German Jordanian University

School of Applied Technical Sciences

Mechatronics Department

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Jo-Car2 Intelligent Ground Vehicle

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Faculty Statement:

I certify that documentation is valid and was compiled by my students for the IGVC2012

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Introduction:

Jo-Car is basically an intelligent autonomous ground vehicle, designed to follow GPS way-points, avoid crashing into obstacles, and keep positioned within a lane of two white lines painted on the ground. This Robot is actually designed to participate in the Intelligent Ground Vehicle Competition (IGVC) on June 2012 at Oakland University Michigan, USA, so that along our design we have been restricted by the IGVC rules.

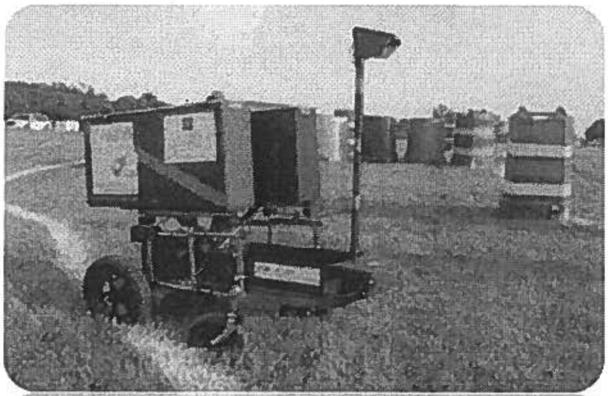
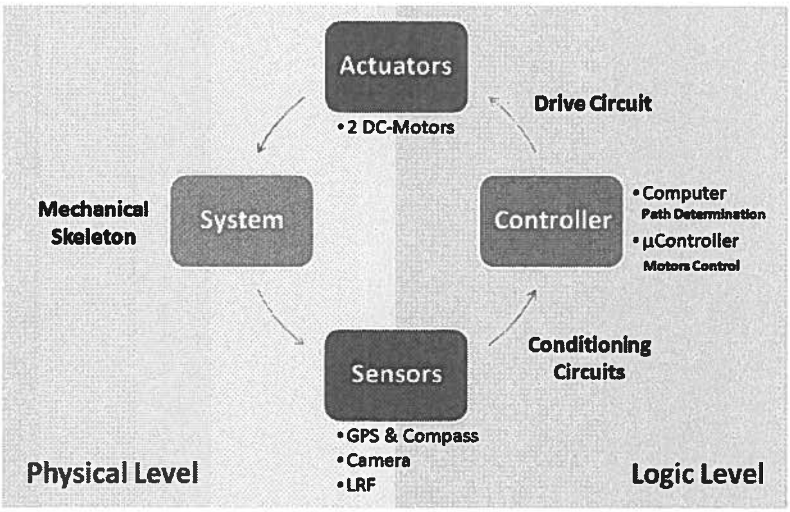


Figure 1: Jo-Car1 at IGVC 2011

Jo-Car is actually a Mechatronics system that consists of two main levels; physical level (the robot mechanical system with its skeleton and shell), and logic level (Controllers). Specific Sensors and Actuators are located in between.

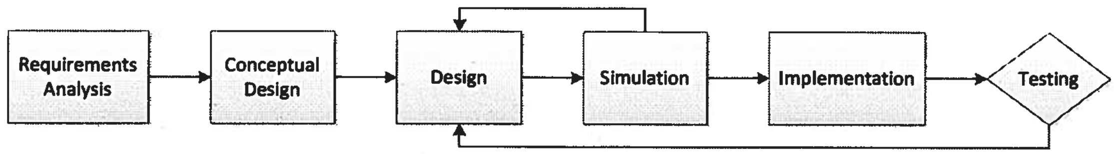


Design Procedure:

Our design procedure consists mainly of six Stages; firstly, we have analyzed the IGVC rules and requirements, and turn them into System Requirements.

Secondly, we have created the Conceptual Design for our robot, and then the Third stage was the Detailed Design where we made the full mechanical design, the power system, and the Sensors and Actuators Selection. The last design stage was the Control and Controller Algorithms; in which both the low- and high-level control algorithms have been created.

The fourth stage was simulating the System parts; that included mechanical stress analysis with CATIA v5 Software, and simulating the Laser Mapping Methods, the Motor Drive System, and also simulating the Path Planning Algorithm on a sample Video. Based on these simulations, some modifications on both electronic and mechanical designs have been made. Then we reached the Implementation stage which is stage five, followed by the last stage were the robot was tested. So let's go through our Design Journey.



Stage 1: User and System Requirements:

A. User Requirements:

According to the IGVC rules [reference], many restrictions and requirements for mechanical, electrical and control aspects will be taken into considerations.

In the following lines, we will summarize the IGVC requirements:

- **Design**: Must be a ground vehicle (directly contacted to the ground).
- **Length**: Min. 3 feet, Max. 7 feet.
- **Width**: Min. 2 feet, Max. 5 feet.
- **Height**: Not to exceed 6 feet (excluding emergency stop antenna).
- **Propulsion**: Vehicle power must be generated onboard.
- **Average Speed:** above one (1) mph.
- **Minimum Speed:** There will be a stretch of about 44 ft. long at the beginning of a run where the contending vehicle must consistently travel above 1 mph. A vehicle slower than this speed is considered to "hold-up traffic" and will be disqualified.
- **Maximum Speed:** (10 mph). All vehicles must be hardware governed not to exceed this maximum speed.
- **Mechanical E-stop location**
- **Wireless E-Stop (*in the range of 1.5Km*)**
- **Safety Light**
- **Payload**: Each vehicle will be required to carry a 20-pound payload. The shape and size is approximately that of an 18" x 8" x 8" cinder block.
- **Lane Following**
- **Obstacle Avoidance**
- **Waypoint Navigation**

B. System Requirements:

From the previous user requirements we can determine our system requirements as follows:

- **3-wheels Ground Vehicle.**

- **Mechanical Dimensions:**
    - **Length**: approx. 90 cm.
    - **Width** : approx. 70 cm.
    - **Length**: approx. 60 cm.
- **Robot Kinematics:**
    - **Speed** = approx. 2 m/s
    - **Acceleration** = approx. 1 m/s^2
- **Robot Weight** = approx. 35 kg without the payload.
- **Suspension System** for stabilization might be needed.
- **Power Source**: Rechargeable Electric Batteries.
- **Type of Actuation**: 2 Electric Motors.
- **Type of Sensing**:
    - Machine Vision for lane detecting.
    - Obstacles Detector.
    - GPS.
    - Direction Sensor.
    - Speed Sensors.
- **Mechanical E-Stop**.
- **Indicators:**
    - Safety Light.
- **Control Modes:**
    - <u>Remote</u> (Tele-Operated) Control Mode with E-Stop.
    - <u>Autonomous</u> Control Mode with Obstacles Avoidance and Path Planning algorithms.
- **Controllers**: we have used Computer for machine vision, and embedded system for motors driver.

C. <u>Budget:</u>

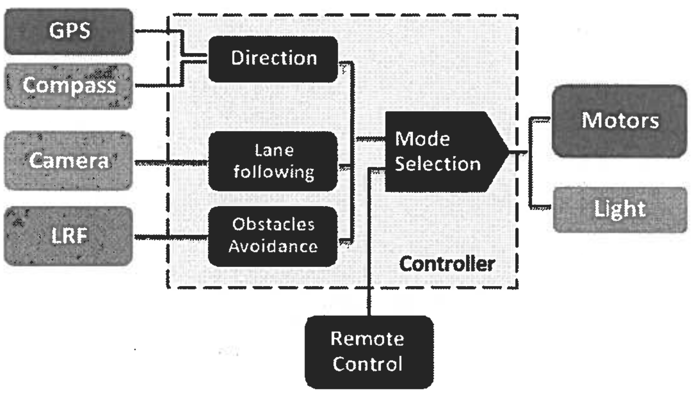
	Item	Qty	Cost
1	Garmin OEM GPS 17x HVS Sensor	1	220
2	Garmin OEM 17x and HVS Mount	1	
3	Futaba 6EX 2.4GHz Radio System	1	1100
4	IMU ±2g Triple Axis Accelerometer Magnetometer	1	
5	Anti-Static Work Mat (WS-2)	2	
6	Elenco SL-75 Temperature Controlled Soldering Station	1	
7	Third Hand with Magnifying Glass	1	
8	Phidgets 30 Amp Current Sensor AC&DC	2	
9	Phidgets Precision Voltage Sensor	4	
10	Arduino Mega 2560 Microcontroller	2	155
11	GWC HU2SA0 USB 2.0 10-Port Hub	1	205
12	Kensington K33366 PocketHub USB 7 Ports	2	
13	Defender Digital Wireless DVR Security System with 7 Inch LCD Monitor, SD Card Recording and Long Range Night Vision Camera (Black)	1	330
14	AOpen DE57-HA Digital Engine (Core i5 -	2	2300

	2.4GHz)		
15	SeeedStudio DSO Nano Pocket 1MHz Digital Storage Oscilloscope	1	120
16	Manitou Radium RL Shock 2010	2	460
17	10" Pneumatic Tire (Harbor Freight)	2	200
18	10" Pneumatic Swivel Caster (Harbor Freight)	1	
19	Power Bright PW2300-12 Power Inverter 2300 Watt 12 Volt DC To 110 Volt AC	1	540
20	Power Bright 2-AWG3 2 AWG Gauge 3-Foot Professional Series Inverter Cables	1	
21	Raptor RANL1502 50 Amp ANL Fuses, 24K Gold Plated, 2 Pack	6	
22	Scosche EWFH Single ANL Fuse Holder	3	
23	Hokuyo URG-04LX Laser Scanner	1	1300
24	PMDC 24V (9A)	2	1000
25	Shell Manufacturing		1500
26	Skeleton Manufacturing		500
27	ICs and Components	x	600
			Total Price = 10530

Stage 2: Conceptual Design:

In this Stage we are going to introduce our System Concept, by providing a Block Diagram for our system includes all Sensors, Actuators, and Controllers, and how they are connected together. The System operation sequence will be shown later on as a process flow-chart.

A. System Block Diagram:

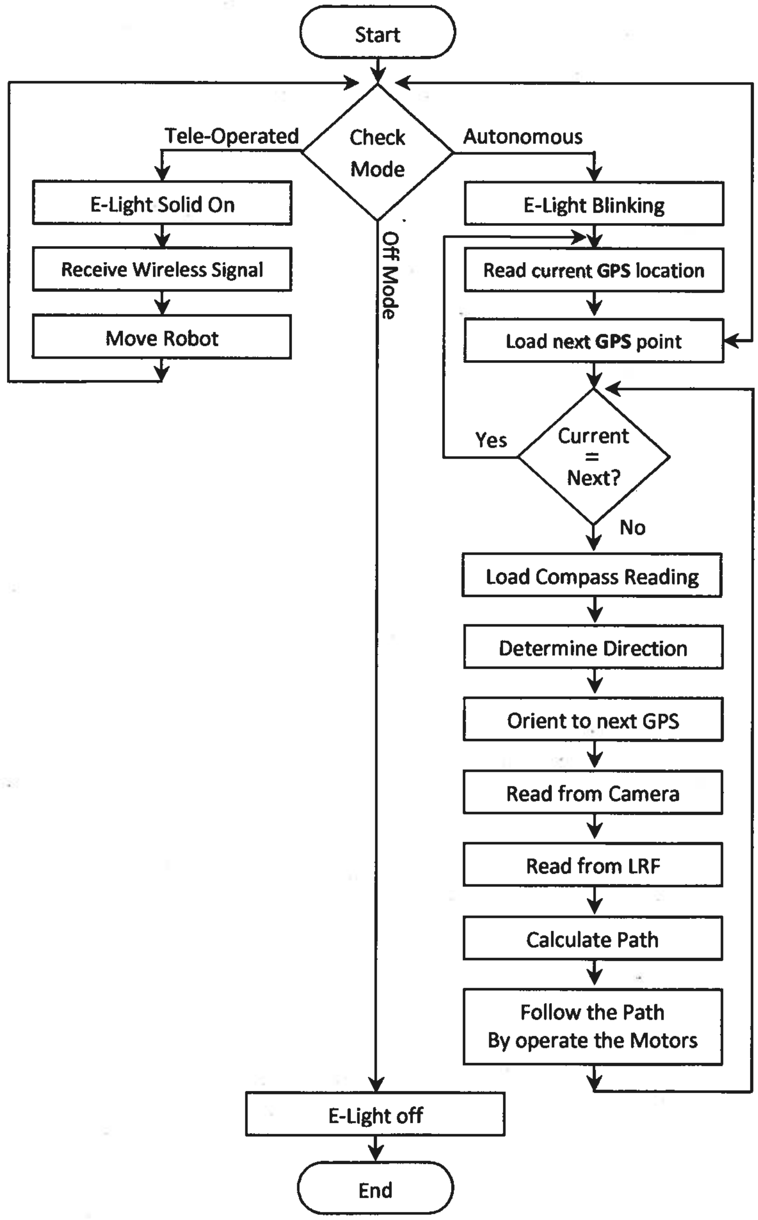


From this block diagram you can see that we have three main Sensors;

- The first set contains **GPS Receiver** and digital **compass**; they are used for **direction determination.**
- Then comes the **Camera** which has the role of **machine vision,** it takes a real time video for the path, and sends it to controller, which is here a computer. The path view will then go through a processing stages in order to obtain a digital image to be used in **lane following**.

- The third sensor set is the **Laser Range Finder**, which acts as an **Obstacles detector**, it draws a polar map for the obstacles contains there angle and distance, this will be sent to the controller for the **Obstacles Avoidance** algorithm.
- You can also notice that we have **two motors** as **actuators**; this means we have a differential drive system (explained in the Control Algorithms part of this report).
- For the **wireless remote control** mode of operation we have the RC unit of Transmitter and Receiver. The software implementation is included inside the controller as well.
- The only **Indicator** we have in our system is the **E-light**.

B. Operation Flow-Chart:



Stage 3: Detailed Design:

A. Sensors Selection:

We have the following sensors:

1. Camera:
   A Microsoft LifeCam Cinema camera will be used for machine vision. This camera has the ability of brightness adaptation.
2. Laser Range Finder:
   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 this detector is 240 degrees. Distances are reported from 20mm to 5.6 meters, Pitch angle is 0.36º, and a distance resolution ranges from 1 to 3mm.
3. GPS:
   The **Garmin OEM GPS 17x HVS Sensor NMEA 0183** will be used for GPS way-points navigation. It has high accuracy that suits our application.
4. 3-Axis Magnetometer:
   The **IMU ±2g Triple Axis Accelerometer, ±2000°/s Gyroscope, Triple Axis Magnetometer** uses rate gyros, accelerometers, magnetic sensors, and an onboard 32-bit ARM Cortex processor to estimate sensor orientation at 1000 Hz.
   Sensor orientation is reported using either quaternion's or Euler angles over a TTL serial interface at user-customizable rates. It was designed specifically to be easy to use as an external enclosure protects sensitive electronics.
5. Batteries:
   3 Lead-Acid Batteries;
   2 Batteries in series (Total 12V 18Ah) for Motors
   1 Battery (12V 12Ah) for Computer and Sensors
6. DC to AC Converter:
   It's used to generate 120AC power to the computers from 12V battery. It comes with remote shut-down.

Stage 4: Controller and Control Algorithm:

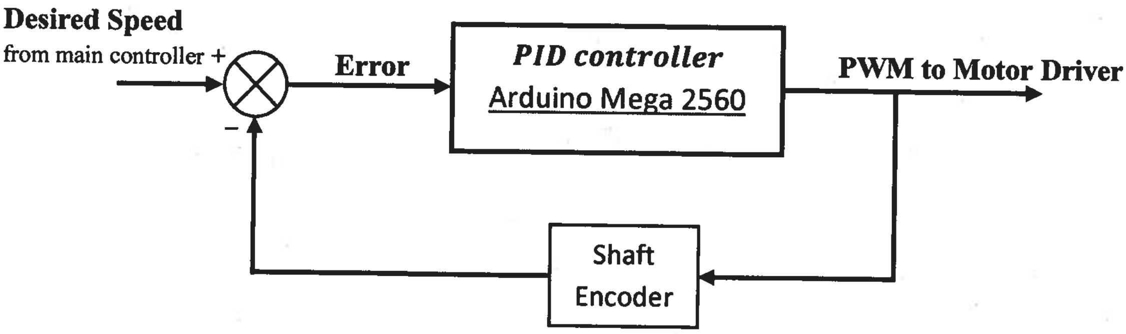
A. Overview.

Two levels of control are included in our design, first is the low level control; that aims mainly to keep the motor's speed at a desired value determined by the controller, and second is the high level control that contains both Remote Control and autonomous navigation.

B. Low-Level Control Algorithms.

✓ **PID Speed Control.**

On each dc motor a specific microcontroller (Arduino Mega 2560) is fixed to do the speed control function, it takes the desired signal from the main controller, and takes the actual speed from the shaft encoders, calculates the error, apply the PID control algorithm and generate the suitable PWM signal for the Motor drive circuit.



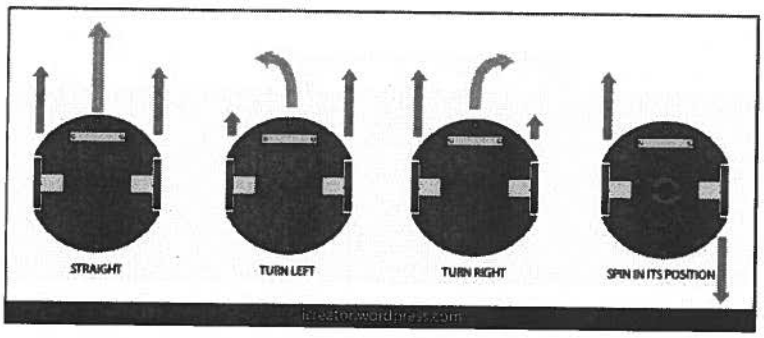
Closed-loop speed control system

C. High-Level Control Algorithms.

1. Differential Drive.

Differential mode is basically when the vehicle has two drive motors, right and left motors; this gives it more freedom in rotating; because it can rotate around itself without changing its position.

The following figure explains the four movements that can be achieved by differential drive.



2. Remote Control Mode:

For remote control mode, the vehicle must navigate according to signals sent from RC transmitter. Look at the following figure:

3. Autonomous Mode:

In order to achieve its mission and reach the GPS goal safely without crashing into obstacles or leaving the lane, Jo-Car2 uses three main sources of information; **GPS with magnetometer**, **Camera** and **Laser Range Finder**.

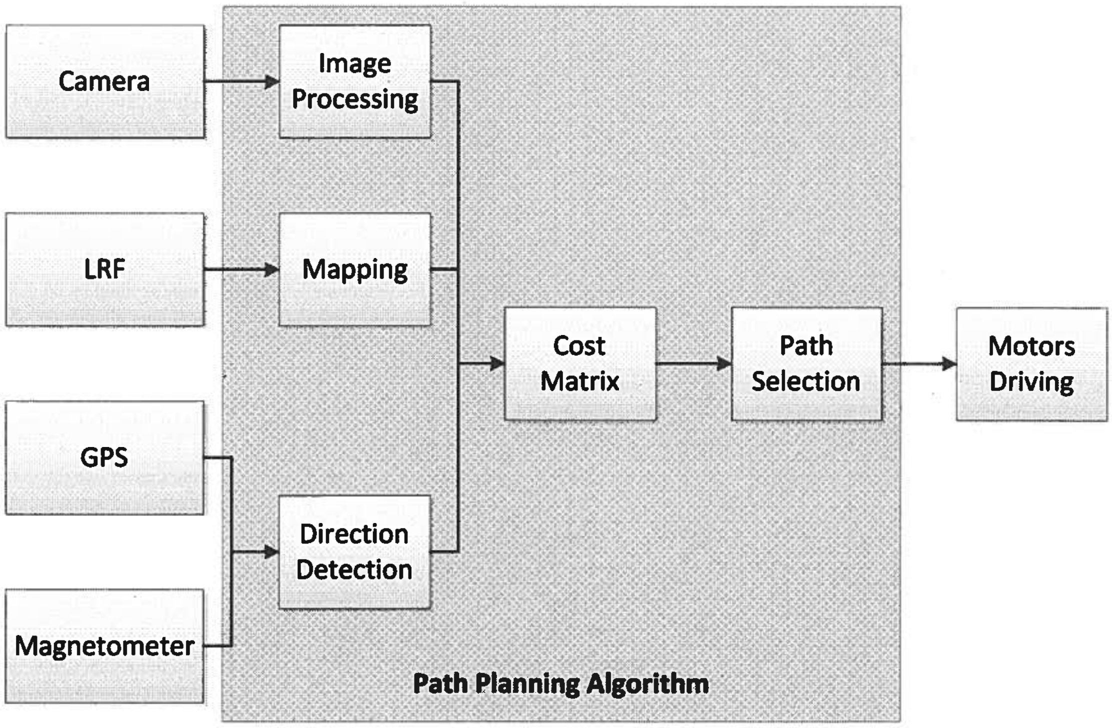
Using the combination between the GPS and magnetometer readings, we can determine the desired direction of the robot.

The **Camera** is used to detect the path lines and also the obstacles, by applying the image processing algorithm described in section **XXX**. While the **Laser Range Finder** is used also to detect obstacles.

The three sensors are then fused into one source of information; **The Cost Matrix**, that Jo-Car2 depends basically on for its artificial intelligence.

The Cost Matrix is a 7x7 matrix, whose values represent the risk value for each position on the cam image plane; i.e. it has large values where obstacles or path lines exist, and low values in safe positions.

Each sequence of matrix elements represents a path; which has its own cost (the sum of elements values), the path of lowest cost is the best path.

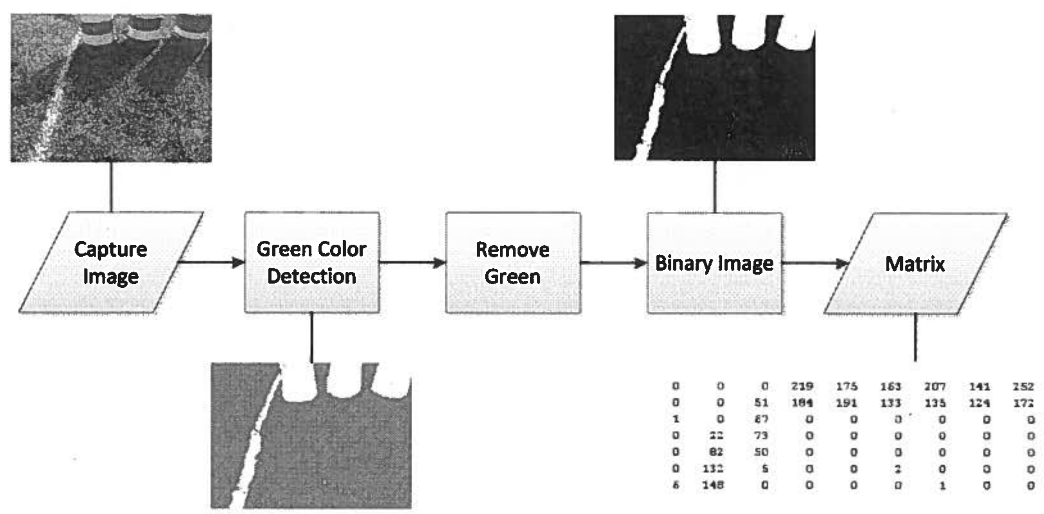


After choosing the best path, the controller must convert it into its relevant desired speeds for the both motors.

The PID controller will guarantee that the motor will operate at the desired speed.

i. <u>Image Processing.</u>

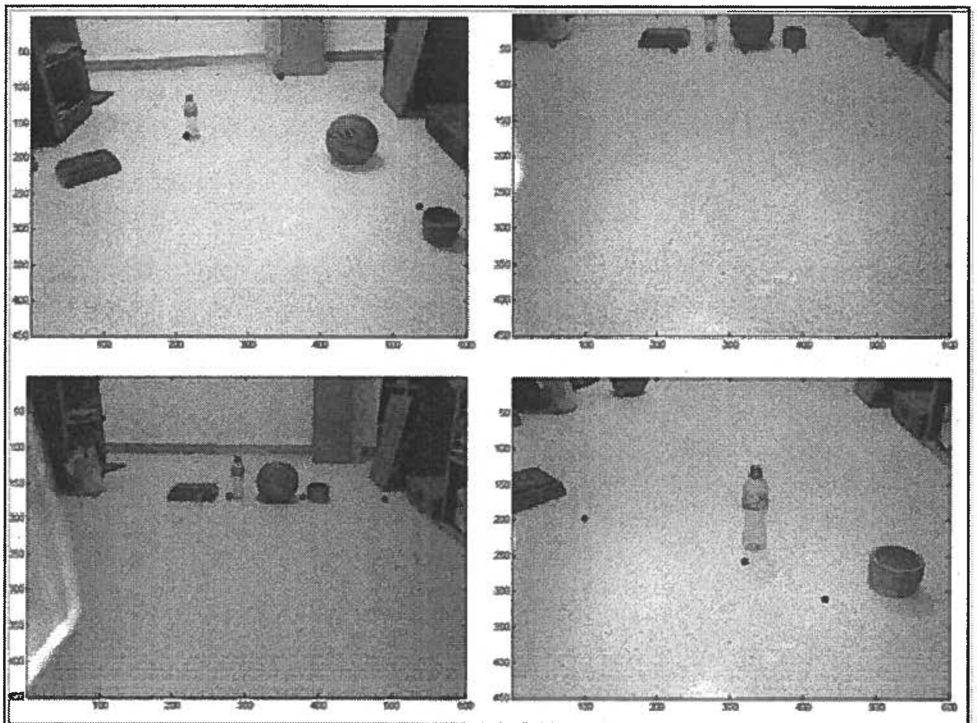
Lane detection is achieved by processing a color image of a forward pointing camera that is positioned to capture an adequate field of view of the area in front of the robot. Safe areas for travel are detected on apixel level by noting all pixels that have a green hue. Even shadows on the grass, are classified as safe. Non safe areas, such as the orange barrels are detected and translated as large weights into the Cost Matrix. This makes paths with onstacles in them "costly" and unlikely to be selected.



<u>Image Processing in detail</u>

ii. <u>LRF Mapping.</u>

To fuse LRF data into our Cost Matrix, we need first to map the laser points on the camera image plane; to do so we have used different experimental methods, from which we have chosen the best method that gives the following results.



LRF Mapping Samples

iii. GPS Way-Points Navigation.

This can be done using the GPS receiver and the digital compass together; the GPS gives the current point, knowing the next GPS point we can determine vector between the two GPS points, from which we can determine the GPS angle (the angle between positive y-axis and the vector).

Furthermore, the compass gives the angle between the y-axis (North) and the vehicle direction.

The angle that the robot must rotate to face next GPS point can be determined then by subtract the GPS vector angle from the compass angle.

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

When the angle is positive the robot must rotate right, while it must rotate left for negative angle, Look at the following figures:

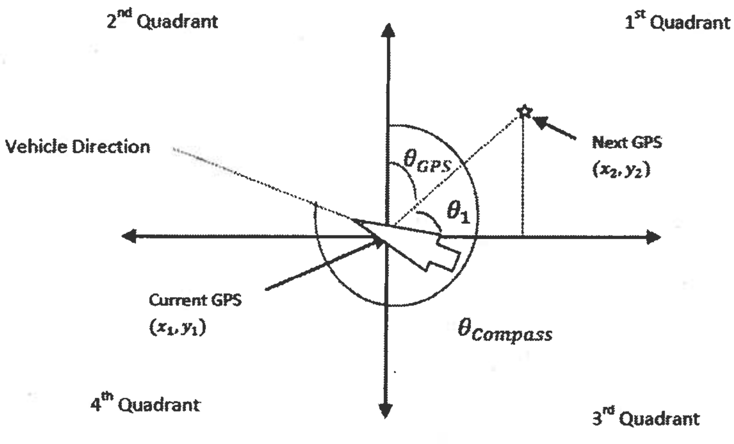


Figure 12:
$\theta_{final} = \theta_{Compass} - \theta_{GPS} = +ve$
meaning that the vehicle should rotate right to face the GPS point

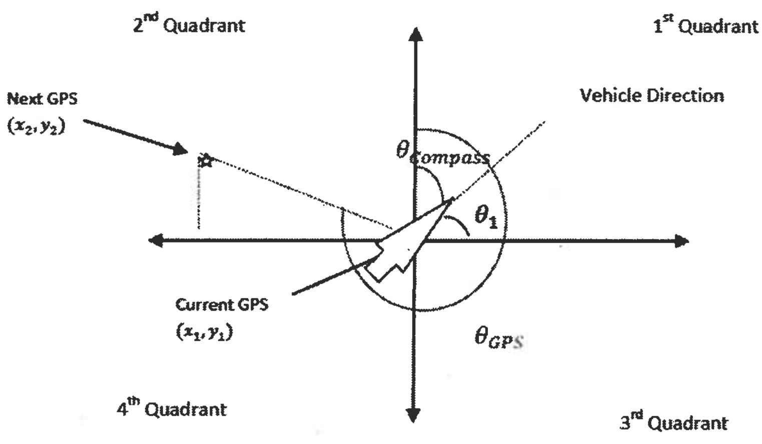
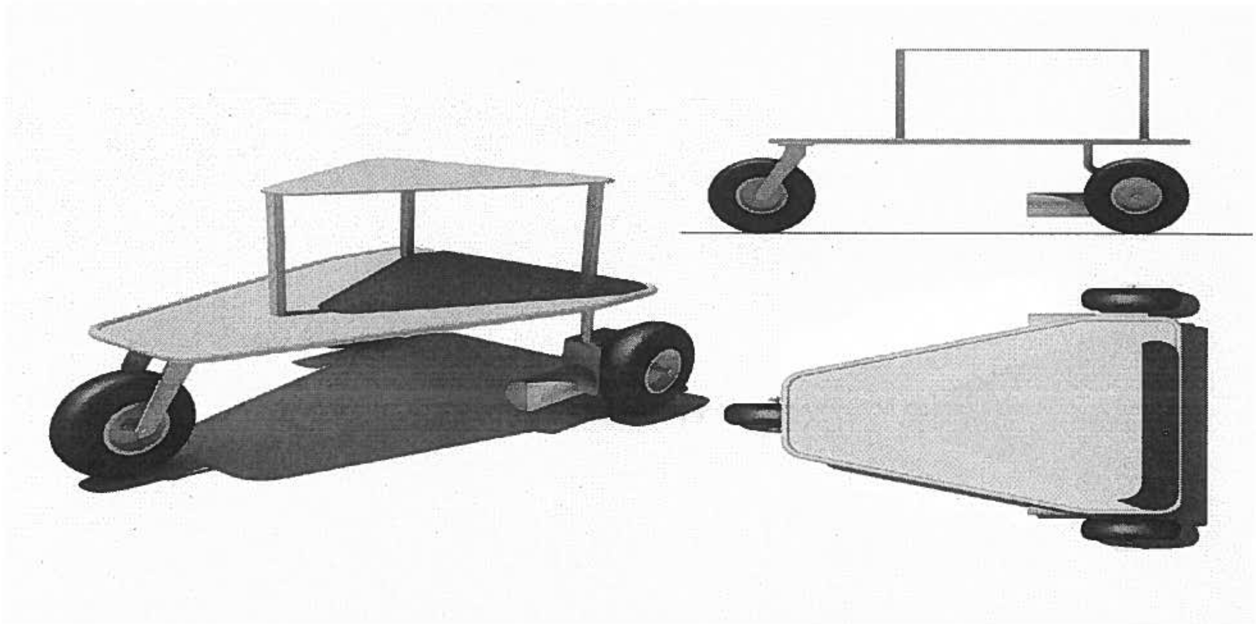
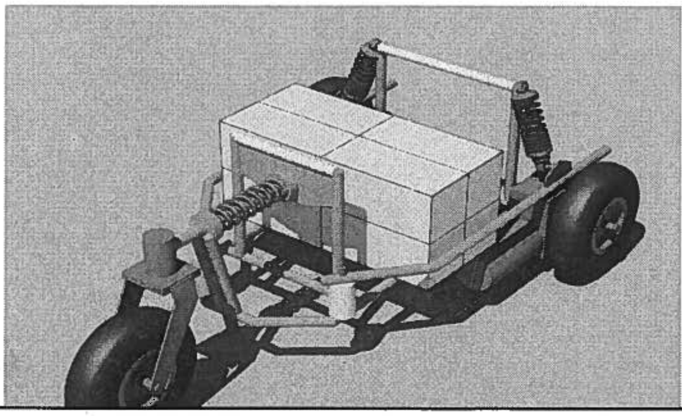


Figure 13:
$\theta_{final} = \theta_{Compass} - \theta_{GPS} = -ve$
meaning that the vehicle should rotate left to face the GPS point

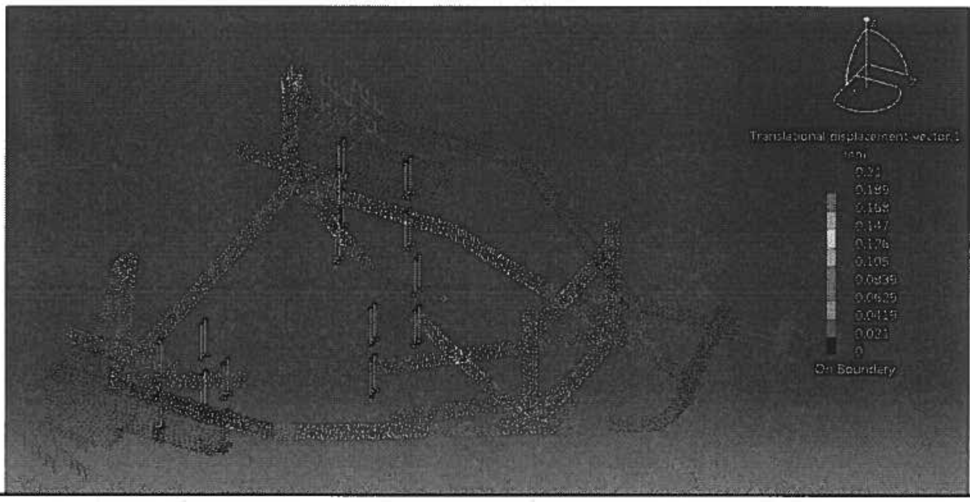
Mechanical design

Jo-car2 skeleton is basically made of steel tubes 2X2 cm and 2X4 cm, which has the Modulus of Elasticity (E = 200 GPa), The main reason we've chosen the steel tubes for the skeleton is its high strength and relatively light-weight.

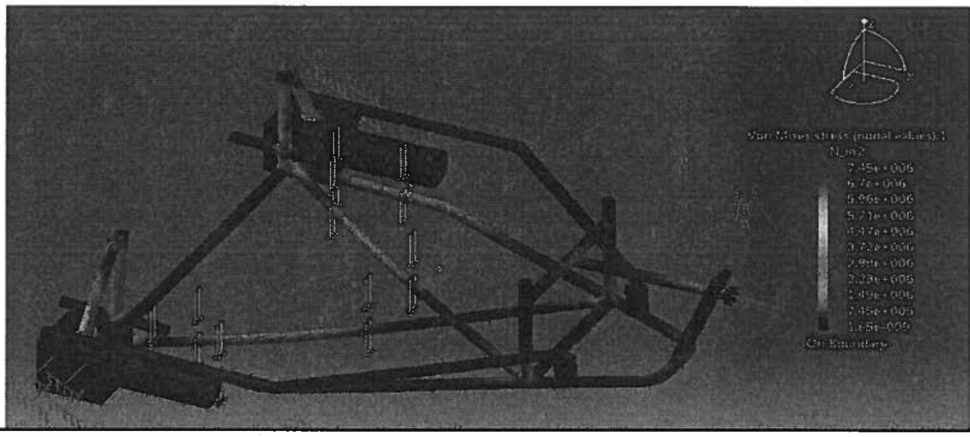




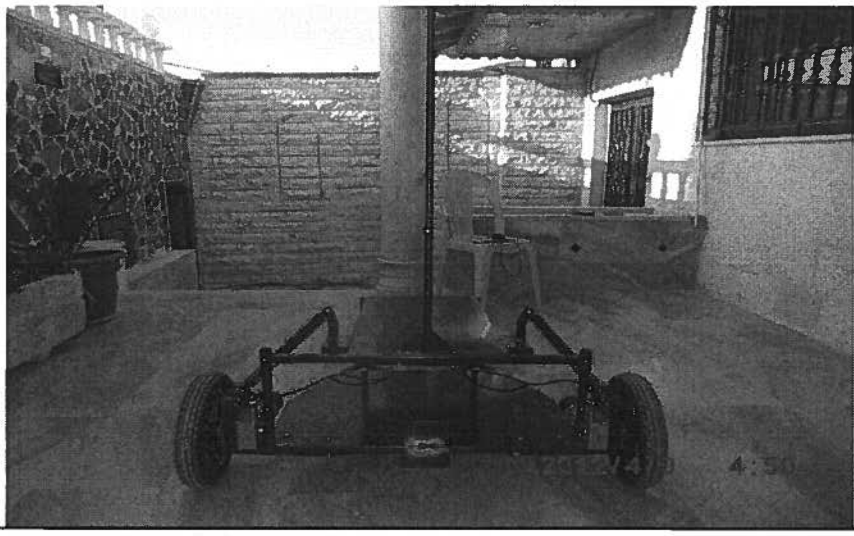
Mechanical skeleton sketch with payload using 3D max



Simulation using Catia v5 shows the translational displacement on the skeleton



simulation using Catia v5 shows the von-mises stress on the skeleton



Implemented Vehicle Chassis