

E500 JO-BOT

Princess Sumaya University for Technology

**Hamza Al-Beeshawi, Enas Al-Zmaili
Raghad Al-Harasis, Moath Shreim
Jamilie Abu Shash**

**Faculty Name:Dr. Belal Sababha
Email:b.sababha@psut.edu.jo**



I certify that the engineering design present in this vehicle is significant and equivalent to work that would satisfy the requirements of a senior design or graduate project course.

Signed,

 , Dr. Belal Sababha, Faculty Advisor

1 INTRODUCTION

This is the first time a team from Princess Sumaya University for Technology (PSUT) is to participate in the Intelligent Ground Vehicle Competition. PSUT's entry to the IGVC 2104 is called E500. The E500 vehicle has been designed to meet all the design requirements of the competition. Our team is made of five senior students. The vehicle's body and chassis are custom made. The power plant is based on two scooter electric motors. The team was not able to get access to expensive laser-based range finder sensors. However, the team believes that the navigation algorithm that they have developed will compensate for this and will boost the vehicle's navigation abilities. The brain of our vehicle receives three different kinds of feedback signals and reacts accordingly. The UGV's (Unmanned Ground Vehicle) feedback signals come from a Camera, a few ultrasonic range finding sensors and a GPS receiver. The feedback signals are received by a Laptop computer running the computer vision algorithm. The algorithm processes the received images along with other feedback signals and sends the required actions to the microcontroller unit (MCU) driving the motors. Our UGV is based on two driving motors that are able to move in two directions, giving the vehicle the ability to maneuver easily.

1.1 Requirement Analysis

After careful consideration of the IGVC Competition requirements, the UGV was designed to carry out those specific requirements. The team analyzed battery life, speed, GPS waypoint accuracy, ramp climbing center islands. The resulting vehicle was able to meet required speeds, navigate between GPS waypoints, avoid obstacles, recognize solid and dashed lines, climb ramps, and has multiple safety features.

1.2 Systems Engineering Approach and Design Process

Our team consists of five undergraduate senior students' four communication engineers and one electronic engineer. The team conducted weekly meetings to insure progress on the subsystems. The overall system is comprised of the following subsystems: Chassis, Body, Power plant, Computer Vision algorithm, GPS waypoint navigation subsystem, low-level motor driver speed control, wired and wireless communication systems. The subsystems and tasks were distributed among all team members. Each subsystem was designed and tested separately. Then the team started integrating different components and testing them together until the whole system was put together. Finally, the team started testing and evaluating the whole system together

with all of its components. The team found this to be a practical and efficient way to accomplish things fast and efficiently. Team members reported the status of all subsystems during the weekly meetings. Problems were discussed and ideas were exchanged. The team defined several milestones and short term tasks and worked hard to progress to the goal: The UGV System. Figure 1, illustrates the distribution of all tasks and subsystems among the team members. Figure 2, shows the design process we have followed. This is referred to as the "Linear Model". It is estimated that about 1600 man-hours were put into this project.

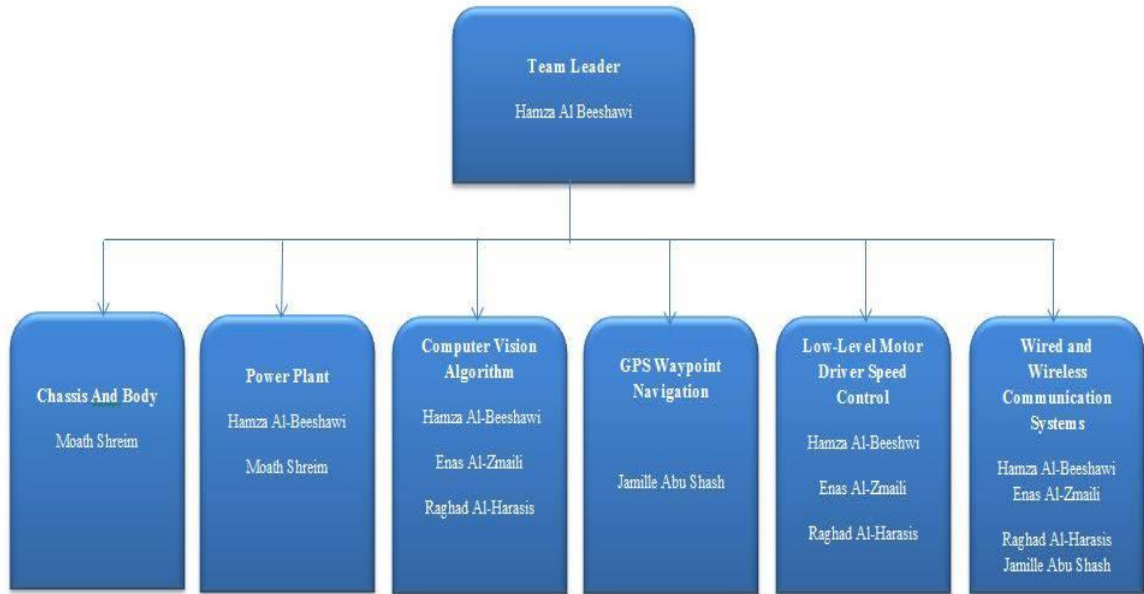


Figure 1 Organizational chart Of the Team.

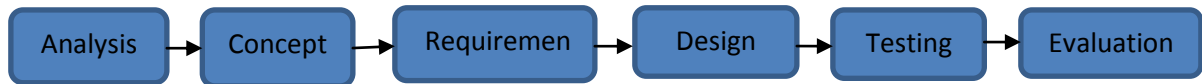


Figure 2. “Linear Model “Design Process.

1 INNOVATIONS

Here is a list of the innovations in our project which is going to be discussed in detail later in this project

- ❖ Lane detection and obstacle avoidance algorithm built on MATLAB.
- ❖ GPS android application designed by our team.

2 MECHANICAL DESIGN

2.1 Chassis

The base of our vehicle is made of iron bars. Iron bars have been selected because they do not bend easily and are really durable and cost efficient. The iron bars were covered by a layer of plastic to insulate the base. The vehicle’s base dimensions are 130 cm in length and 108 cm in width. Figure

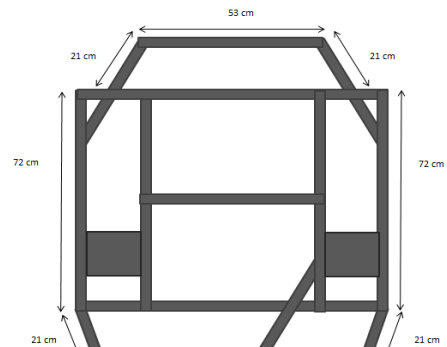


Figure 3 Metal base.

3, shows the design of the metal base of the vehicle. The base is made of separable pieces that are connected together by screws. This makes it easy to disassemble and carry in a small container. Two pieces of wooden plates are mounted over the metal frame. These are to carry all on board components. The two plates of wood are separated by a center metal piece whose function is to stabilize the vehicle so it does not bend as shown in figure 4. The electronics are housed in a plastic cover. This plastic housing is important to protect the electronics from weather and other possible external conditions. It is also to safeguard it from electric shock.

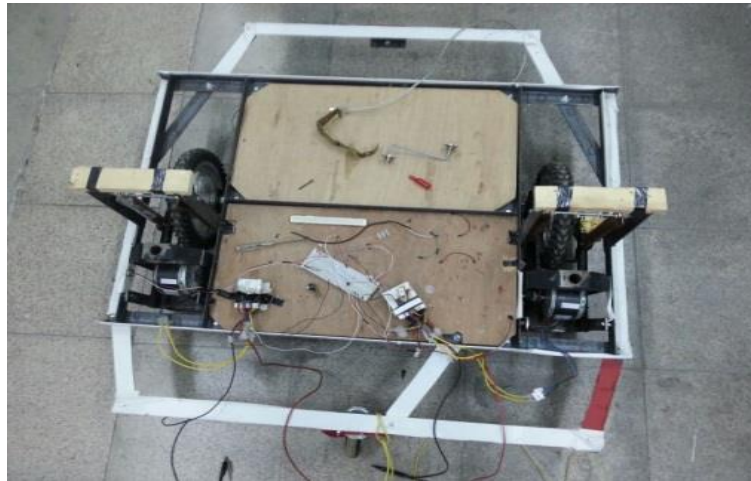


Figure 4 Metal Base

2.2 Suspensions

To control vibration onboard the vehicle, a custom made suspension system was designed and implemented. The system makes use of two copper pipes of different diameters. The one with the smaller diameter is inserted inside the one with the bigger diameter. An internal custom made spring separates the inner copper pipe from the outer pipe as shown in figure 5. The suspension system design incorporates two suspensions for each wheel to protect the vehicle from shocks. The suspensions connect the wheels to the chassis by two pieces of iron on both sides of the wheel and on both wheels. For safety purposes, a piece of wood is placed on the exposed metal as shown in Figure 6.



Figure 5. Suspension



Figure 6 Suspension System

2.3 Drive Train

The system incorporates two driving wheels placed at the center of the left and right sides of the vehicle. Each wheel is powered by a DC motor connected by two cogs and a chain. On the front and back of the vehicle are two free motion wheels just to keep the UGV balanced. They have no driving and steering control. The vehicle is designed so that it can turn in its place making it have much better range of mobility. The two wheels rotate in opposite directions in order to turn the vehicle without it moving from its location. They may also move in different speeds in the same direction to turn the vehicle while moving. When the wheels rotate in the same direction with the same speed, this results in move the vehicle forward or backward.

3.4 Outer Body

The outer body of the vehicle is made of thin plates of wood. Wood is used because of its relative light weight. It is easy to shape and its cost met our budget. The maximum height of the body is 180 cm where the camera is mounted to cover the widest area needed for the image processing algorithm as shown in figure 7.



Figure 7 Body

3 ELECTRONICS COMPONENTS

3.1 H-bridge

A high current H-bridge has been used to be able to deal with the high current driving the wheels of the UGV. The used H-bridge is a Dual VNH5019 Motor Driver Shield for Arduino as shown in figure 8. The H-bridge's function is to reverse the direction of the motors driving the wheels. It is also used for Electric Braking by continuously and rapidly reversing the direction of the wheels.



Figure 8 H Bridge

3.2 Speed Controller

The speed controller shown in figure 9 is used to control the speed of the vehicle. The speed controller receives an analog signal command from the onboard microcontroller unit specifying the required speed. The speed controller responds to the required commands by generating PWM (Pulse Width Modulation) signals to control the speed of the motors.



Figure 9 Speed Controller

3.3 Sensors:

3.3.1 Hall Effect Sensors

Two Hall Effect sensors were used to provide the feedback signals to the vehicle's speed closed loop control system. The speed control system is a PID (Proportional Integral Differential) control system. Several pieces of magnets are mounted on the axes of the wheels. The Hall Effect sensors are used to count the number of wheels rotations. This is then used to compute each wheel's speed. The PID controller is used afterwards to control the vehicles overall displacement speed and direction. The used Hall Effect sensor is shown in figure 10.



Figure 10 Hall Effect Sensor

3.3.2 Ultrasonic Sensors

An Ultrasonic range finding sensor is used to detect obstacles. A sensor module HC - SR04 shown in Figure 11 that provides 2 cm to 400 cm detection distance is used. By utilizing five modules of such sensor, the vehicle is able to detect and avoid obstacles.



Figure 11. Ultrasonic sensor

3.4 Camera

The main sensing unit utilized in the UGV is an H5D-00013 Microsoft LifeCam Cinema. The camera is shown in Figure 12. It consists of a high-precision glass lens and Clear Frame Technology to improve the picture even in low light conditions. In addition, the camera is equipped with a fisheye lens to capture a wider angle of the scene.



Figure 12 H5D-00013 Camera

3. 5 Computing Hardware

3.5.1 Arduino Mega

An Arduino Mega MCU shown in Figure 13 is used to implement the low level drivers for the ultrasonic sensors, GPS receiver, hall effect sensors and wireless transceivers. It also executes the speed control PID loop. Moreover, this MCU communicates wirelessly with a remote control to manually drive the vehicle. Finally, the most important task is receiving commands from the computer vision algorithm being executed on the Laptop to control the UGV in its autonomous mode.



Figure 13 Arduino mega

3.5.2 Laptop

We have used a Sony Vaio laptop E series VPCAA42EA core i3 as shown in Figure 14. This computer is responsible for executing the image processing algorithm.



Figure 14 Laptop

4 POWER PLANT

The power source for the E500 UGV is a system of four 12V Batteries shown in Figure 10. Every two batteries are connected in series to power one of the two motors providing a total of 24V. The motors driving the vehicle are rated at 200 Watt each with a maximum current of 13A.

❖ Batteries

The batteries used are valve regulated lead-acid rechargeable batteries. Each battery supplies 7 Ah at 12 V. The batteries are shown in Figure 15.



Figure 15 12V Battery

❖ Motors

The motors driving the vehicle are Electric 24 Volt Unite 250 Watt. Each one of the motors has been taken off a scooter that is able to carry about 75 KG. The motor is shown in Figure 16



Figure 16 Dc Motor

5 SAFETY CONSIDERATIONS

During the work on this project, the team spent a considerable amount of time to design and implement a UGV system that meets safety requirements. The main things utilized by our design to boost the safety features of the vehicle are:

❖ **Wireless Estop**

A wireless remote control that contains a big red lightning stop button has been designed and implemented. The button will be pressed to stop the car in emergency conditions. The button is connected wirelessly using a zigbee to the h-bridge driver to stop the car directly when the button is pressed. The Estop can be used from a far distance around one kilometer to approve high safety consideration.

❖ **Mechanical Estop**

Another red button that meets the requirements is placed in the mid rear of the vehicle. When pressed, this button will cause a hardware Estop by directly communicating with the H-bridge without the involvement of any kind of software.

❖ **Fuses**

Many fuses were used in the vehicle to protect the components and circuits from excessive currents or short circuits. We placed a 20A fuse after each component connected to the batteries. This will guarantee a high degree of protection.

❖ **Base Material**

The base of the vehicle is made from iron; iron was selected because it doesn't bend easily and is really durable to protect the vehicle from bending when a collision happens.

❖ **Cover Metal**

The base of the vehicle is made basically from iron, the iron used is covered with a layer of plastic to insulate the base and protect it.

❖ **Smooth Edge**

In designing our vehicle we avoid getting sharp edges in the vehicle to provide more safety when a collision happened with other objects.

6 Autonomous System

6.1 Lane Following and Obstacles Avoidance Using Image Processing

E500 relies in most of its processes on image processing. The image processing algorithm is developed in MATLAB. E500 can choose the right path easily and fast without any interference from the surrounding area especially that our algorithm mostly depends on keeping the vehicle in the needed path and far away from obstacles while neglecting everything outside the two lines or anything that is not in front of it and it won't cause any collisions.

How does E500 work?

E500 is equipped with a Microsoft camera that continuously takes snapshots to keep the vehicle in the safe area. A snapshot as the one shown in figure 17(a) will pass through several stages of processing by a MATLAB code which will choose the best and the fastest decision that should be taken.

Once a snapshot is taken it will be processed to detect white lines in the image and neglect anything else. In this case we will get an image consisting of the white lines of the path and the white lines of the obstacles and anything else will be black. Then we reprocess the snapshot to detect the red colors of the obstacles used in the basic course. After that we add the two images to get a very clear image which consists of the white lines and the obstacles as white objects. Everything else as shadows or unclear colors will be neglected and made black as shown in figure 17(b).



Figure 17-a. Snapshot

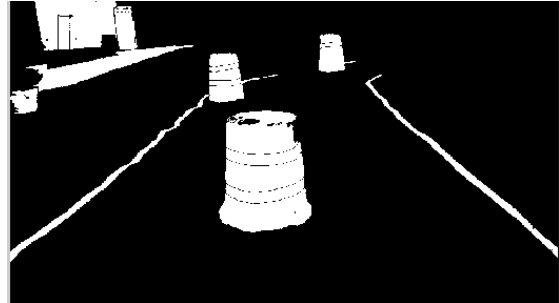


Figure 17-b. Processed Snapshot

After processing we choose the best path using a fast algorithm to speed up the serial communication between MATLAB and Arduino. We assumed that we have virtual sensors distributed far away from each other at same distances and placed in front of the vehicle to read from a specified distance “safety distance” from the vehicle to the white point, the virtual sensors should cover greater size than the vehicle to guarantee that we will not cross the white lines or crash an obstacles then it will send instruction to be followed immediately by the real vehicle, Figure 18 illustrates more.

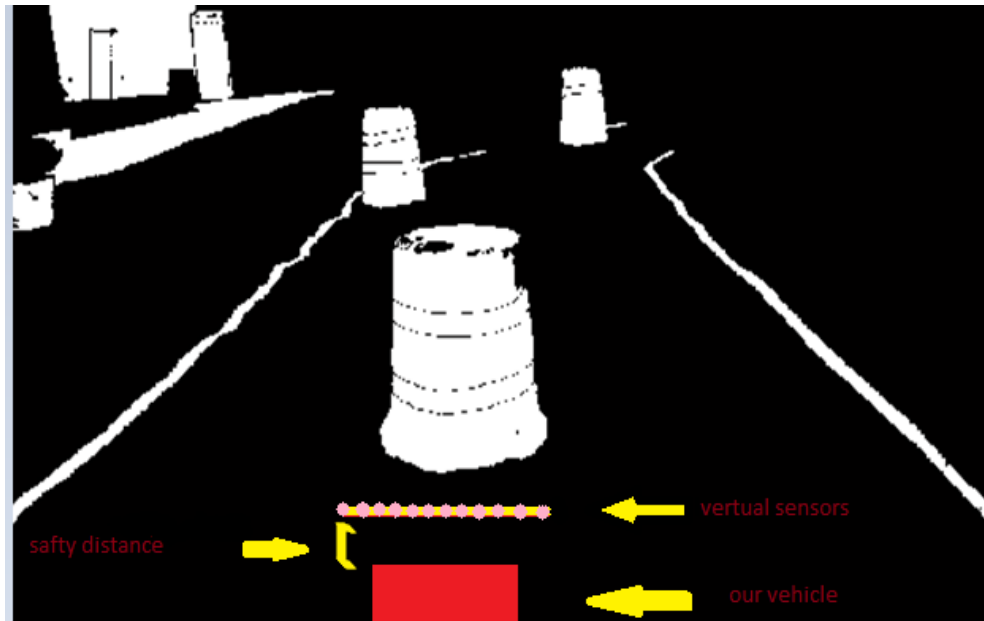


Figure 18. Path Sensing Explanation

The sensing processing was divided into four major parts, straight lines, curves, U-turns and obstacles.

Sensors will start reading the pixels values (0 or 1) from left to right and sense if there is anything to be avoided if one has been read. If all the sensors read a zero values which mean that the path is clear to go forward in straight line, but if a the maximum right sensor read one value the sensors will send instruction for the car to turn right as shown in Figure 19(a) and if the sensors read a one value at the maximum right they will send instruction to the vehicle to move left as shown in Figure 19(b).

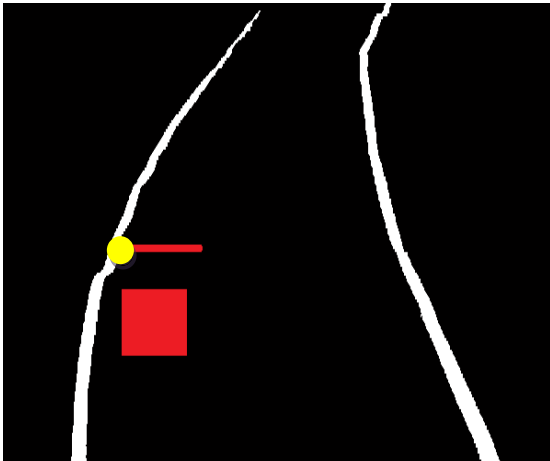


Figure 19-a. Sensing the Curve to Turn Left

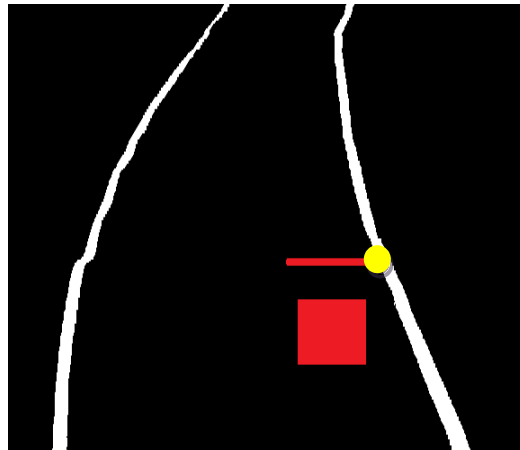


Figure 19-b. Sensing the Curve to Turn Right

If we found that the maximum left sensor and the maximum right one read one at the same time we will notice that there is a U-turn in front of the vehicle, in this case the vehicle should analyze the path to know the direction of the curve to move through it smoothly

The last case is to read one value in any sensor except the ones at the maximum left or the maximum right, in this case there will be an obstacle in front of the vehicle and it should avoid it.

In this case the our algorithm will measure the distance between one side of the line and the obstacle and the distance between the other side of the line and the obstacle to decide which path is better to go through, Figure 20 illustrates this.

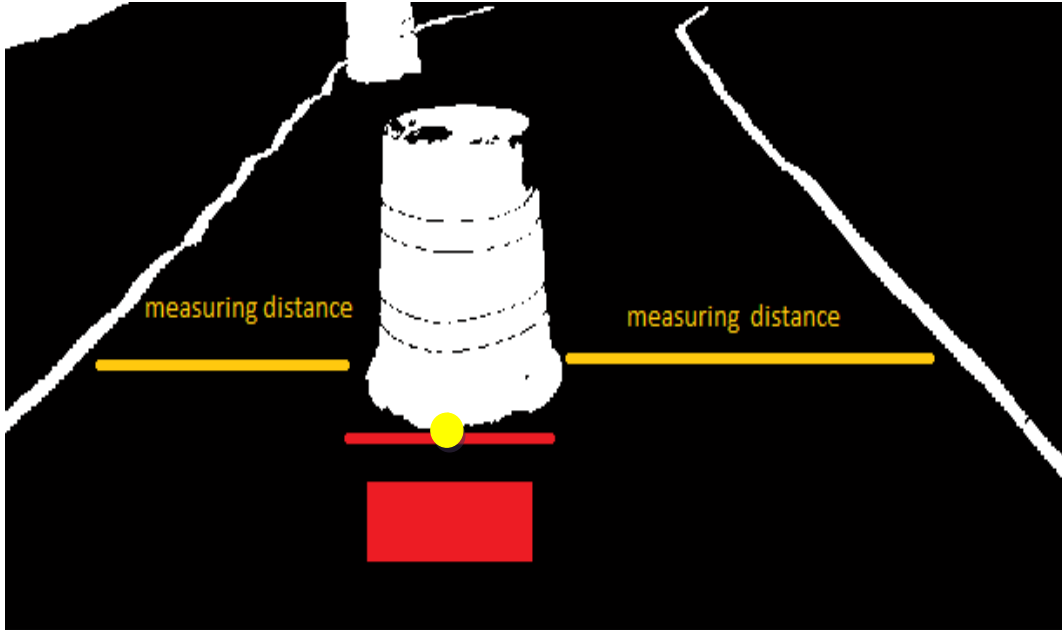


Figure 20. Detecting an Obstacle And Measuring Distances

6.2 Obstacle Avoidance Using Ultrasonic Sensors

We noticed that in the most competitions that took place all the teams used LRF " e Hokuyo UTM-30LX" but according to our conditions we couldn't get one, so we depend on image processing and we used several ultrasonic sensors to increase the accuracy and detect obstacles that our algorithm couldn't detect. Five ultrasonic sensors is distributed around E500, three in the front and one at the back of the right side and the fifth is located at the back of the left side, as shown in Figure 21.

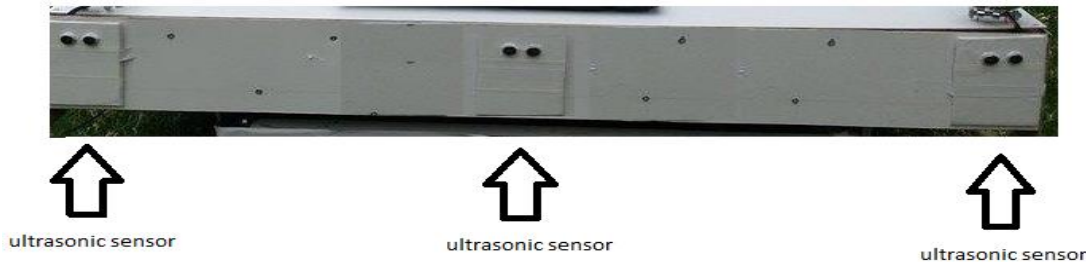


Figure 21 Ultrasonic Sensors Distribution

If an obstacle has been detected between the left sensor and the middle one the vehicle will turn right and go forward till the side sensor read the obstacle which indicate that the obstacle is away

from our path, the same process will happen if an obstacle was detected from the right and the middle sensor but with inverting the turning direction.

6.3 Navigation System

We utilized the GPS and compass sensor of the Samsung Galaxy note 2 mobile phone (**GT-N7100**) shown in Figure 22.



Figure 22 Galaxy
NOTE 2

We implemented an android application that provides GPS location and compares it to a predefined target coordinate. The compass in the Samsung mobile provides the azimuth of the phone and the bearing between the mobile and a target location. These two angles are enough to determine the direction angle the phone needs to point to, to the target location. If the direction angle is between -10 and 10, then the robot need only move forward until the current GPS location is equal to the target GPS. This is done serially, from the mobile phone to an Arduino board, which in turn controls the motors accordingly. We have found that using 5 decimal places for the GPS target locations; we get accuracy to below 1m.

Process

Once the mobile is connected serially to the E500, the mobile application detects the serial port, and the application opens automatically. The app then waits until it has a fixed gps current location.

This is done by using a location manager that initiates the GPS server and a location listener. The listener is used to detect changes in location and update the latitude and longitude coordinates. Every time a new location is obtained, we calculate the bearing angle to a target location (target location is defined by a user and saved in the shared preferences). The bearing angle is calculated using a function, defined in the android libraries. Another function is then called, that takes the bearing angle, and the azimuth angle as parameters, and uses an equation to calculate the direction angle. . The direction angle is then saved into a global variable.

The azimuth angle is found using an orientation sensor, built into the mobile device. The direction angle is then passed to another function, which converts the numerical direction angle into characters. While this process is happening, another thread is running, which is responsible for sending the character to the E500. A driver is opened, which is used to send the character from the application to the E500 serially, at a defined frequency. Another thread, which runs simultaneously, is used to compare the GPS coordinates that the listener obtained with the target locations, responsible for stopping the E500 by sending a specific character.

Table1. Characters

Right	R
Left	L
Drive forward	D
Stop	S

Principal Of Operation

The azimuth is defined as the angle between compass north and the direction to which the E500/mobile phone is pointing, as shown in Figure 23

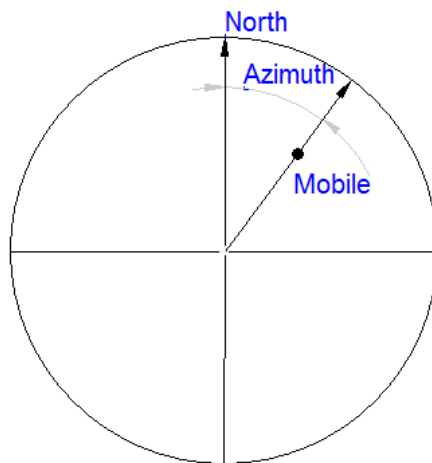


Figure 23
Azimuth angle

If we draw a straight line between the mobile and the target, and take the angle from north to this line, it is known as the bearing angle, shown in figure 24

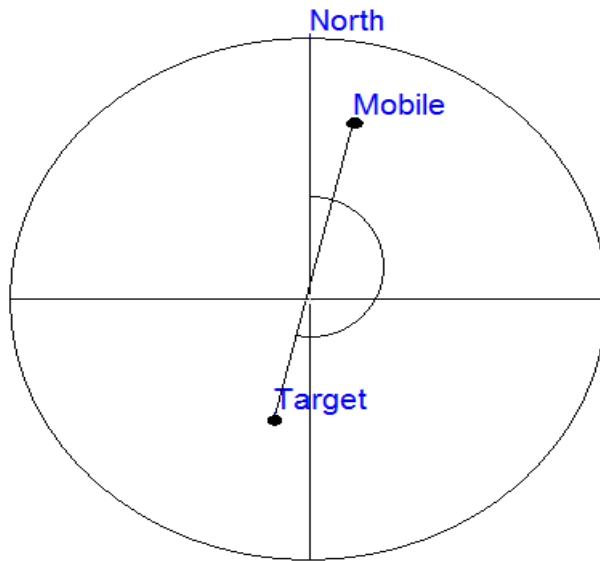


Figure 24 BEARING ANGLE

Both these angles are obtained from the mobile phones sensors.

Given the example above, if we subtract the azimuth angle from the bearing angle, we obtain the direction angle shown in Figure 25 which the mobile should rotate, so that it points to the target.

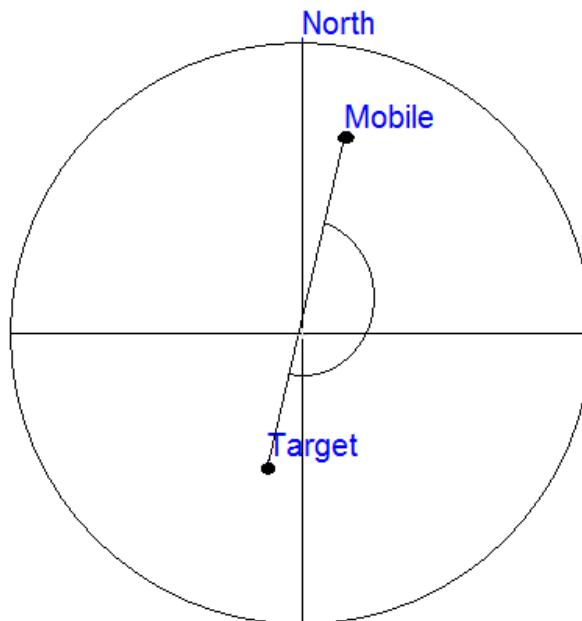


Figure 25 DIRECTION ANGLE

The android application has two setting pages, the first one allows a user to enter 2 GPS coordinates shown in figure 26, the robot will drive to the first location, once reached, and it starts driving to the second:

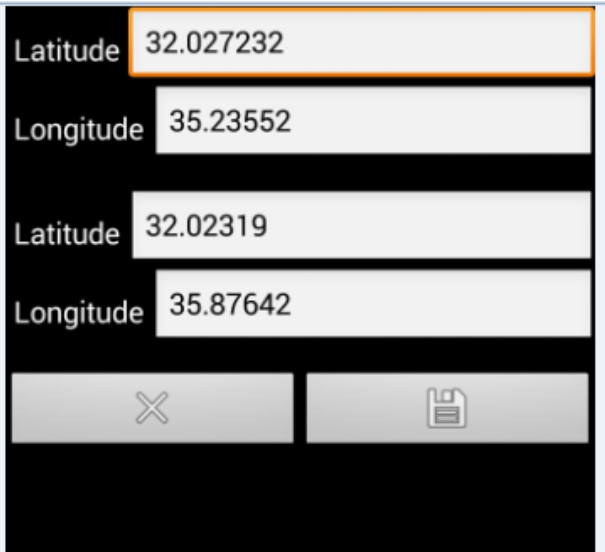


Figure 26

The second page allows a user to enter Baud rate, speed of transmission, sensitivity and refresh intervals shown in Figure 27:

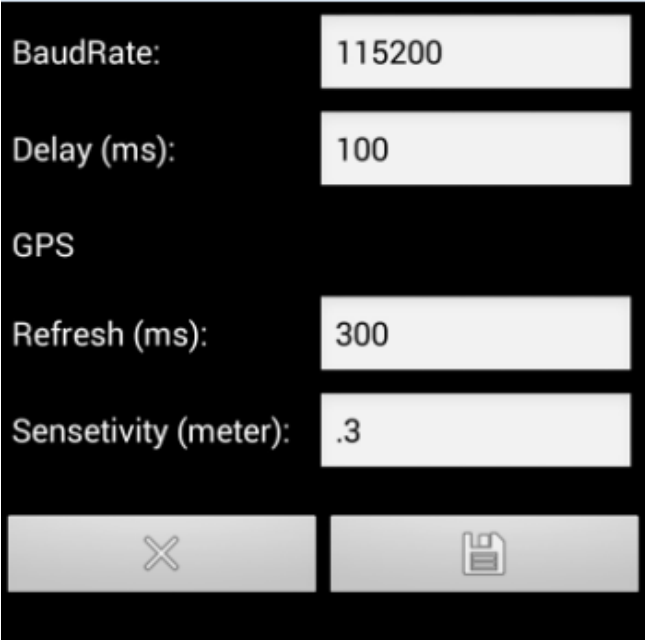


Figure 27

The application will calculate the direction angle, and decide if the robot should rotate left, right or go straight. Here is an example of the application running, where the robot must rotate left because the direction angle is -114, figure 28 illustrates more

```
My location: 32.02319556556238
              35.87642892165795
Target 2: 31.86795
           35.82020

write: -114 > L
```

Figure 28

As shown below, when my location equals target location, angle will equal 500, and the robot will stop.

```
My location: 32.02336087901491
              35.876365736965454

write: 500 > S
```



7PATH PLANNING

E500 path planning system is capable enough to make the vehicle travel and navigate smoothly between obstacles ,our path planning depend the most on the results of the processing which get place on the laptop which is going to identify the best path along 5 meter distance from where the vehicle and keep on refreshing the path while moving by taking new snapshots the best path chosen can be seen in figure 29(a)/ figure 29(b) , the planning of E500 will depend more on the ultrasonic sensors when the vehicle reaches the first point and travel to the other one.

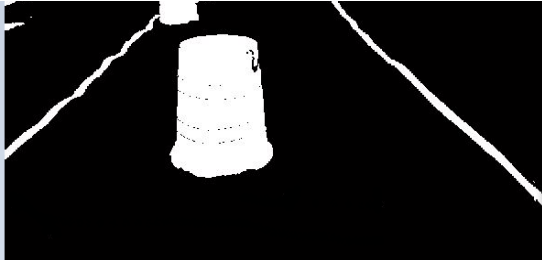


Figure 29-a



Figure 29-b

The planning system keep on refreshing the position coordinates every 300ms,to inform the system if it arrives to the first way point to increase the depending on the ultrasonic sensors.

8 EXPERIMENTS AND RESULTS

In designing E500, our team has done many tests on E500, the most important test and experiments were:

1- Image Processing In MATLAB Software

At the beginning of our work in image processing, we started using Simulink blocks in MATLAB software, after we start working and testing we realized that writing a code in MATLAB without using Simulink block will be more flexible and suitable for E500 image processing.

2- Noises In Image Processing

In image processing testing in MATLAB we get photos with high noise, so we solve this problem and remove the noises by changing and testing different threshold values and parameters until we get a clear and high quality photos.

3- Number Of Wheels In E500 Design

The first design of E500 contains three wheels, one free motion wheels and two controlled wheels using motors, when we test this design we notice that if the car stuck in a small hole in the path it can't get out of it and continue moving.

We solve this problem by changing the design from three wheels design to four wheels design with two free motion wheel.

4- Convert Values From Pixels To Meters:

In our software work and codes we needs to identify some distances that appears in E500 camera in meters ,but E500 camera takes photos of the road as pixels , we convert these pixel to meters by finding an equation that represents the relation between the pixels in the photo taken by E500 camera and there real values in meter.

E500 team find this equation using MATLAB and Excel, by taking a picture using E500 camera of a ruler that is divided and marked every 20cm as show in figure 30.

The next step was to find the number of pixels for each 20cm in the ruler, as we go to the top of the ruler the numbers of pixels for the 20cm decrease even if it's constant and equal to 20cm in real. The next step was plotting the relation between pixels and meters then finding the equation as shown in figure 31.



Figure 30

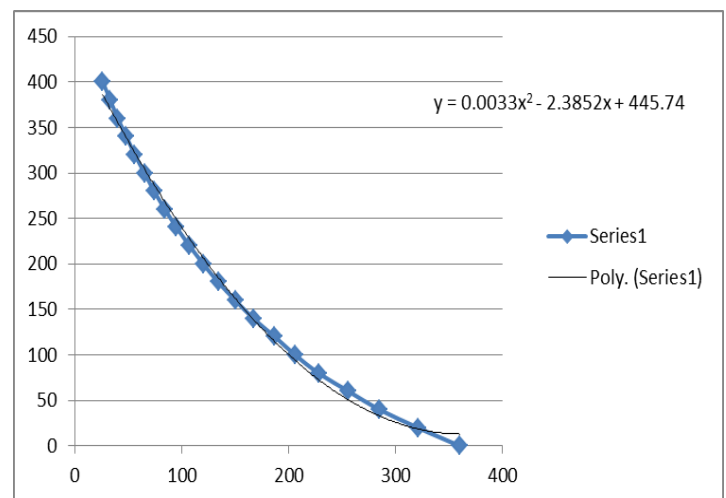


Figure 31

5- Controlling The Speed Of Vehicle Wheels

E500 consist of 3 wheels, one free motion wheel and the others two wheels were controlled using a separate motor for each. When we start testing the wheels speed and give the two motors the same PWM speed the two motors didn't move in the same speed and a speed mismatched appear.

E500 team solve the speed mismatches by reading the speed of each motor using hall effect sensors then control their speed using PID controller, and finding the values of K_p , K_d and K_i by testing and keep changing the values of them until we found the suitable values.

9 COSTS

Table 2 shows the details of E500 components cost.

Table 2 components costs

Item	Number	Cost	Cost to team
Battery	4	\$ 85	\$ 85
Wheels	4	\$ 28	\$ 28
Laptop	1	\$ 851	\$ 851
Camera	1	\$ 120	\$ 120
Hall effect sensor	4	\$ 25	\$ 25
H-bridge	3	\$ 127	\$ 127
Arduino	4	\$ 113	\$ 113
Fish eye lens	1	\$ 42	\$ 42
Speed controller	2	\$ 99	\$ 99
Joystick	1	\$ 7	\$ 7
Ultrasonic sensor	6	\$ 75	\$ 75
Xbee	2	\$ 169	\$ 169
Iron metals		\$ 78	\$ 78
Suspensions	2	\$ 113	\$ 113
Motors	2	\$ 110	\$ 110
Misc		\$ 88	\$ 88
Total		\$ 2130	\$ 2130

10 PREDICTED PERFORMANCES

- Speed

The speed of E500 on grass can reach about 11 mph which is the speed of an electrical scooter specially that we used two scooter's motors to get the needed performance

- Battery life

Batteries in E500 are chargeable batteries that need an hour to be completely charged, and it takes about two hours to be consumed if E500 stayed in its average speed.

- Distance at which obstacles are detected

Obstacles can be detected from about 5meters from E500 by the camera and the ultrasonic sensor which provide a feedback for the obstacles that can't be detected using the processing.

- Accuracy of arrival at navigation waypoints

The accuracy that we got from our application is a great result specially that the best devices in Jordan can reach 2.5 meters accuracy in best conditions, but our android application makes E500 capable to reach 10cm accuracy .

11 CONCLUSIONS

In this project, an unmanned ground vehicle (UGV) called E500 has been designed and implemented. The vehicle is a fully autonomous UGV, designed to detect its way by line following and obstacle avoidance with a high accuracy GPS waypoint navigation system. The E500 UGV is ready to compete in the 2014 Intelligent Ground Vehicle Competition.

12 FUTURE VISIONS

This is the first time for Princess Sumaya University for Technology to participate in the IGVC competition. We have worked so hard with the limited funding and resources to design and implement a system that is able to compete in the 22nd IGVC. So our main goal for us this year is to be one of the winners and try to gain as much experience as we could to improve our skills and to participate in the coming years with new innovations and stronger vehicles to be one of the first place winners.

On the other hand, our vehicle has many useful applications that it could be used for in the future. We are looking to develop the E500 to be used by disabled and blind people. It may also have many other useful surveillance applications.

13ACKNOWLEDGEMENTS

E500 Team would like to thank several people and organizations for helping in building E500. A special thank for Dr.Belal Sababha our great instructor ,Thanks for Princess Sumaya University for technology, thank for our sponsors Orange Company and The Jordan Phosphate Mines Company.

