Jo-Car

German Jordanian University - Mechatronics Engineering

Ahmad Bino

Tariq Adaileh

Hudhaifa Jasim

Supervised by: Dr. Nathir Rawashdeh

I, Dr. Nathir Rawashdeh, assistant professor at the Department of Mechatronics Engineering at the German Jordanian University do hereby certify that the engineering design of the vehicle, JO-CAR, has been significant and each team member has earned at least three semesters hours credit for their work on this project.

Signed   Date

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FUND FOR DEVELOPMENT

Phone: +962 788822112   Email: nathir.rawashdeh@gju.edu.jo

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1. Team Overview:

Our team of Mechatronics Engineering at the German Jordanian University (GJU) in Amman, Jordan, is glad to be the first team from the Middle East to participate in the Intelligent Ground Vehicles Competition (IGVC) for the first time and present there JO-CAR vehicle. This project is thankfully funded by King Abdullah Fund for Development and King Abdullah Design and Development Bureau.

The German Jordanian University IGVC team consists of three members, all are undergraduates of Mechatronics Engineering and supervised by Dr. Nathir Rawashdeh. Aside from the IGVC this project is also considered to be our graduation project. Despite the difficulties that faced the team, such as lack of professional equipment, the necessity for ordering the components from foreign countries, lack of free laboratories at the university as its currently temporary located at hired building and the one semester development cycle of the project, JO-CAR possesses the capabilities required to compete at the IGVC.

Since our team is considered to have a relatively smaller number of members than other teams, the necessity to organize and structure our work in most efficient way was a most. The most efficient and professional method for the completion of tasks and achieving progress on the assigned time and according to the time-plane we agreed on at the early stages of the project. Members were grouped by their area of expertise as hardware or software. The hardware member, mainly Tariq Adaileh is responsible for mostly the physical aspects of the robot. These include also design, fabrication of body panels. The software group, mainly Ahmad Bino is responsible for the high level programming and development of algorithms and later, mainly by Hudhaifa Jasim the implementation of software including sensor processing, intelligent navigation schemes and robust feedback control systems. Elementary tasks of sensors selection, electronics, electrical wiring and computer is conducted by the whole team. Also to oversee these groups, one student was designated as team leader, namely Ahmad Bino and one handled accounting and logistics, namely Tariq Adaileh. Weekly team meetings were held to set goals, establish tasks and track progress.

2. Mechanical Design:

2.1 Mechanical Skeleton

The mechanical skeleton of JO-CAR is wheel chair based, it consists of two electric 24V 9A DC-Motors and two steering wheels, the skeleton is made of rigid steel-chrome coated metal bars. See figure 1.

Figure 1: The initial mechanical skeleton

2.2 CAD Model and Body Frame

The body frame passed through many design stages staring from a CAD model through CNC machining. The body panel is made of light wood and acrylic. The outer design is meant to meet the aerodynamic lines of modern cars and trains and features panoramic roof where the components can be seen inside.
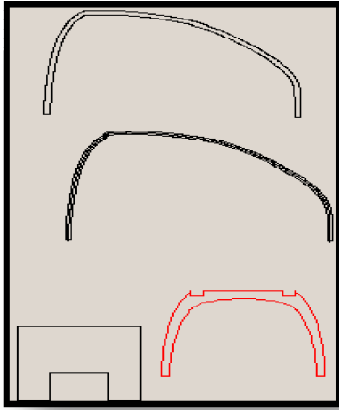

Figure 2: CAD model of the body panels   Figure 3: Complete body panel

3. Electrical and Electronic Components and Design:

3.1 Batteries

Two rechargeable Lead acid batteries from FIAMM (24V 18AH) will be used to power the motors. Another two sealed rechargeable batteries (12V 2.2AH) will be used to power the rest of electronics such as development board, Wireless Transceiver, 12V alarm light…etc.

3.2 Motors

Two 24 V 9A DC Motors provided with gear boxes are used to drive the vehicle, they provide high torque and reasonable speed and can sustain high loads 150 Kg weight.

3.3 Development Board

The PICPLC4 development board is used as a main controller for the vehicle it contains (Figure 4) :

- PIC18F87J60 is the microcontroller controlling the operation of the PICPLC4 v6 PLC system
- On-board 4 relays for current up to 16A. Each relay has a LED for optical signalization.
- DIP switch is used as pull-up/pull-down resistors.
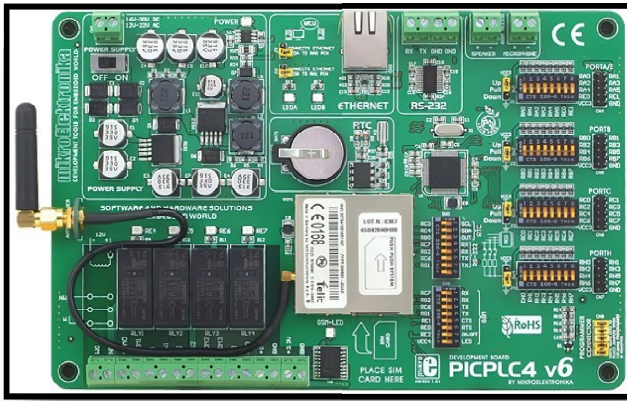- 18FJprog programmer

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Figure 4: Development Board

Figure 5: GPS Unit

3.4 Laptop

TOSHIBA – Satellite Pro – Intel Pentium Dual CPU 2.16 GHz, 3GB DD Ram. Matlab-Simulink is used for Image processing and lane detection.

3.5 Manual Emergency Stop

The E-stop is red in color, more than one inch in diameter. It is mounted at a place where it can be easily identified and can activate safely. The button will is hardware based and not controller through software and will bring the vehicle to complete stop once pressed.

3.6 Wireless Emergency Stop

The Vehicle will be also provided with wireless emergency stop to enhance safety measures, the E-stop is effective for a minimum of 100 ft. This feature is provided by using two Xbee Pro chips, one will be used as transmitter and will be located inside a white plastic box as shown in figure 6, and the other will work as a receiver and will be located inside the vehicle. Special encryption is

Figure 6: Wireless e-Stop

provided to ensure having no disturbance to the signal.

3.7 Alarm light

12 V safety alarm light will be mounted at the top of the vehicle and will be used for warning when the vehicle goes to autonomous mode. The light will turn on whenever the vehicle power is turned on and will start blinking when the vehicle goes to autonomous mode.

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4. Sensors:

4.1 Machine Vision Camera

A **Microsoft LifeCam Cinema camera** will be used for machine vision. The camera will be located in front of the vehicle and will be connected to the Laptop using USB cable.

Figure 7: Microsoft LifeCam Cinema

4.2 Obstacle Avoidance Sensor

For obstacle avoidance, Hokuyo **URG**-04LX-UG01 laser range finder will be is used. It **will be located in front of the vehicle. This** laser utilizes a USB 2.0 interface. The field-of-**view for thi**s detector is 240 degrees. Distances are **reported from 20mm to 5.6 meters,** Pitch angle is 0.36°, and a distance **resolution ranges from 1 to 3mm.**

Figure 8: URG laser range finder

4.3 GPS

JO-CAR used Telit GSM/GPRS modules: GM862-GPS to navigate through GPS waypoints. See figure 9.

Figure 9: Hokuyo URG-04LX-UG01

4.4 Digital Compass

Honeywell HMC6352 is a fully integrated compass module that combines 2-axis magneto-resistive sensors **with the required analog and digital support circuits, and algorithms** for heading computation. **The compass is** used to determine the orientation of the vehicle **relative to the north and** subsequently determining the angle to the next GPS way point.

Figure 10: Compass Module

5. Software **Development**

Our software is based on a very efficient algorithm. First step regarding the software and code that will be used to control the vehicle was to conduct several meetings and discussions to be able to imagine how the process of the control should be. The target was to define the problem, and find the easiest and fastest response. However, to avoid the mistakes and to be aware of every single detail, we divided the process to single parts, or what's called in programming, abstraction. The communication among the

controller and the peripheral devices is done according to the priority of the device. For example, the controller gives priority to line detection sensor and obstacle avoidance, GPS.

Technical innovations in programming:

As the team entered the stage of writing the code, sub procedures and or sub-routines representing solutions to the main tasks, namely, GPS navigation, Lane detection and obstacle avoidance. Each stage of the code was tested separately. To demonstrate, we considered the GPS navigation as a problem. We developed a theoretical solution to it and implemented as code. This is what we called "Navigator". Next step was the line avoidance. We considered it as a problem, once it was done, next problem, namely obstacle avoidance, was considered. Then we integrated both of them as one problem calling the solution "Path Planner". This technique was very useful to figure out the errors in programming. Our goal during writing the code was to build effective and real time program. To do so, we divided the code to sub-routines. They inherit from each other. This technique is very useful while tracking the error in the code, or modifying the code in the future. The program is a real-time control. It's based on software and hardware interrupts. For example, the current that passes though the motor driver is monitored and it has a limit that should not exceeds. When the current reaches the critical level, there will be a change in the logic level of the BJT to send a trigger (hardware interrupt) to the controller to reduce the speed of the motor. There is a periodic discussion among the team member that takes place weekly to reduce the code to the smallest number of instruction. This is a key to make the program faster.

6. GPS Navigation:

Theory:

The GPS (global positioning system) provides position information depending on the longitude and latitude. The longitude and latitude position is accompanied with a letter indicating where the position is located relative to the original longitude line of GMT and the latitude circle of equator, see figure below. Letter 'N' means to the north of the equator, 'S' south of the equator, 'W' west of GMT and 'E' east of GMT.
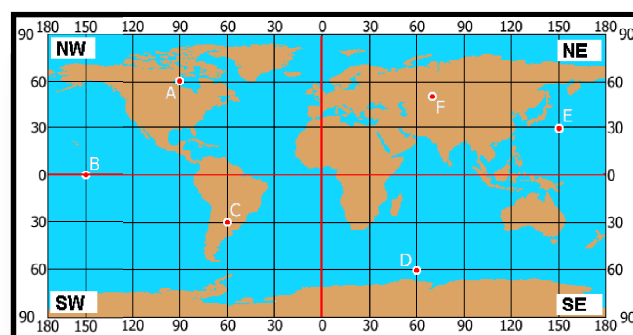

Figure 11: The longitude and latitude

Our development board uses Telit GM862-GPS Module to fetch the GPS position of the vehicle.

Objectives of the Function

This function is supposed to give the angle between the direction of the vehicle and the direction of the target GPS point by using trigonometric functions. This function will use the value acquired by the compass in order to calculate the current orientation and the target orientation.

Mathematical and trigonometric background:

In order to be able to calculate the proper orientation, we need mainly to use:

- Pythagoras theorem for calculation of the distance

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

- Tangent function for the calculation of the angle.

$$tan\theta = \frac{|y|}{|x|}$$

From which it follows that

$$\theta = tan^{-1}\frac{|y|}{|x|}$$

Development:

For the development of the function, we need to know the following data:

1. Determine in which quarter of the globe we are.

2. Angle from the current GPS point to the next GPS point.

3. Compass angle.

Specifying the quarter:

The specifying of which quarter of the globe the vehicle is located is essential since we need it to determine the quadrant of the target GPS point relative to the current GPS. This is explained as follows:

The data produced by the GPS module (Telit GM862-GPS) is associated with two letters representing the quarter of the globe at which the vehicle is located (see figure 1). At the case of the competition at Oakland University in Michigan, USA, this will be (NW) meaning that we are located to the north of the equator and to the west of GMT.

Specifying the angle of the next GPS point relative to the current GPS point

The angle between the current and next GPS points, θ_{GPS}, is calculated as follows:

Suppose that the vehicle is located at a random position represented by (x_1, y_1), and the next GPS is (x_2, y_2). We need first to determine the quadrant at which the next GPS point is located.

At this stage, the orientation of the vehicle is not important. With orientation, we mean the direction of the vehicle relative to the north.

As seen in the figure below, the current position is considered to be the origin of the coordinate system. This helps in determining the quadrant at which the next GPS point is located. See figure 12.
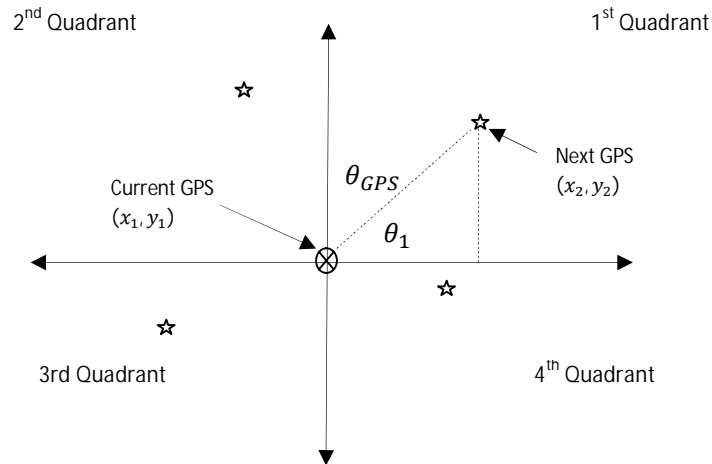

Figure 12: The vehicle is considered to be at the origin of the coordinate system.

The determination of the quadrant is essential so we will be able to either subtract or add θ_1 from 90 degrees to calculate the angle with respect to the north direction. θ_{GPS} is the angle with respect to the north direction.

Next GPS location is determined depending on the following two formulas to be at one of the 4 quadrants, remember that we are in the NW quarter of the globe and x value increase as we go to the left, as well as that y values increase as we go up:

$$x = x_2 - x_1$$
$$y = y_2 - y_1$$

Case 1: if x is negative and y is positive, then next GPS is located at the 1st quadrant. i.e.

$$\theta_{GPS} = 90 - \theta_1$$

Case 2: if x is positive and y is positive, then next GPS is located at the 2st quadrant. i.e.

$$\theta_{GPS} = 270 + \theta_1$$

Case 3: if x is positive and y is negative, then next GPS is located at the 3st quadrant. i.e.

$$\theta_{GPS} = 270 - \theta_1$$

Case 4: if x is negative and y is negative, then next GPS is located at the 4th quadrant. i.e.

$$\theta_{GPS} = 90 + \theta_1$$

That is the next GPS point relative to the current GPS point is given in degrees with reference to the north direction.

Compass Angle

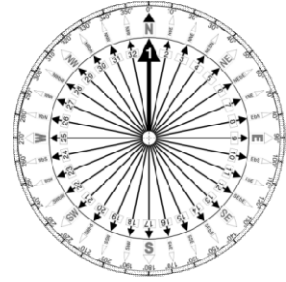The compass angle from our compass module (HMC6352) is given relative to the north direction in degrees. See figure 13

Figure 13: Compass Scale

Calculation of the final angle

With the final angle we mean the angle between the direction of the vehicle and the direction of the next GPS point, This angle serves only to get the direction the vehicle should rotate in orfer to face the next GPS. In calculating the final angle, we have to subtract θ_{GPS} from $\theta_{Compass}$, i.e.

$$\theta_{final} = \theta_{Compass} - \theta_{GPS}$$

The result of this equation will be either positive meaning that the next GPS point is located to the right of the vehicle, or negative meaning that the next GPS is located to the left of the vehicle, see figures 14 and 15 below.
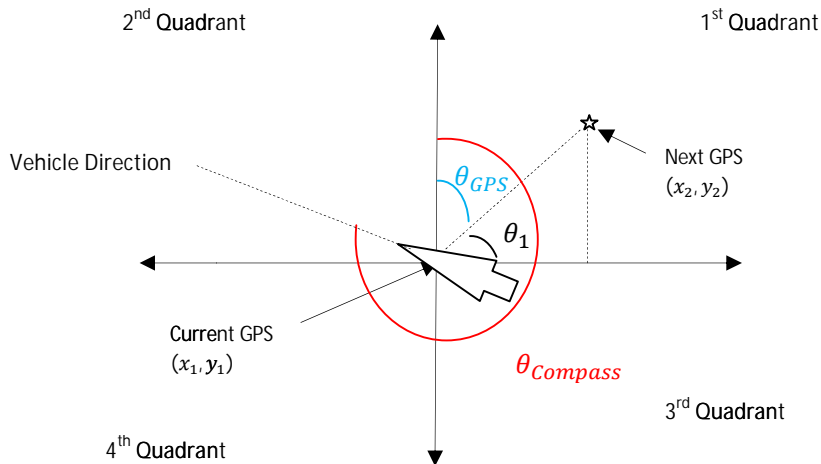

Figure 14: $\theta_{\theta inal} = \theta_{Compass} - \theta_{GPS} = +ve$ means vehicle should rotate right to face the GPS point
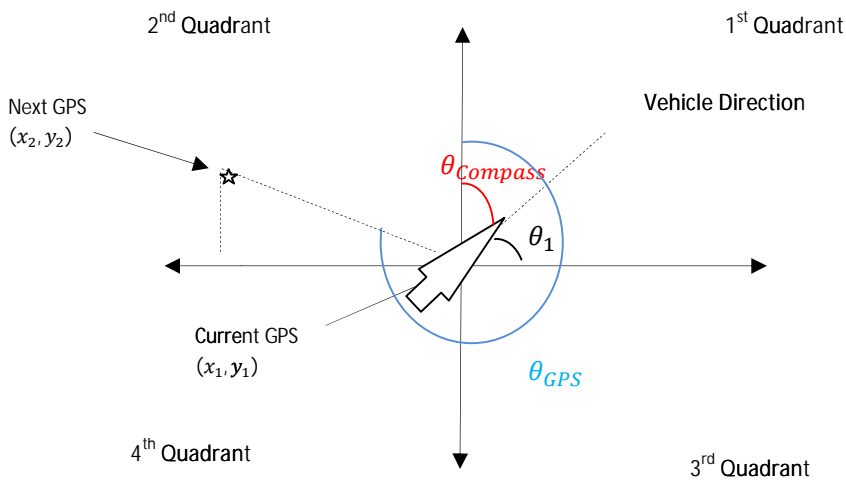

Figure 15: $\theta_{final} = \theta_{Compass} - \theta_{GPS} = -ve$ means vehicle should rotate left to face the GPS point

7. Path Planner

This function mainly consists of three threads:

1. Image Processing Thread
2. Laser Range Finder Thread
3. GPS Permittivity Thread

Each thread is specifically responsible for one function, the image processing is responsible for lane detection, and the laser range finder is responsible for obstacle avoidance.

The output of this function should be summarized data that indicates how far is the nearest white line segment or obstacle, and on which side it is located. Upon this data, the function will decide the type of motion of the motor and provide any other required parameters.

7.1 Image Processing Thread

Image processing depends on the image acquired by the camera. The camera provides a certain number of frames per second (fps). Depending on the processing capability and speed of the laptop, the number of frames per second could be reduced to a value that the laptop is capable to process them side-by-side Figure17 shows the block diagram used in the image processing in Matlab-Simulink, along the obstacle avoidance block diagram. Those functions are performed by the on board laptop.

7.2 Obstacle Avoidance Thread

Obstacle avoidance is based purely on laser range finder operation. The data coming from the laser range finder, HOKUYO represents a 2-D map that relates angles of obstacles with distances. Hokuyo range finder can cover 240 degrees.

There are several modes of motion for the vehicle. Depending on the mode of operation, we can specify the angle to be covered, that is zone, since this will simplify the control algorithm and allow the controller to avoid processing data of areas that are out of interest. The entire range is divided into zones. For example, the fast forward picks the zone from -20° and +20° (green zone), the medium forward mode picks the zone -45 to 45 (yellow zone), the slow forward mode picks the zone -75 to 75, and the revolving mode picks the entire laser range finder zone from -120 to 120. See figure 16.
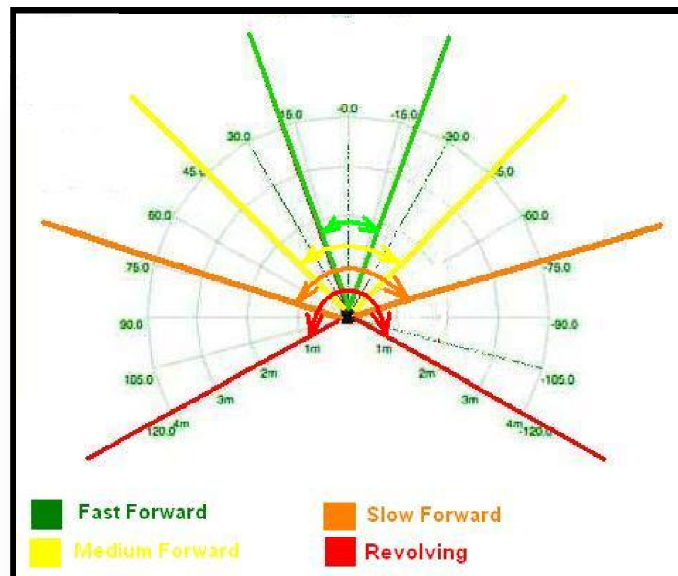
Figure 16: Angles of interest (Zones)

Modes of operation are divided into:

Mode 0: Stop : Here we don't need to get any data from LRF.

Mode 1: Fast Forward (Green Zone): This is the mode where the LRF can detect no obstacles ahead. Vehicle will start its motion and the motors are provided with full duty cycle in order to achieve maximum speed and reduce time required to finish the track. Here, our interest is only to know the obstacles right in front of the vehicle. Therefore, we can limit the range of observation for obstacles to be ±20°. See the figure below

Mode 2: Medium Forward (Yellow Zone): In this mode of operation, the obstacle is located in the range of 4m to 1.5m and the vehicle starts to steer away from the obstacle. This means that the motors are provided with differential speed. This will ensure a smooth steering away from the obstacle. Execution of this loop is terminated depending on the occurrence of one of the following conditions:

  a. No obstacle is in front of the vehicle within the range of 4 – 1.5m any more, i.e. the vehicle returns to fast forward mode. Figure 17 shows such a scenario.
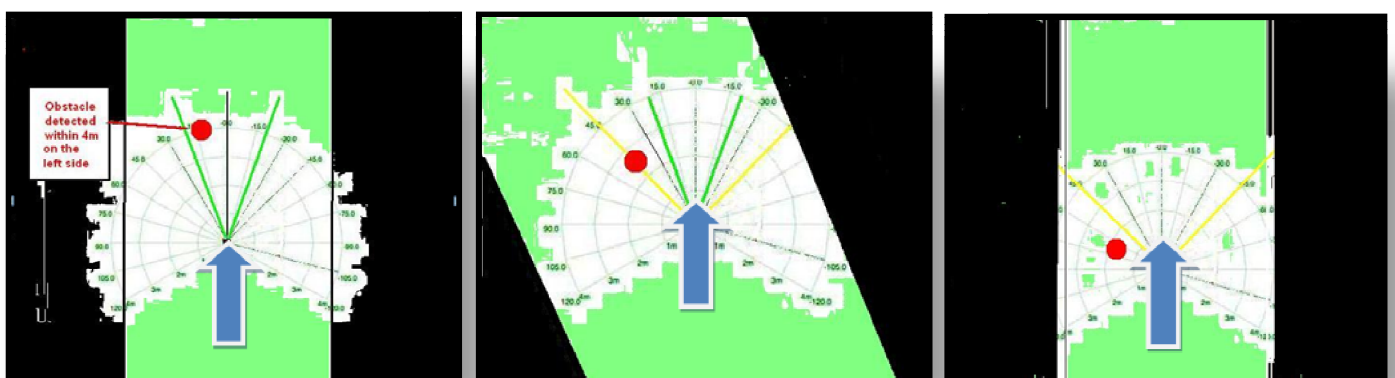

Figure 17: Avoidance of obstacle

b. More than one obstacle is in the range. Or in other words, two obstacles or more are in two different clusters with different distances. See Figure 18.

If this case occurs, the control will jump to the orange and/or red zones, in which the vehicle will only move slowly in straight line or revolve around itself.
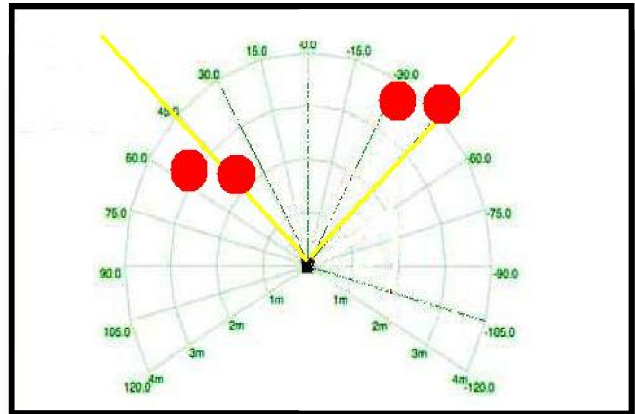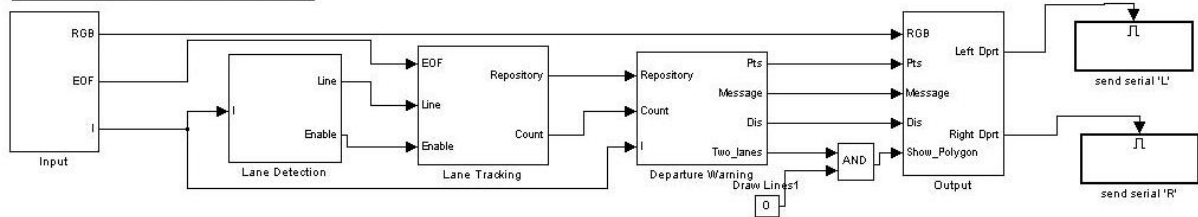

Figure 18: Obstacles in more than one cluster

Mode 3: Slow Forward

Mode 4: Revolving

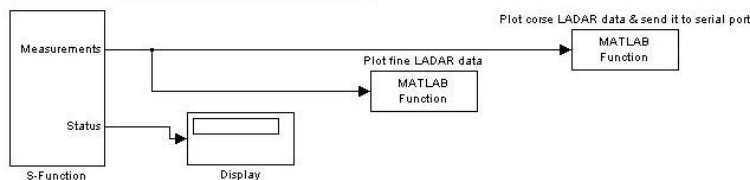This modes are activated at the occurrence of situations such that in figure 19.

Figure 19: The block diagram of the image processing and the laser range finder in Simulink

8. GPS Permittivity Thread

Depending in the mode of operation, or in other words the zone, we will need to adapt what we called, permittivity range for the angle between the actual vehicle direction and the direction of the next GPS. See figure 20.
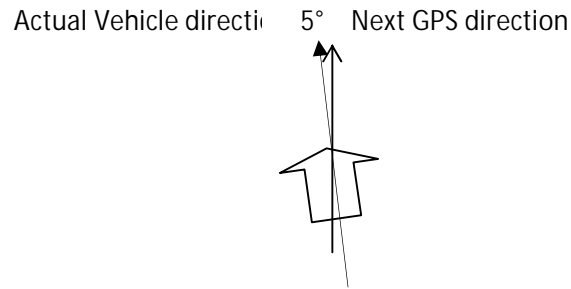
Actual Vehicle directi   5°   Next GPS direction

Figure 20: Permittivity toward next GPS

This thread will ensure that the path planner is given some "allowance" to navigate away the obstacles, while in the same time, not loosing its orientation towards the next GPS point. We will take each mode of operation separately and define a certain range of permittivity for each mode.

9. Fast forward : Here, the vehicle is given some "hysteresis" until it reorients itself, while driving in the fast forward mode (green zone for obstacles). Of course, the non-flat ground and the presence of shocks will cause the vehicle to alter its orientation to the next GPS point by few degrees as the vehicle moves along the track. Here we allow a limit of ±5°, as seen in figure 11. When this values are exceeded, the vehicle turns into medium forward mode that applies steering, but without affecting the laser range finder zone.

10. Medium Forward : In this mode, the vehicle will need to avoid obstacles that are located in a distance from 1.5m to 4m. Therefore, the range of permittivity should be increased to allow the vehicle to avoid the obstacle, without being restricted to precisely face the next GPS point. This range of permittivity is assigned the values ±45°.

11. Slow Forward: In this mode, the vehicle will need to avoid obstacles that are located in a distance from 0.5m to 1.5m. Therefore, the range of permittivity should be increased to allow the vehicle to avoid the obstacle, without being restricted to precisely face the next GPS point. This range of permittivity is assigned the values ±100°.

12. Revolving: In this mode, the vehicle is in a critical situation and will need to avoid obstacles that are located in a distance less than 0.5m. Therefore, the range of permittivity is increased to a maximum value to allow the vehicle to avoid the obstacle, but at the same time to ensure that the vehicle is not moving in the opposite direction. This range of permittivity is assigned the values ±120°.

8. Project Budget

Items	Cost [$]	Electronic	Cost[$]
Mechanical		Laser Range Finder	1837
Wheel Chair + Batteries + Charger	536	Laptop	0
Building and installation of body panels (Acrylic)	786	Development Board (PIC PLC4 V6 PLC System).	481
Modification on Wheel Chair	50	Motor Driver Circuit	409
Electric		Xbee Pro 60mW Chip Antenna	167
Motor Batteries		Xbee USB Programmer	54
Controller Battery	40	Blue 20*4 LCD	39
Alarm Light	14	Logic Level Converter x2	17
Emergency button	14	PIC 16F877 x8	36
Miniature Relay	16	Active GPS Antenna	46
Relay Schrack	16	Compass Module	63
Emergency Switch	7	Voltage Regulator 12V	2
Fuse Holder	3	PIC Socket	2
		Diode 30A	4
		Msicillaneous: Transistors, Resistors, level converter	200
		Total	$4647

9. Innovations

1. Separation of controlling logic circuits through use of buffer transistors to avoid maximum current limits and for more disturbance immunity.

2. Rigid mechanical frame that originally is a wheel chair. This insures high load sustainability.

3. Combining the path following and obstacle avoidance functions into one simulink block diagram that work simultaneously.

10. Conclusion:

Since it's our first trial to participate in this competition and keeping in mind the technical and logistic difficulties we faced through the project, nevertheless we are very interested in the IGVC 2011 and glad to have the opportunity to participate in it. Of course the competition itself would be the best feedback for us and the faculty. Improvements and more innovations will be implemented after we come back, hoping that the German Jordanian University will be able to make it next year also.