and the texture of the surface. Thus, larger objects will return an acoustic pulse at larger distances than smaller objects. Also, objects with a surface normal to the acoustic pulse will return an acoustic pulse at larger distances than objects with a surface not normal to the acoustic pulse.

There is one acoustic obstacle sensor mounted on the top of the vehicle pointing straight forward. Unless there is an obstacle within the specified range, the TTL signal output is zero. If an obstacle is detected, the output goes high with the delay proportional to the distance to the obstacle. Since a pulse train is transmitted, the echo output is periodic and has a higher frequency for closer objects, and a lower frequency for objects farther away. This TTL signal is sent to the EMAC board to determine if there is an obstacle in front of the vehicle. If the TTL signal indicates that an object is within a certain distance, the vehicle will enter obstacle mode and stop. The vehicle will remain stopped until the TTL signal indicates that the obstacle is gone, and then the vehicle will reenter its previous mode of operation.

Digital Compass Subsystem

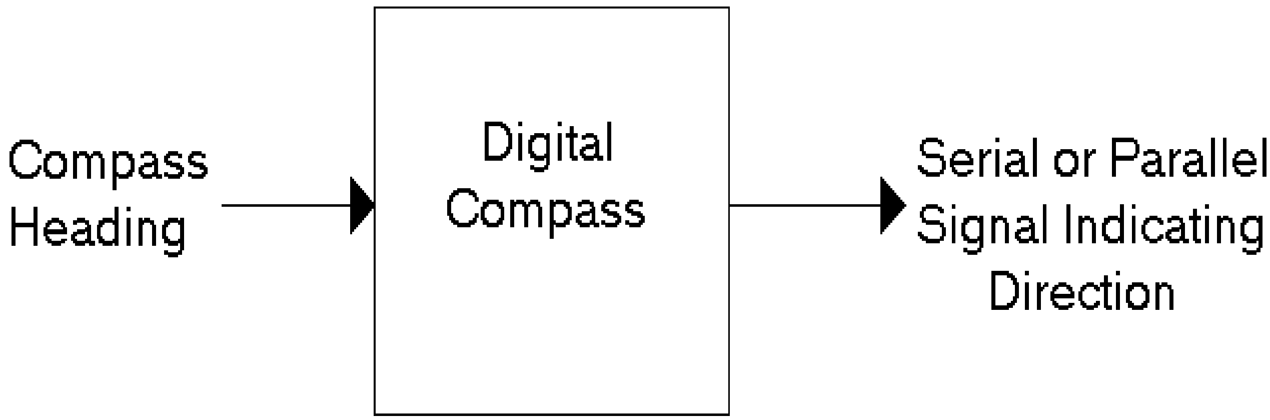

Figure 6 – Digital Compass

Compass Heading Input:
The compass, attached to the vehicle, responds to heading of the vehicle**.**

Serial or Parallel Signal Output:
It is assumed that there is a correlation between the compass' heading (and therefore vehicle heading) to electronic output of the compass. Obviously, more investigation needs to be done to determine the nature of the outputs and compatibility with inputs to the EMAC. This output is sent to the EMAC board where it is interpreted as the direction of the vehicle in degrees relative to North**.** This computed direction of the vehicle is used by the EMAC to aid in determining where the vehicle is heading on the internal map of the Jobst-Baker quad.

Shaft Speed Encoder Subsystem

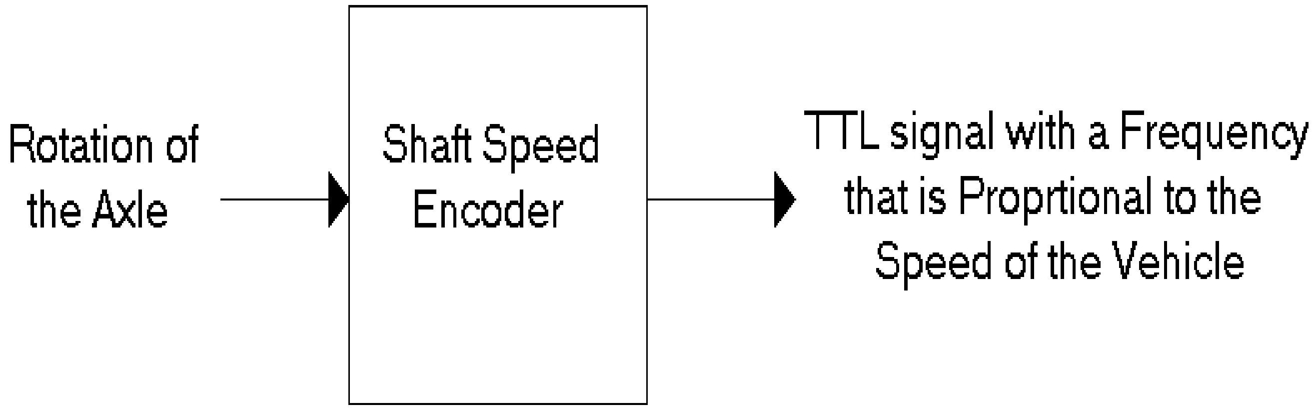

Figure 7 – Shaft Speed Encoder

Rotation of Axle Input:
This input is the rotation of the axle that spins a disk. A clear disk is attached to the axle with opaque markings on it. The rotation of the axle causes the disk to spin.

TTL Signal Output:
The TTL signal output has a frequency that is proportional to the RPM of the shaft. An opto-isolator is used to produce the output signal. Every time an opaque mark reaches a sensor the opto-isolator pulses. More investigation needs to be done to determine the number of opaque markings needed to make an accurate calculation of vehicle speed. If four opaque markings are used, for example, then after every fourth pulse, the axle has made one complete revolution. The output frequency is therefore proportional to the RPM of the shaft. The higher the frequency means the faster the rotation of the axle. The faster the rotation of the axle means the faster the vehicle is traveling.

This TTL signal is sent to the EMAC board. The EMAC software uses the output of this subsystem to determine the speed of the vehicle, which in turn, allows distance traversed to be determined. From the distance the vehicle has traveled, the software is able to determine where the vehicle is on the internal map.

Linear Actuator Subsystem

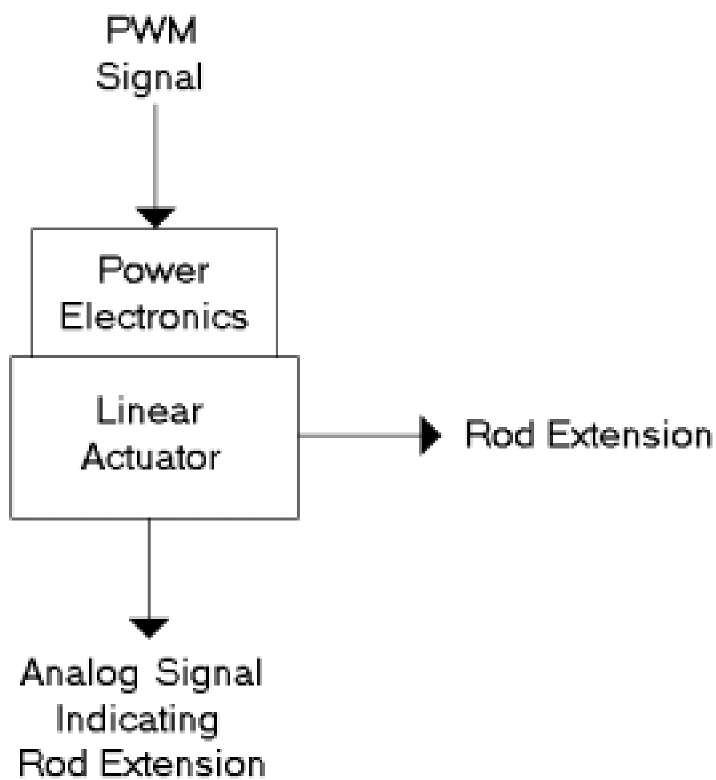

Figure 8 – Linear Actuator

PWM Signal Input:
The PWM signal input is sent to the power electronics from the EMAC board. This signal indicates what the extension of the rod should be.

Rod Extension:
This output is a mechanical output. The power electronics and linear actuator interpret the input PWM signal as the desired rod extension, and the rod extension output is the realization of the desired rod extension.

Analog Signal:
This output signal comes from the potentiometer on the Linear Actuator, and it indicates the current rod extension.

The Power Electronics receives an input PWM signal from the EMAC board indicating the desired rod extension. This information is transferred to the linear actuator, which then produces the mechanical output of rod extension to achieve the desired rod extension. The mechanical output of rod extension is what causes the vehicle to change its wheel angle. The output signal from the potentiometer is sent back through the A/D converter to the EMAC board. The software interprets this analog signal as the current rod extension. The EMAC software uses this information to determine if the vehicle is going straight, turning right, or turning left.

Motor Subsystem

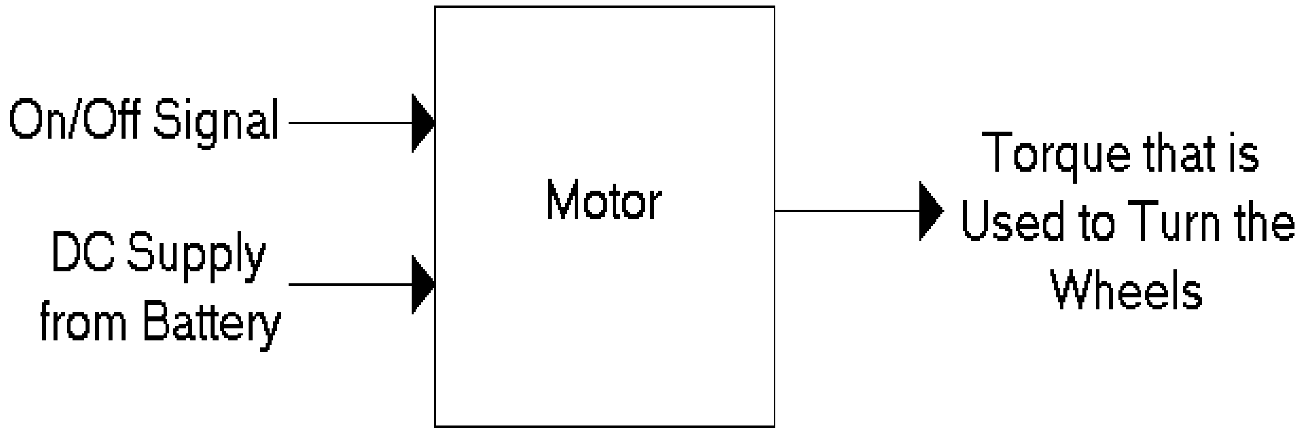

Figure 9 – Motor

On/Off Signal Input:
This input turns the motor on or turns the motor off.

DC Supply Input:
This input comes from the DC battery supply. It provides the motor with the appropriate DC voltage to operate.

Torque Output:
The torque output is a mechanical output produced by the motor.

The EMAC board sends an on/off input signal to the motor. When the motor is on, the motor produces a mechanical output. This mechanical output is torque, and it is applied to the appropriate gearing on the axle to turn the wheels of the vehicle. When the EMAC based system is in query mode or obstacle mode, the EMAC sends a signal to the motor indicating that the motor should be off. When the EMAC based system is in the maneuver mode, it sends a signal to the motor indicating that the motor should be on.

Software:

Query Mode

Before entering query mode, it is assumed that all components are initialized and system is ready for operation.

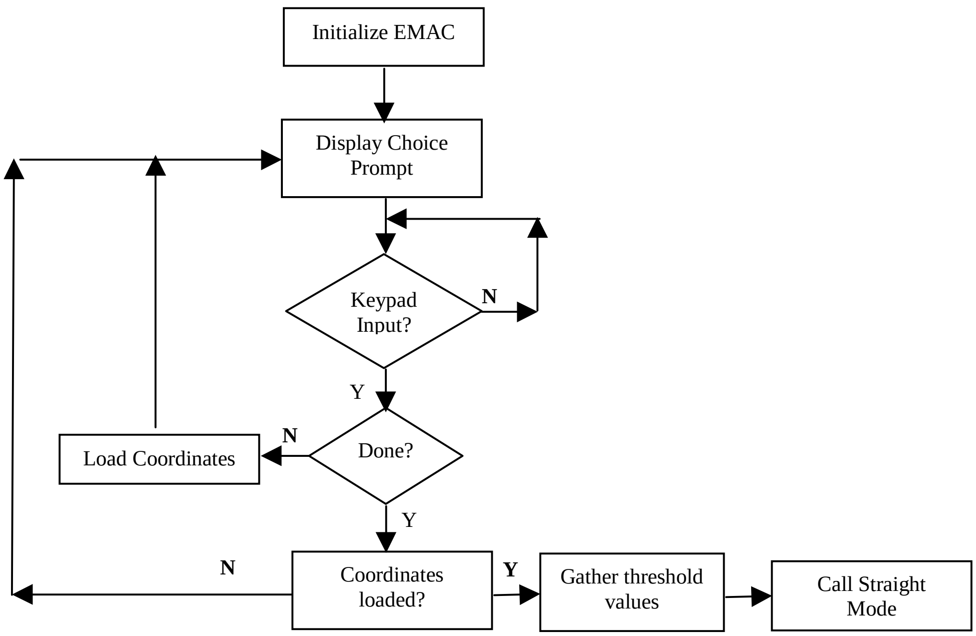

Figure 10 – Query mode flowchart

In Query mode, after the waypoint prompt is displayed, the microprocessor will wait for input from the user. After initial input, the microprocessor will check for a 'Done' input. If no 'Done' is detected, the current waypoint will be stored and a prompt for more points will be displayed on the LCD. Once a 'Done' input has been detected, the microprocessor checks to verify that waypoints were entered. If no points were entered the software will return and prompt the user for a waypoint. Otherwise, the microprocessor will gather a collection of 10 data points from the grass sonar and 10 data points from the concrete sonar to create an average threshold value to compare with future sonar readings. Once the threshold value is computed the **Straight** routine will be called by the microprocessor.

Maneuver Mode

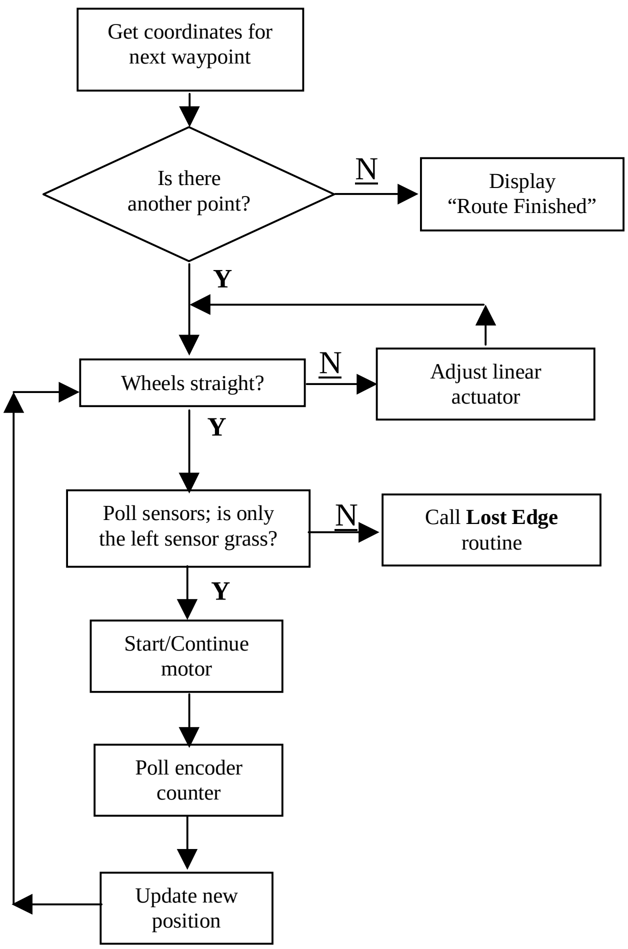

Figure 11 – Straight routine flowchart

In the straight routine the microprocessor is polling the sonar sensors at a minimum 80ms. Currently, this time is derived from the minimum time between sonar transmissions (recycle time). First, the EMAC gets the coordinates of the next waypoint. If there is not another waypoint stored, it is assumed that all user-entered waypoints have been traversed and the cycle is complete. Otherwise, the microprocessor will verify that the wheels are straight and adjust as necessary with the linear actuator. Next, the microprocessor polls the sonar sensors. If only the left sensor has a grass signal, then it is assumed that the vehicle is aligned with the sidewalk therefore power to the motor is started or continued. Otherwise, the microprocessor will call the **Lost Edge** routine. Lastly the microprocessor will poll the wheel encoder count and update its registers with the new position.

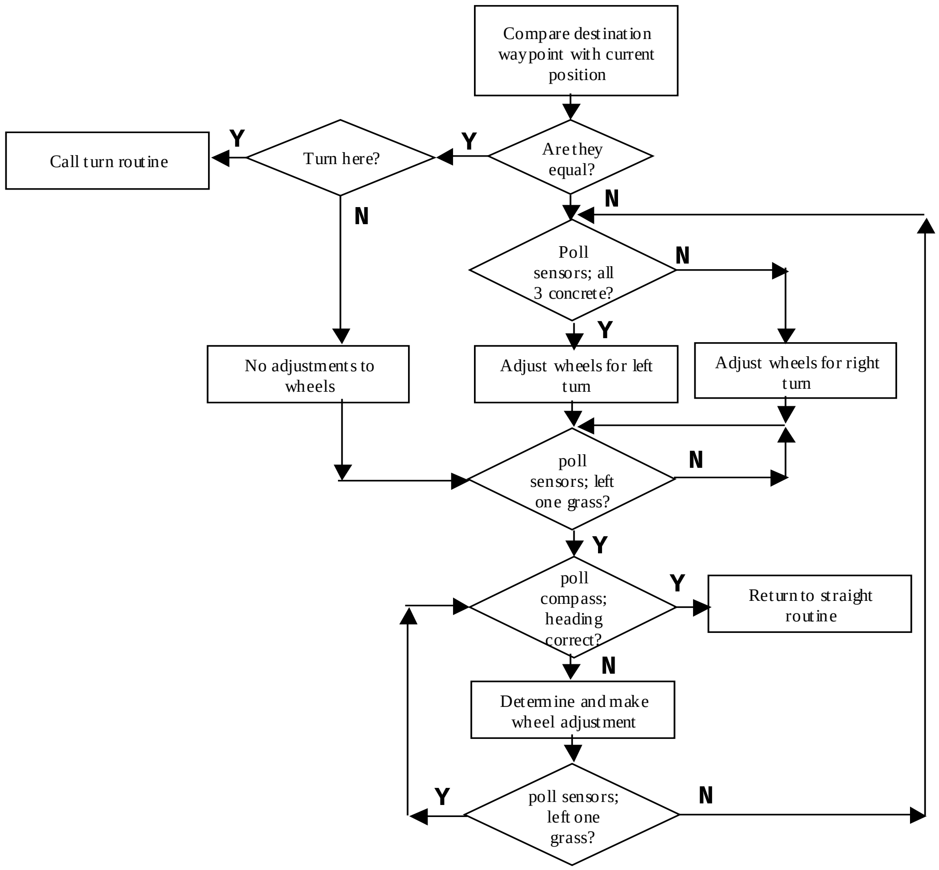

Figure 12 – Lost Edge routine flowchart

In the **Lost Edge** routine will compare the current coordinates of the vehicle with the coordinates the desired waypoint vehicle as entered by the user. If the two sets of coordinates are equal, then the microprocessor will check if a turn is necessary at this way point. If a turn is required at this way point the **Turn** routine will be called (see Figure 13) by the microprocessor. Otherwise, the EMAC will continue moving forward with the wheels straight until grass is detected on the left sonar sensor. If the coordinates are not equal than the vehicle has lost alignment with the sidewalk and needs to be realigned. To correct alignment the microprocessor will poll the sonar sensors and determine if all three sensors are over concrete. If this is true, then the wheels should be adjusted for a left turn and right otherwise. At this point the microprocessor will continue to poll the sonar sensors until a grass signal is detected on the left sensor. Once this occurs, the microprocessor will poll the compass and compare this value with stored heading to verify proper heading of vehicle. If the vehicle has a correct heading, then the microprocessor will return to the **Straight** routine. Otherwise, the necessary heading correction will be determined and the linear actuator adjusted accordingly. The microprocessor will poll the sonar sensors to ensure that the vehicle's left sensor is still on grass. If the left sensor is no longer on grass then the microprocessor returns to the earlier function that acquires the grass edge. Otherwise, the compass will be polled to recheck the vehicle's heading and repeat this process until the heading is correct and the left sensor is on grass. At this point the **Lost Edge** routine returns to the **Straight** routine.

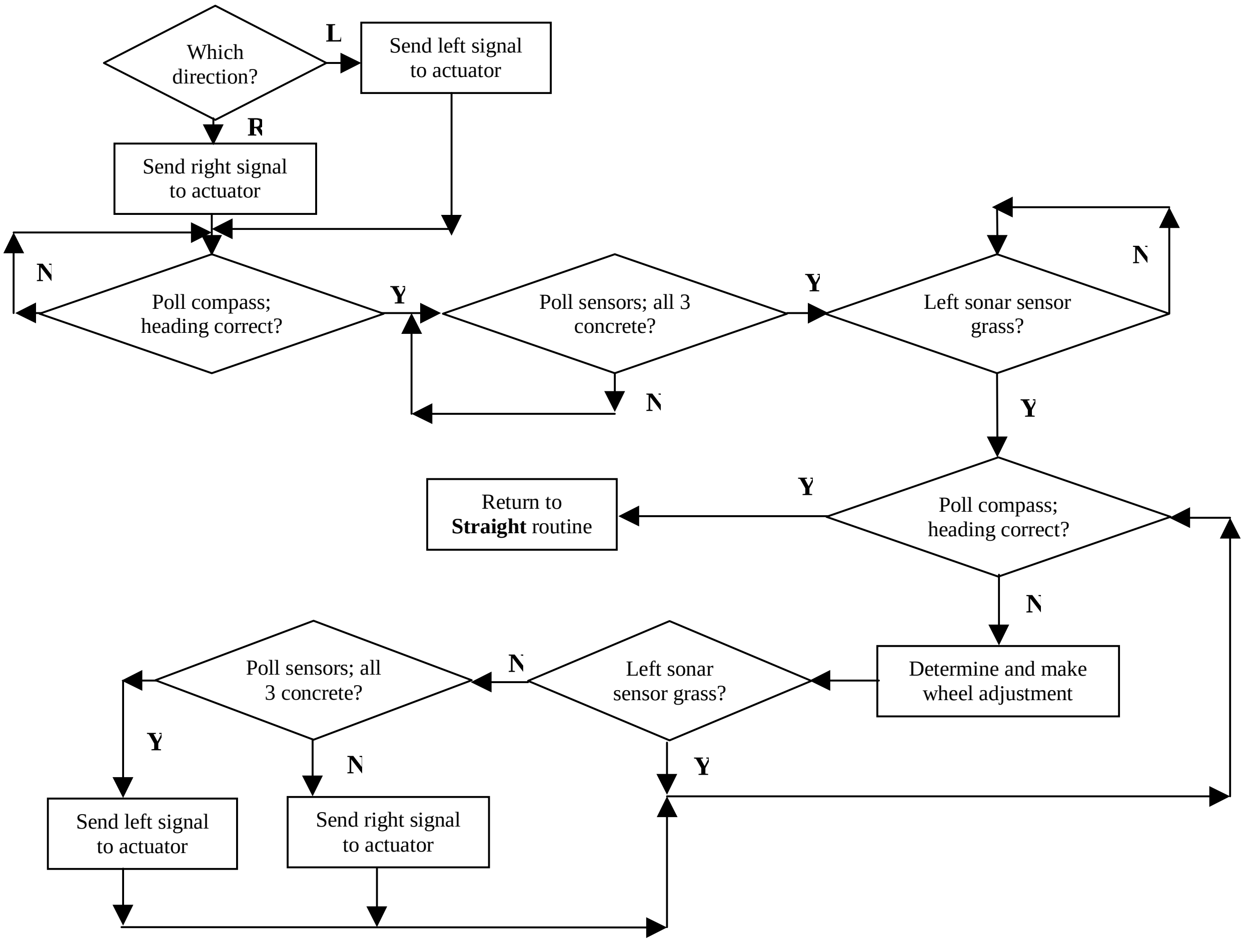

Figure 13 – Turn routine

This routine is called by the **Lost Edge** routine. After the desired direction is determined by the microprocessor, it sends the appropriate signal to the actuator. The microprocessor will poll the compass and wait for the a predetermined heading to be reached. Afterwards, the microprocessor will poll the sonar modules and wait for all three to be concrete of signals. Once this set of signals is acquired, the sonar modules will be polled until only the left sonar has a grass signal. Then, the routine will check the heading of the digital compass and compare it to a stored value for this intersection. If the heading is correct, the vehicle is aligned with the sidewalk and is ready to return to the **Straight** routine. Otherwise, a calculated wheel adjustment is made. Then the compass and sonar sensors are polled until the vehicle is aligned.

Obstacle Mode

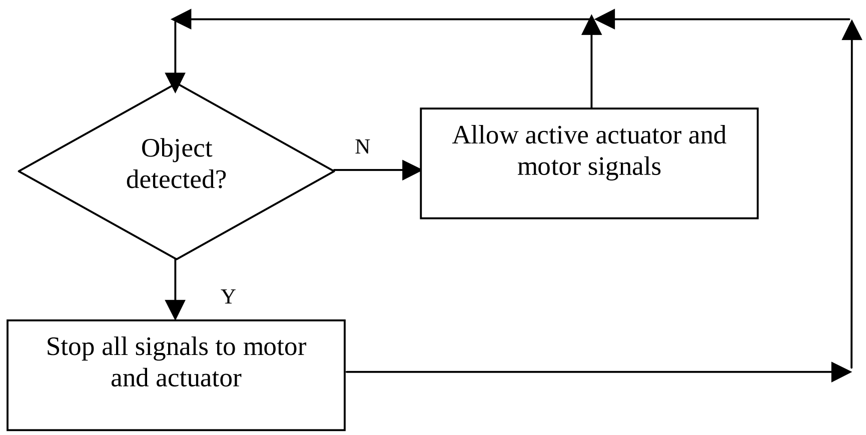

Figure 14 – Obstacle mode flowchart

This mode will be interrupt driven. One sonar module mounted parallel with the ground will determine if there are any objects in the vehicle's path. If an object is detected, the interrupt routine will be called. This routine will halt any further movement until the object is removed or the vehicle is placed at start and reset.

Patents

There are several patents that have some similarities to this project, but none of the patents use sonar sensors to help navigate the autonomous vehicle. The associated patents are listed below.

- "System and Method for Causing an Autonomous Vehicle to Track a Path"
  - U.S. Patent 5,657,226 August 12,1997
  - Integrated vehicle positioning and navigation
  - Combination of apparatus and methods
  - Included GPS and an IRU (inertial reference unit)
  - Position calculations and vehicle control with obstacle detection

- "Autonomous Vehicle Arrangement and Method for Controlling an Autonomous Vehicle"
  - U.S. Patent 6,151,539 November 21,2000
  - System includes
  - Input of travel orders
  - Digital map
  - Path generating unit
  - Laser and radar sensors for detecting obstacles and condition of path

- "Autonomous Vehicle Capable of Traveling/Stopping in Parallel to Wall"
  - U.S Patent 6,038,501 March 14,2000
  - Wheel encoder for distance and speed
  - Gyro for detecting direction

- "System and a Method for Enabling a Vehicle to Track a Present Path"
  - U.S. Patent 5,838,562 November 17,1998
  - GPS & IRU
  - Remote Control

- "System and Method for Enabling an Autonomous Vehicle to Track a Desired Path"
  - U.S. Patent 5,684,696 November 4, 1997
  - Plans a continuous path and return path if vehicle deviates from desired path
  - GPS & IRU

DATA SHEET

Specifications for each mode of operation will be discussed in this section. Also, the testing procedures to show that the autonomous vehicle is working will be discussed.

- Specifications for Query Mode
  - There will be a user interface that consists of a keypad and LCD display.
  - The vehicle is stationary during this mode. The user is prompted to enter the destination or destinations of the vehicle. First, the user enters the number of destinations, and then the user enters the destinations in sequential order.
  - The user can enter up to 15 waypoints (or destinations).

- Specifications for Maneuver Mode
  - In the Straight Sub-mode:
    - The position calculation of the vehicle on the internal map of the quad will be within +/- 0.5 meters of the vehicle's actual position.
    - The maximum speed of the vehicle is 2.24 meters/second.
    - For this project, the vehicle will travel at a constant speed of 0.25 meters/second.
    - The deviation of the vehicle from the sidewalk edge will be no more than 10 centimeters.
  - In the Intersection/Lost Edge Sub-mode:
    - If the edge of the sidewalk is lost, but the position of the vehicle does not match the location of an intersection on the internal map, the vehicle will have 5 seconds to reacquire the edge of the sidewalk.
    - If the edge of the sidewalk is not reacquired, the vehicle will stop, and it must be reset by the user.
  - In the Turn Sub-mode:
    - The minimum turn radius is 10 ft.
    - It will take 5 seconds for the vehicle to acquire the straight sub-mode after a 90° turn has been made.

- Specifications for Obstacle Mode
  - Detection Zone
    - Objects are detected between 3 and 7 meters.
  - Alarm Zone
    - An alarm will sound if objects are detected between 1 and 3 meters, which will warn the obstacle that the vehicle is coming.
  - Stop Zone
    - The vehicle will stop if an object is detected between 0 and 1 meters.
    - After the vehicle has stopped, it will wait for the object to move, and then it will continue in its previous mode of operation.
    - If the object does not move, the vehicle must be reset by the user.

- Testing of Autonomous Vehicle
  - Test 1 (Tests Straight Sub-mode):
    - Run the vehicle from the starting point to the first waypoint, and then have it stop.
  - Test 2 (Tests Lost Edge/Intersection Sub-mode):
    - Start the vehicle at an angle on the sidewalk where there is not an intersection. The angle will force the vehicle to lose the sidewalk edge. This test will show if the vehicle can reacquire the edge of the sidewalk within 5 seconds, or if the vehicle will stop if it does not reacquire the edge of the sidewalk within 5 seconds.
  - Test 3 (Tests the Turn Sub-mode):
    - Run the vehicle to the first two waypoints and then have it stop. The vehicle will have to turn to reach the second waypoint.
  - Test 4 (Tests the Obstacle Mode):
    - Run the vehicle with an object in front of it to see if the alarm goes off and the vehicle stops.

Preliminary Work

- Experimented with Acoustic Sensor
- Took Measurements from Acoustic Sensor for different surface textures (sidewalk, grass, etc).
- Examined Shaft Speed Encoder
- Learned about Digital Compass
- Worked on Power Electronics for Linear Actuator
- Worked on Design for the Power Electronics for the Motor

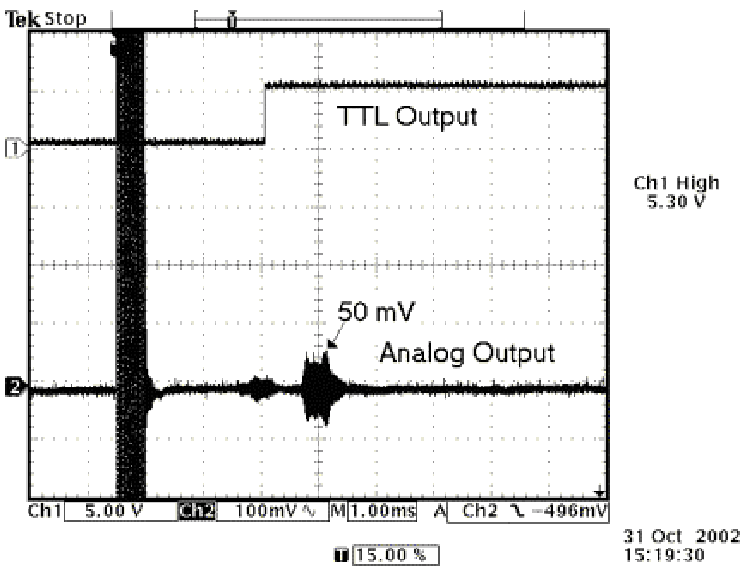

Figure 15 – Sensor Output in Response to Grass

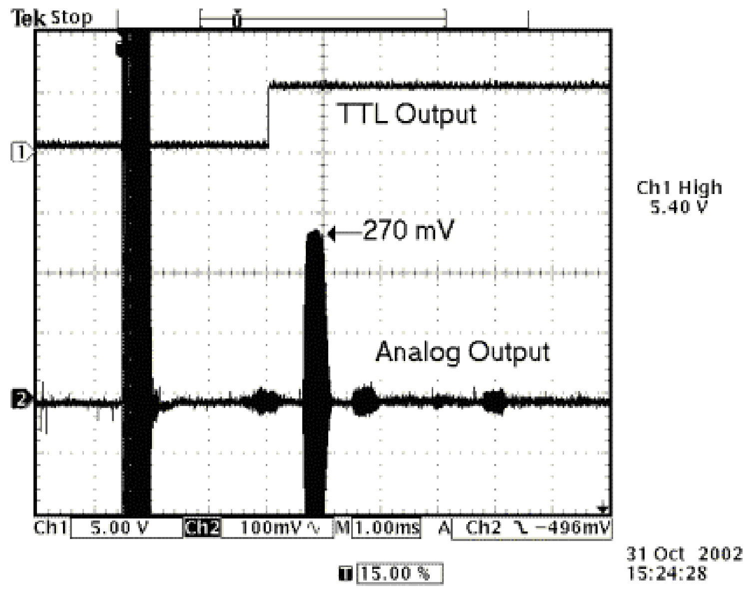

Figure 16 – Sensor Output in Response to Concrete

As can be seen in figure 15 and figure 16, there is a 230 mV difference in the magnitude between grass and concrete. This is a large enough difference to distinguish between grass and concrete.

Schedule and Division of Labor

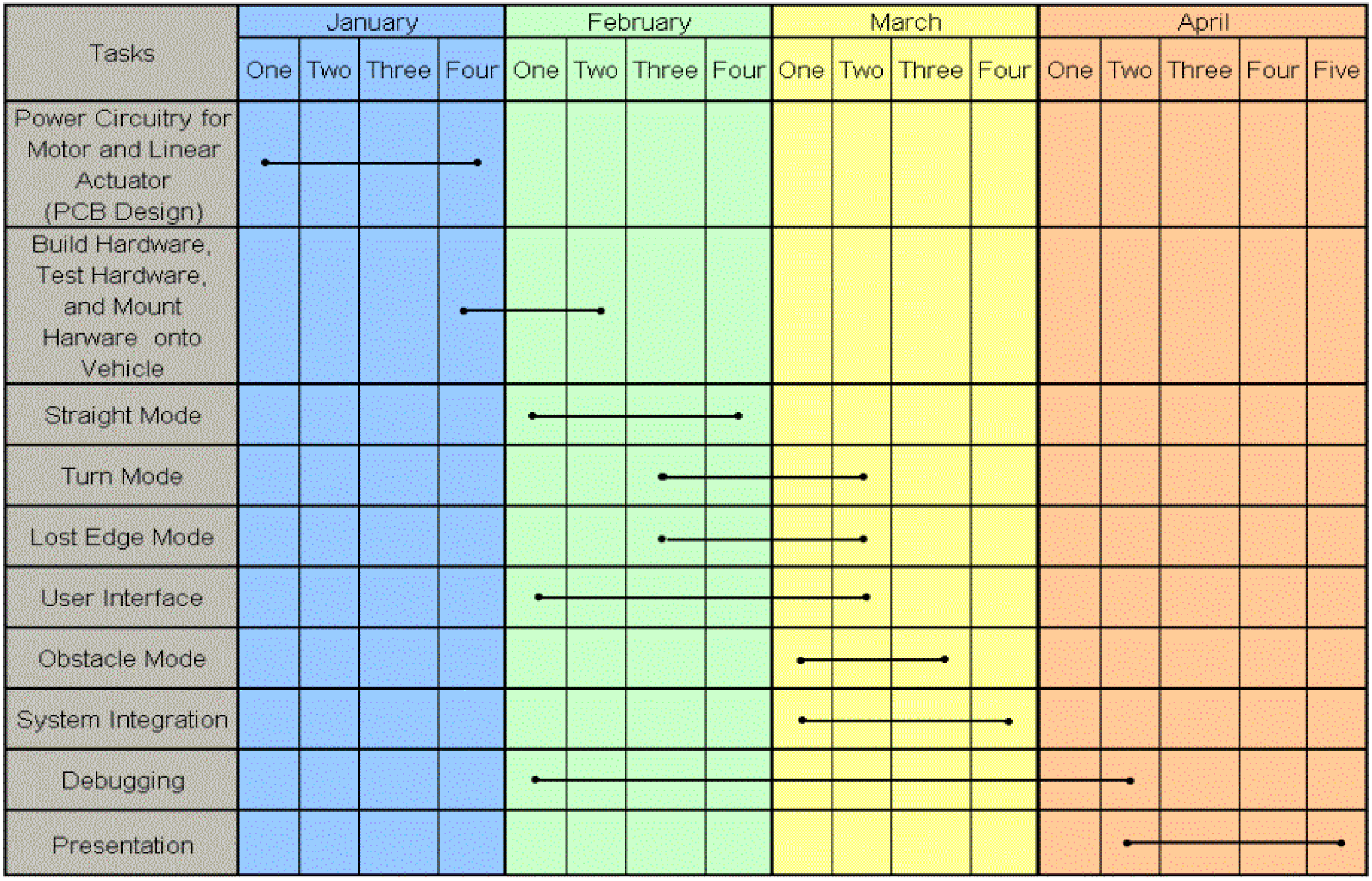

Table 2 – Schedule of Tasks

	Erin Cundiff		Ramona Cone
Hardware:	Acoustic Sidewalk Sensors	Hardware:	Linear Actuator
	Acoustic Obstacle Detection Sensor		Motor
	Shaft Speed Encoder		Digital Compass
Software:	Acoustic Sidewalk Sensor Software	Software:	Linear Actuator Software
	Acoustic Obstacle Sensor Software		Motor Software
	Obstacle Mode		Digital Compass Software
	Query Mode		Turn Mode
	Straight Mode		Lost Edge Mode
	Quad Map		

Table 3 – Division of Labor

Equipment List

- Acoustic Sensors
- Sensors for Shaft Speed Encoder
    - Preliminary Design includes Hall Effect Sensors
- Digital Compass
- EMAC board with Keypad and LCD display
- H-Bridge Chip
- Motor and Linear Actuator
- Vehicle and Battery

Bibliography

Beetz, M., S. Buck, R. Hanek, B. Radig, and T. Schmitt. "Cooperative Probabilistic State Estimation for Vision-Based Autonomous Mobile Robots." IEEE Transactions on Robots and Automation, vol.18, no. 5, p. 670, October 2002.

Clark, S., M. Csorba, M. W. M. Gamini Dissanayake, H. F. Durrant-Whyte, and P. Newman. "A Solution to the Simultaneous Localization and Map Building Problem." IEEE Transactions on Robots and Automation, vol.17, no. 3, p. 229, June 2001.

Heber, T., N. C. Txourveloudis, and K.P. Valavanis. "Autonomous Vehicle Navigation Utilizing Electrostatic Potential Fields and Fuzzy Logic." IEEE Transactions on Robots and Automation, vol.17, no. 4, p. 490, August 2001.

Jacobsen, S., P. Pederson, and J. Willhjelm. "The Influence of Roughness, Angle, Range, and Transducer Type on the Echo Signal from Planar Interface." IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 48, no. 2, p. 511, March 2001.

Laiv, A. "Adaptive Output Regulation of Robot Manipulates under Actuator Constraints." IEEE Transactions on Robots and Automation, vol.16, no. 1, p. 29, February 2000.