Palestine Polytechnic University

College of Engineering

Mechanical Engineering Department

Graduation Project

Special firefighting vehicle

By

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Aysha Idrees Shaloudi Oday Mohammed Al-Natsheh

Mohammed Darwish Abu Nijmeh

Supervisors:

Eng. Zohair Wazwaz

Eng. Nafeth Shaarawi

Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor degree in Mechanics Engineering

توقيع مشرف المشروع .... توقيع رئيس الدائرة ....

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Abstract:

Buildings in the Old City including mosques, shops and schools are not accessible by regular firefighting systems because the size regular firefighting vehicles. This project will focus on design and make a suitable firefighting system for those places.

The project aims to design and build a model of an electric vehicle suitable for use in narrow passages and arcades within the Old City of Hebron and similar location .The proposed vehicle have a total mass of 1500 kg including electric vehicle with a firefighting unit. The electric vehicle with maximum speed of 30 km/h equipped with electric differential drive by microcontroller "Arduino" with electric two wheel_steering for good maneuverability with adjusting special dimensions (L*W*H = 274.3*113*120.7 cm) and shape to ensure efficient firefighting in small isolated spaces. A prototype has been designed and build with respect to project requirement it has a dimensions of (120*70*57.5 cm) and weight of 56.2 kg .

الملخص :

تضم البلدة القديمة في الخليل العديد من المساجد كالمسجد الإبراهيمي والمدارس والمباني الحكومية والمحلات التجارية وغيرها، لا يمكن الوصول إليها من قبل سيارات الإطفاء في حالات الطوارئ ، بسبب وان حجم السيارات التقليدية الكبير نسبيا ما يصعب من وصولها إلي أي نقطة من البلدة القديمة ، في هذا المشروع سوف يتم عمل سيارة إطفاء خاصة للعمل في هذه المنطقة.

يهدف المشروع لتصميم وبناء سيارة إطفاء كهربائية مناسبة للعمل في الأروقة و الممرات الضيقة في البلدة القديمة في الخليل والمناطق المشابهة،السيارة المقصودة كتلتها 1500 كغم،تضم سيارة كهربائية مع وحدة الإطفاء ، السيارة الكهربائية تصل سرعتها القصوى 30 كم/ساعة تعمل بنظام الدفع التفاضلي الكهربائي عن طريق المتحكم الدقيق "ARDUINO" مع مقود العجلين الكهربائي وتستطيع القيام بالمناورة الجيدة ،ومع تعديل شكل وأبعاد خاصة للسيارة (120.7*113*274.3 سم) لتأكيد فعالية الإطفاء في المناطق المعزولة الصغيرة.

تم تصميم وبناء نموذج مصغر من المشروع على سيارة اطفال صغيرة مع تعديلها حسب المتطلبات، وتم تزويدها بالانظمة الالكترونية للتحكم بالمركبة وتوجيهها ، تم بناء النموذج بابعاد (75*70*120سم) ووزن 56.2كغم.

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1. Chapter One: Introduction

1.1. Overview.

1.2. Objectives.

1.3. Project Importance.

1.4. Old City of Hebron.

1.5. Requirements.

1.6. Motivation.

1.7. Project schedule and time plan.

1.8. Budget.

1.1 Overview:

This chapter presents, a general description of the system, starting with a background, objectives, importance of the system, requirements, motivation, project schedule and time plan and budget.

1.2 Objectives:

The main objectives that we want to achieve in our project are the following:

1) Design and build fire fighting vehicle which can reach any zone of the Old City of Hebron.
2) Utilize a microcontroller and build a control code for the operation of system units.

1.3 Project Importance:

The importance of the project is summarized by the following points:-

- The Old City of Hebron have a historic and touristic importance. It contains Ibrahimi Mosque and some other school, shops and government department so a lot of people live there and people there are under risk when a fire occurs. This project help to protect the Old City buildings and save people’s life and to make the work of civil defense easier.

- Firefighting the old city of Hebron faces difficult problems in arriving to the fire zone in emergency cases .The problem comes from the nature of the construction of the Old City which was constructed thousands years ago to accommodate people and animals but not motor vehicles. The smallest commercial vehicle available in the market can’t enter into the old city so the vehicle size and maneuverability must be adjusted.

- Two month ago, in march 28th Al-Rajabi family is a Hebron family who live in the Old City, they had a fire in their house because of electrical fault, they lost their three children (Wael 4 years, Wadee’a 2.5 years and Malak 1.5 years), and that because none of the regular fire fighting could arrive to this family house.

1.4 Old city of Hebron :

There is some properties of the old city:

1) The old city have a population of 6500.
2) Have an area of 1.107 km^2 and have 25% closed area by military.
3) Most of construction and buildings are commercial or mosques, schools, …etc. which increase the chance of fire occur.
4) Most crafts and industries in the old city are:
   Pottery, Poultry Shops, Groceries, Catering Supplies, Perfumery, Antiques, Centware, Hand Embroidery ,Ceramics, butchers, bakeries, sweets, shelters shops and sewing.
5) Number of stores in the Old City is 512, closed by military rule, 450 opened, and almost 200 stores closed by its owners.
6) Some aerial photos of the old city: shown in **Figure1.1 and Figure 1.2**

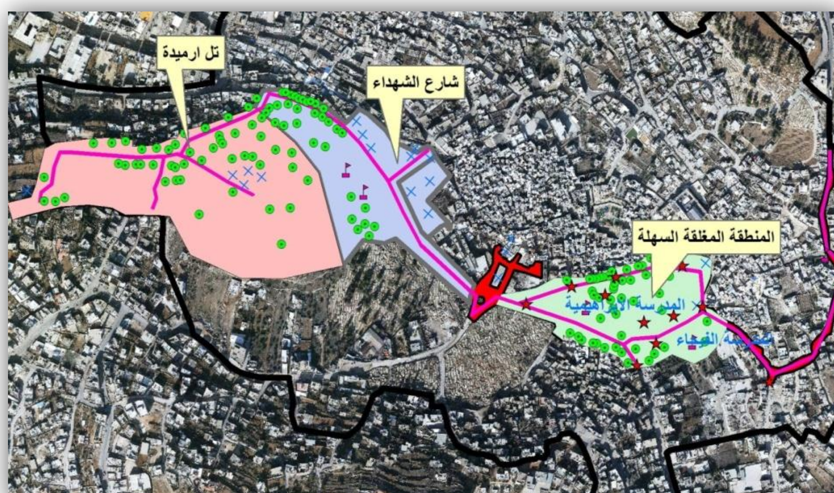


Figure 1.1 Aerial photo of the old city

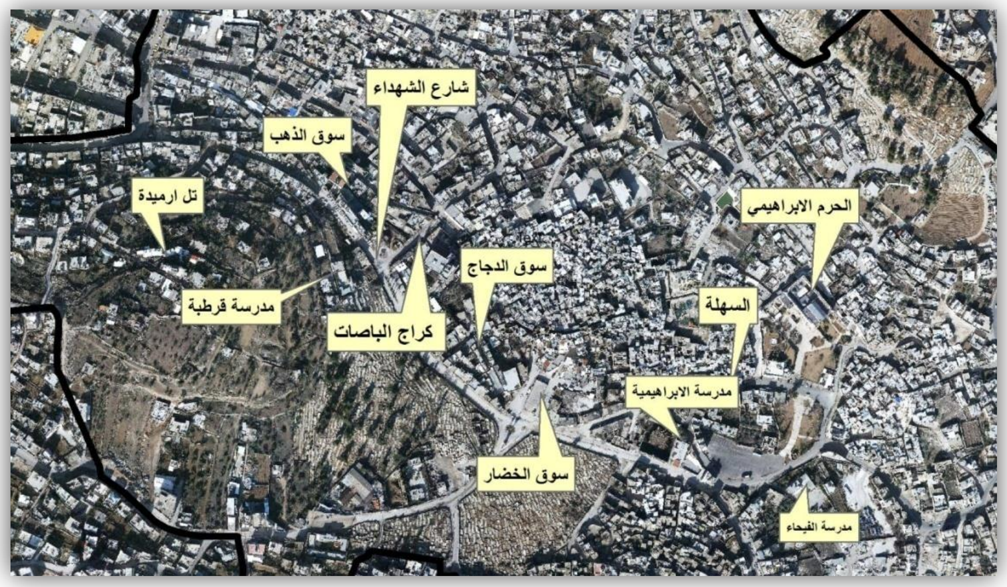


Figure1.2 Aerial photos of the old city of Hebron

1.5 Requirements:

The size of the vehicle is dictated by the dimensions of the passages and arcades of the old city. It is proposed to be plug-in electric vehicle and environment friendly. This system requires hardware and software components in order to make a prototype for the system:

1.5.1 Hardware components:

- Controllers
- Motors
- electric steering
- brake by wire
- Vehicle body (Chassis)
- Batteries
- Pump
- Sensors
- Switches
- firefighting equipments

1.5.2 Software components:

- Controller program (ARDUINO)
- Catia program
- Matlab

1.6 Motivation:

- None of the regular fire fighting vehicles in Hebron have the ability of arriving to every fire cases in the Old City, these vehicles have a big size and cannot pass throw the narrow passages and arcades, and this put the Old City in danger.
- The system is an implementation that contain a mechanical, electrical system and extinguishing system, it is an integration of these systems to achieve the objectives of this project, so that make the need of Mechatronic Engineering, Automotive Engineering and Air Conditioning & Refrigeration Engineering .

1.7 Project schedule and time plan:

Table 1.1 shows the tasks description for the project.

Table1.1 Tasks description

	Tasks description
T1	Project selection
T2	Collecting references from libraries
T3	Collecting references from websites
T4	Select initial design
T5	Create and draw the selected design on CATIA
T6	Do some adjustments on the design
T7	Select the mechanical parts and sensors
T8	Writing the text
T9	Prepare the 1st presentation
T10	Make the required adjustments on the introduction text
T11	Design a prototype
T12	Create and draw the selected design of prototype on CATIA
T13	Buy the mechanical and electronic parts
T14	Build the prototype
T15	Put the mechanical and electronic parts of the system
T16	Build the suitable code for the system and the ANDROID application
T17	Build the schematic diagram on PROTEOS and test the code
T18	Test the result
T19	Do some justification to make the system more efficient
T20	Try to correct the expected problems of the system
T21	Writing the text
T22	Prepare for the final presentation
T23	Make more test on the system

Table 1.2 shows the time table of the first semester for the project.

Table 1.2 First semester time table

Tasks/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
T1	■	■	■	■										
T2					■	■								
T3					■	■	■	■	■					
T4					■	■	■	■	■					
T5									■					
T6									■					
T7										■	■	■	■	
T8										■	■	■	■	
T9										■	■	■	■	
T10												■	■	■

Table 1.3 shows the time table of the second semester for the project.

Table1.3 second semester time table

Tasks/week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
T11	■													
T12		■	■	■										
T13					■	■								
T14							■	■						
T15								■	■					
T16								■	■	■				
T17										■				
T18										■	■	■	■	
T19											■	■	■	
T20											■	■	■	
T21											■	■	■	
T22												■	■	
T23												■	■	■

1.8 Budget:

Before making any project it is necessary to know how much money it will cost. And to make and consider alternatives, to minimize the cost as possible as you can, and make a good synergistic integration. **Table 1.4** shows the budget of the system.

Table 1.4 Budget

No.	Component name	Quality	Price ($)
1	DC Motors and drivers	2	4200
2	Vehicle body (chassis)	1	500
3	Batteries	1	2000
4	Electric steering	1	150
5	Brake by wire	1	130
6	Wheels	1	160
7	Arduino	3	75
8	Pump	1	3000
9	Tank	1	100
10	Generator	1	800
11	Firefighting equipments		100
12	Sensors and switches		100
	TOTAL		11315

2. Chapter two: Conceptual design and functional specification

2.1. Overview.

2.2. State of the Art.

2.3. Needs and requirements.

2.4. Proposed Designs and Evaluation.

2.5. Conceptual Design.

2.6. Functional specifications.

2.7. Block diagram.

2.1 Overview:

This chapter introduce some suggested designs for the project, and describe the conceptual design of the project, taking into consideration the requirements and objectives that have been clarified in the previous chapter, and it is describe the functional specifications of the components and the relations between them.

2.2 State of art:

Firefighting in small areas like the old city, commercial centers and residential communities is very necessary to save people lives and keep those places safe. Regular firefighting have limited ability to get into narrow spaces. By adjusting the dimensions of the firefighting vehicles it can be easy to extinguish the fire wherever it happens. In the following part a summary of some vehicles and robots that help for the firefighting in small areas.

2.2.1 Dangled Electric car

Having huge facilities such as factories and commercial centers in addition to popular neighborhoods and gardens that can be exposed to fire and systems to extinguish as fast and efficient as possible, in the following section is a summary of same of device, and systems that assist in fire process, which is made by a Chinese Company.[1]

Figure 2.1 Pure electric firefighting

Dangled is an electric vehicle shown in **Figure 2.1** with a 48 Voltage battery and a 4 kw motor with a small size, fitted with special equipment and stocks of water, used to put out fires that reside in places difficult to access.

Figure 2.2 Component of pure electric firefighting

The vehicle shown in **Figure 2.2** consists of a structure made for fire resistant steel with a special design gives it appearance and two seating capacity, also both sides are opened (without doors) to facilitate the operator to get off.

Figure 2.3 Suspension of pure electric firefighting

Figure 2.3 shows the suspension of the vehicle from DC motor (4 KW) and batteries provide the energy to driving range distances as a minimum 50 km.

Specifications :

- Model No. EQ8041-3-XF
- Size(mm)L*W*H 3650×1430×1930
- Net weight (kg) 1300
- Water loading capacity 800 kg
- Seating capacity 2
- Driving range distance Km ≥50 km
- Max speed(Km/h) 30
- Braking distance (m) ≤6
- Wheel base(mm) 2250
- Wheel track (mm, front/rear) 1230/1200
- Maximum climbing ability 20%
- Ground clearance(mm Fully load) 150
- maximum loading capacity of water (kg) 800
- Charging Time (h) 8～10
- Battery 48V,6V*8

2.2.2 Firefighting Robot:

Figure 2.4 shows the body of the firefighting robot, It`s a fire extinguishing robot can replace firefighters to approach the fire scene, and implement effective fire rescue. Applied a DC motor with a large capacity battery, Modular distributed control design. The structure consists of track, front and rear arms (4 arms), tire design, remote control, and it can rotate a degree of 360°, and its size is (83*117*148) cm.[2]

Figure 2.4 firefighting robot

2.3 Needs and Requirements:

Fire fighting in the Old City of Hebron have a difficult problem when using the regular fire fighting, and this difficulty comes from the geography of the Old City which have narrow streets and crowded buildings. That put people lives in risk when the fire occurs, from here we have to think of alternative solution makes the process of firefighting more easy and in less time.

1) The working area is 1.107 km and have 25% closed area by military.
2) Possibility of arriving to any zone of the Old City.
3) No depends on the water source of the old city.
4) Make space for one person with fire equipment.
5) Enabling the road control agent.
6) A speed limit of 30 km / h.
7) Work environment:
    i. The climate is relatively mild.
    ii. The roads is temple, narrow and some paths have width of 1.5 meters.
    iii. There is some vault with two-meter high.
8) Most of construction and buildings are commercial or mosques and schools , …etc. which increase the chance of fire occur.
9) Costs do not exceed 12,000 dollars.
10) The system should be safe and user friendly.

2.4 Proposed Designs and Evaluation:

2.4.1 Design1

This design shown in **figure 2.5** assuming two double shaft driving motors one of each axle and an electric steering on the front axle. But after we evaluate it, we visualize that the vehicle will have a large torque so the double shaft motor is not efficient and runaway could happen.

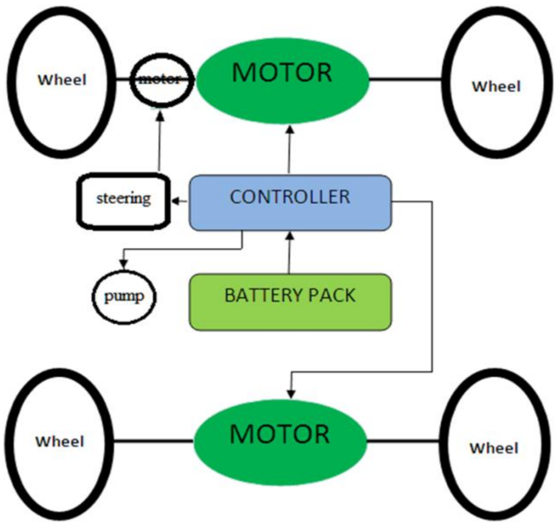


Figure 2.5 Design1

2.4.2 Design 2

This design as shown in **figure2.6** , the system is four wheel drive , and have one in_wheel motor for each wheel , the process of turning the vehicle needs a special steering with intelligent control to make two motors (front right motor with rear right motor / front left motor with rear left motor) rotates in opposite direction of the others. But when we evaluate this design we verify that it require a lot of components and then it going to be expensive.

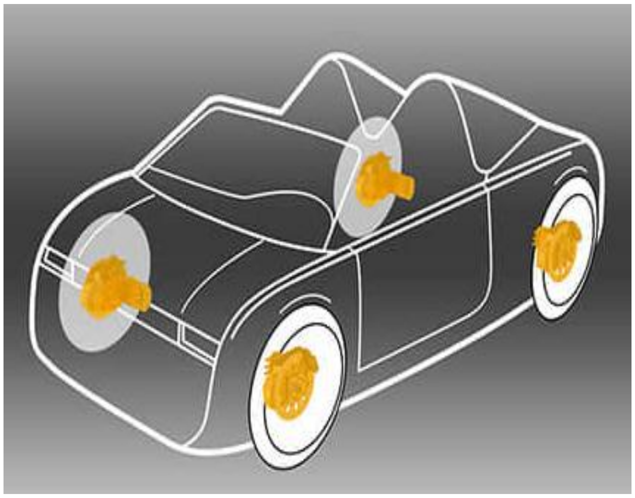


Figure 2.6 Design 2

2.4.3 Design 3 (final design):

This design as shown in **figure 2.7** is an improve from design 2 the design consists of two motors build in the rear axle of the vehicle , the process of turning the vehicle works as an electric differential that make the left motor speed differs from the right motor speed, this design includes less components than the previous two designs and it will be adopted for this project.

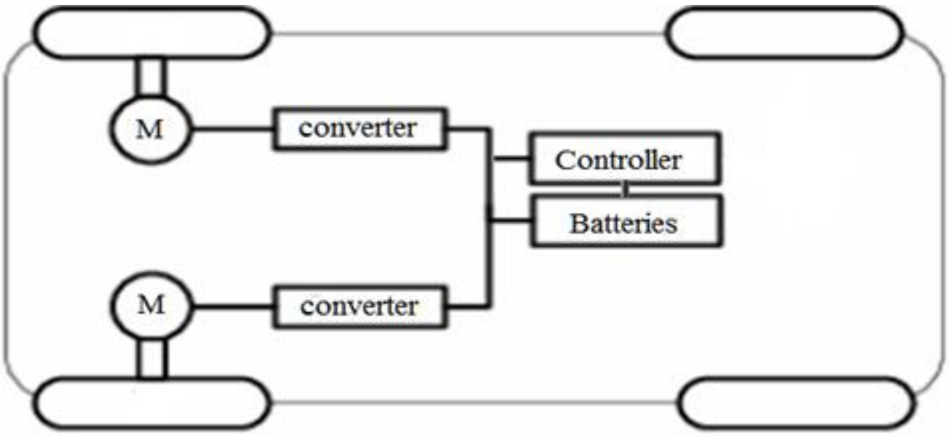


Figure 2.7 Final design

2.5 Conceptual Design:

After defining needs and requirements, and generate solutions by brain storming and morphological chart. Now we want to specify design concept that meet project requirement and functional specification to choose candidate design, to move forward to functional specifications in next section.

The purpose of the conceptual design is to define the required parts and how it will work together, and the relationships between the components.

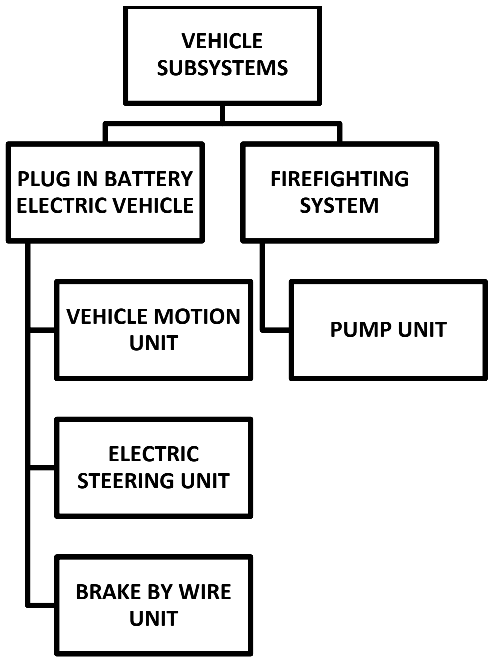


Figure 2.8 subsystems of conceptual design

The system as shown in **figure 2.8 and figure2.9** consists of fire fighting system with electric vehicle as shown in **figure 2.10** an intelligent control that allow to control the motion and rotation of the vehicle and reverse its direction, and to control the pump for fire fighting system.

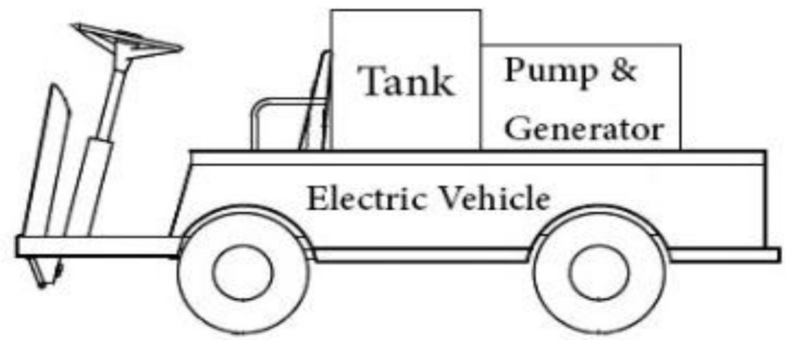


Figure 2.9 CONCEPTUAL DESIGN

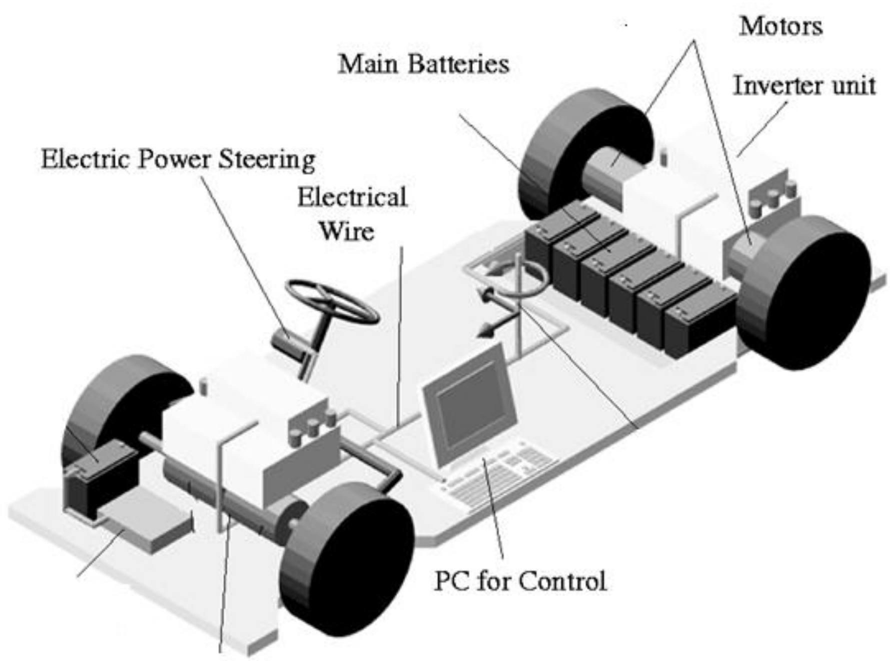


Figure 2.9 PLUG IN ELECTRIC VEHICLE DESIGN

Steering control unit is responsible of controlling the direction of front axle with a ratio 1:24 between the axle angle and the steering angle. the controller is connect to the pump to control the exit of the water when starting the fire extinguish. The control unit is controls the two motors connect with the wheels of the rear axle to create the motion and speed of the vehicle, and controls the direction of the vehicle as it works as electric differential. When need to move through a road junction with small area it have a possible to slow one of the back motor and keep the other, running at its working speed so that it can be steered.

The **figure 2.10** show the vehicle motion through a normal path with a left turn; it will keep controlled by the steering unit and at wide road junctions.

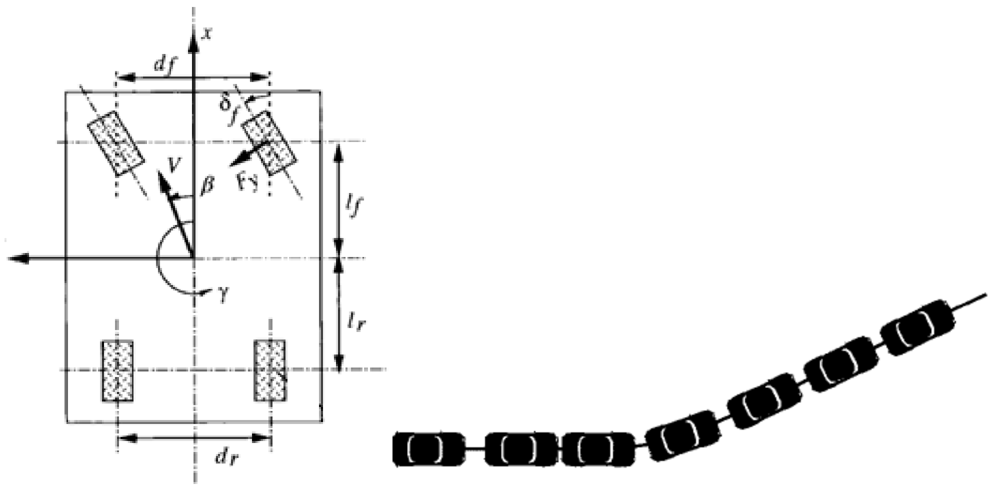


Figure 2.10 Vehicle motion through normal junction

The **figure 2.11** show the vehicle motion when going through a narrow sharp road junction to the left; the rear left wheel will be bracked or reduce it speed to assist the steering at sharp narrow turns.

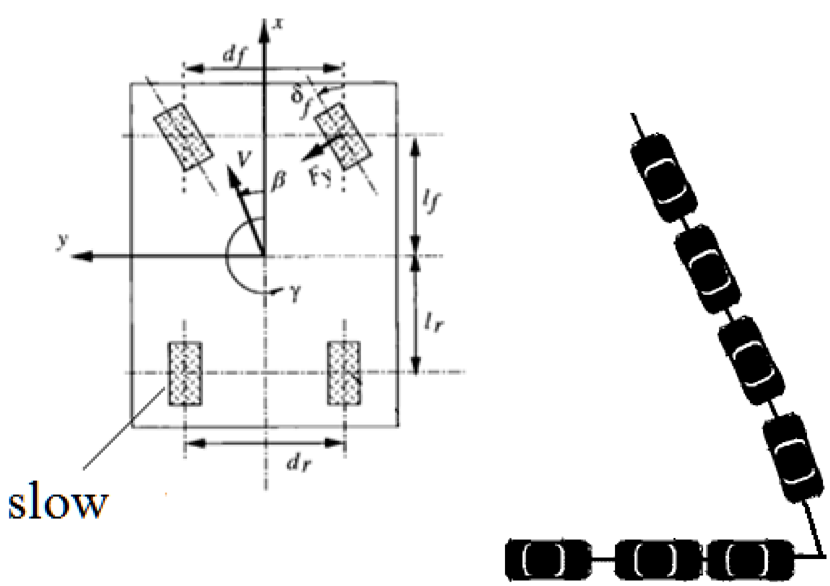


Figure 2.11 Vehicle motion to the left through small size junction

Figure 2.12 show the vehicle motion when going through a small size road junction to the right using the steering system and braking or slowing the right wheel to help achieve a smaller radius of curvature.

:

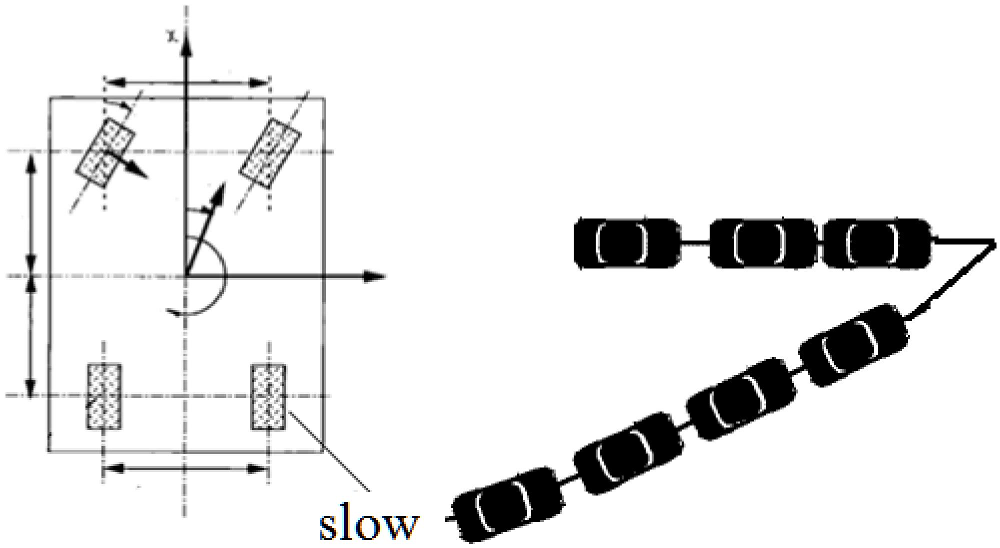


Figure 2.12 Vehicle motion through small junction to right

2.6 Functional specifications:

It explains how subsystem works together in greater detail and compliance with requirements, and exploring the feasibility of the product, to achieve the most efficient design.

1) Using lithium ion battery as electric power source.

2) Two DC motors on the rear axle to move the car.

3) Steering unit to direct the vehicle.

4) Brake system to stop the vehicle.

5) Diesel motor with generator for the firefighting unit.

6) Using Arduino to control the motors, switches and sensors.

7) The shape of the system is prismatic and the dimensions are (length 2.743 m, height 1.207 m, width 1.13 m)

8) The chassis material is Fully Welded 16 Gauge Diamond Plate Steel.

9) Vehicle dimensions : based on the narrowest passage with the sharpest turn in the existing old city of Hebron.

Figure 2.13 shows the dimensions of the vehicle.

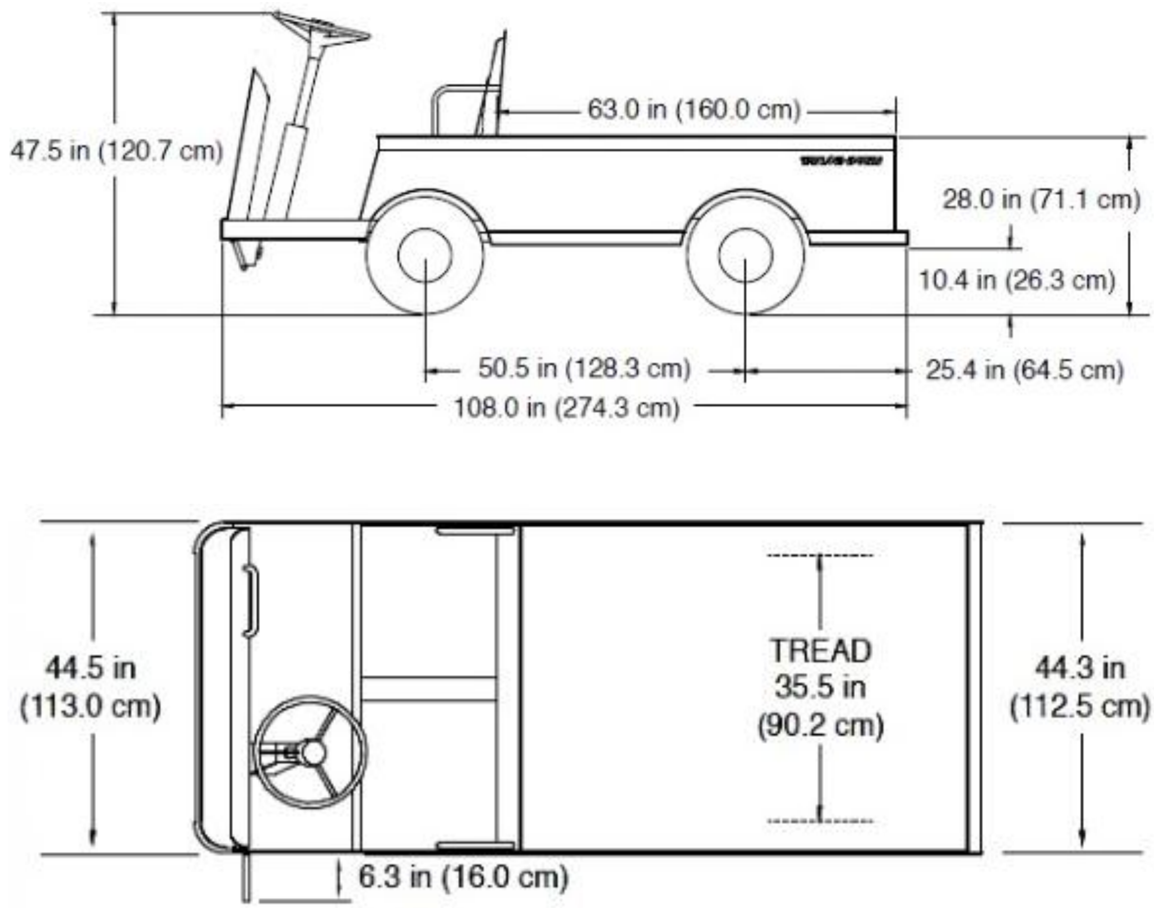


Figure 2.13 Vehicle dimensions

2.7 Block diagram:

Figure 2.14 shows the schematic diagram of the system.

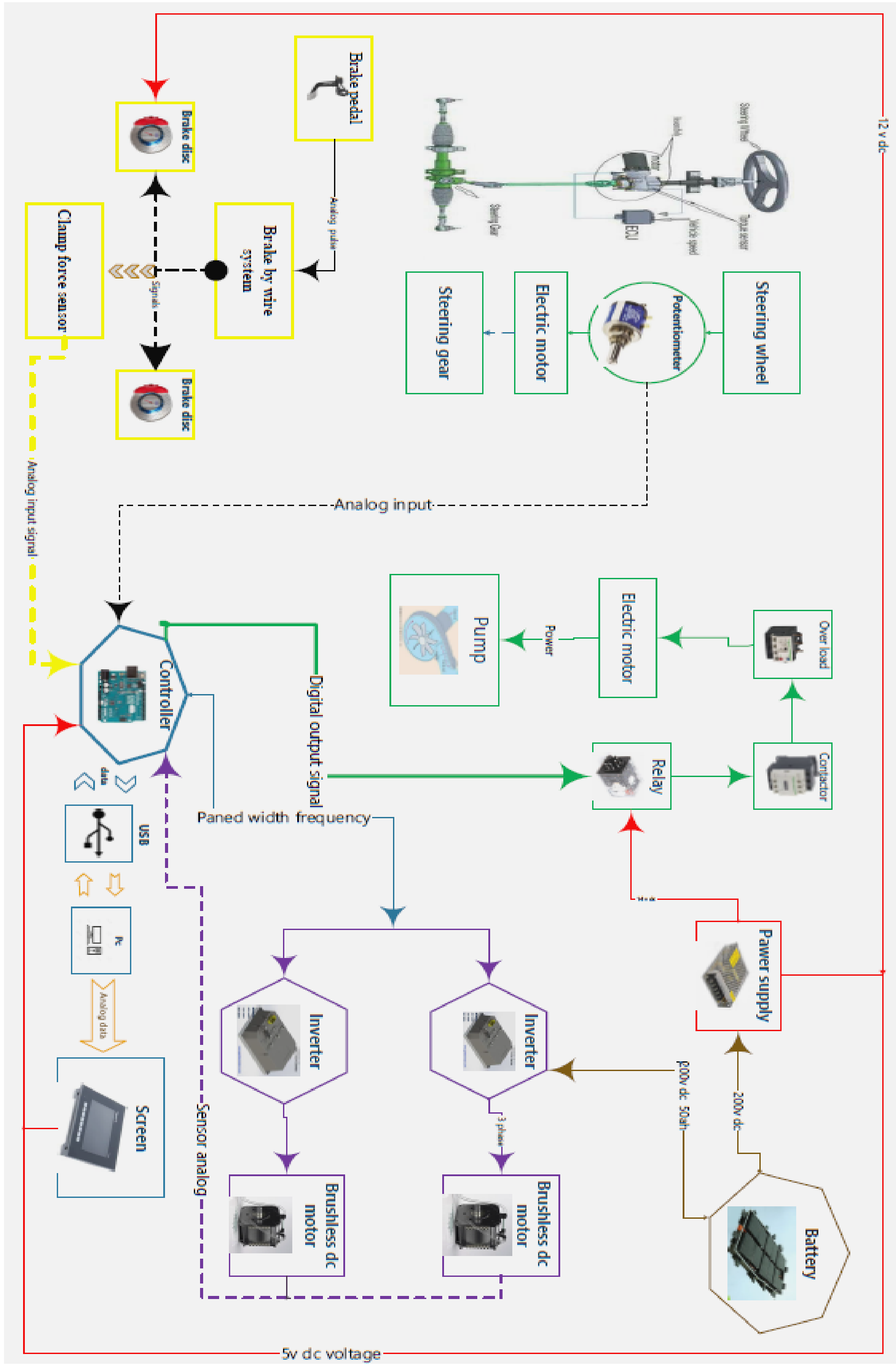


Figure 2.14 Block diagram

3. Chapter three: Theories and Calculation

3.1 **Overview.**

3.2 **Load and motor analysis.**

3.3 **Brake calculations.**

3.4 **Suspension calculations.**

3.5 **Steering calculations.**

3.6 **Pump calculations**

3.1 Overview:

This chapter clarifies the theories and desired calculation for every component to let us choose the suitable components for our project.

3.2 Vehicle dynamic characteristics:

Dynamics of vehicle is the study of how the vehicle will react to driver inputs on a given road , Also an important parameter that affect on different variables which is affect on the vehicle performance , handling and ride characteristics.[3]

Vehicle dynamics is understanding of:

- Behavior of the human driver.
- Characteristics of the vehicle.
- Physical and geometric properties of the ground.

And these are the basic input parameters which control the different variables that effect on the vehicle performance.[4]

By controlling the vehicle to driver commands, and to stabilize its motion against external disturbances, Then the handling of vehicle will be controlled. On the other hand, by controlling of acceleration and declaration of vehicle, ability to overcome obstacles then the performance of vehicle will be controlled. In other way, By controlling the vibration of the vehicle exited by surface irregularities and its effects on passenger and goods, so the ride characteristics will be the most efficient.

3.3 load motor analysis:

It is important to understand the dynamic loads on the motor during operation to know how large the motor should be. To determine the required torque, estimates of the height, acceleration, and friction of the saddle and book were made. These were used to determine the maximum torque on the motor.

the knowledge of the assumed performance figures of the vehicle in which the motor is to be mounted, the vehicle weight (in this particular case, about 1500 kg), acceleration of forward direction (about 0.8 m/s^2), and top speed (about 30 km/h).

With the given parameters available, the demand for power and torque generated by the motor can be determined by considering the forces acting on the vehicle during operation shown in **figure 3.1**

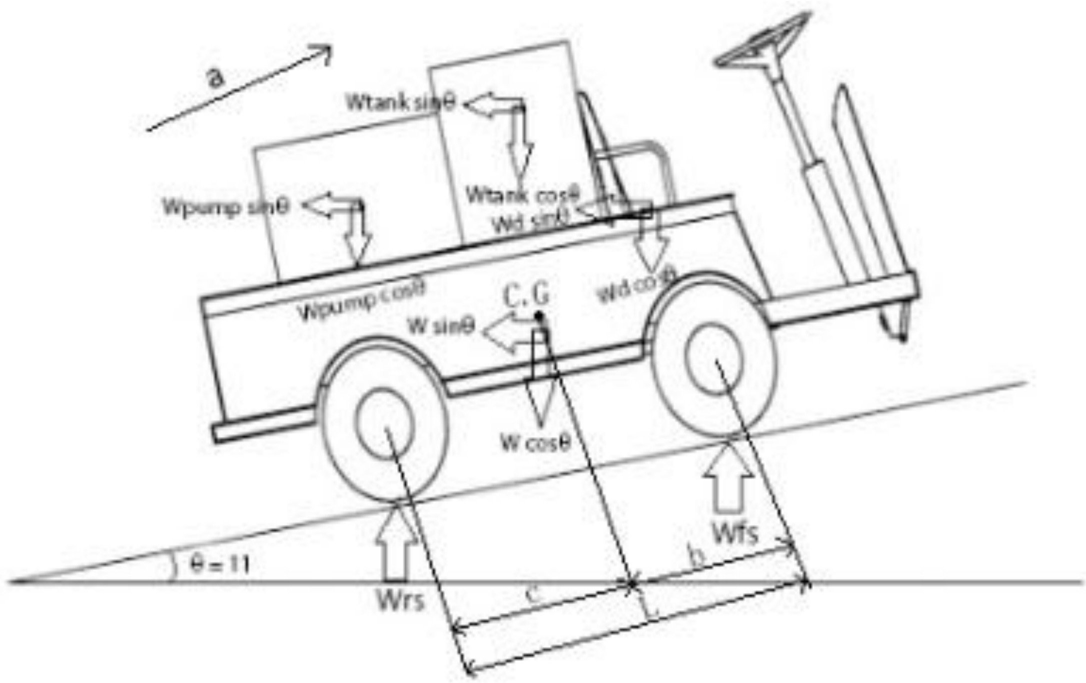


Figure 3.1 load distribution

Axels Loads:

We can measure the load axel by using Newton`s second law by calculate translational system and rotational system.

For translational system :

$$\sum F_x = 0 \tag{3.1}$$

For rotational system :

$$\sum T_x = 0 \tag{3.2}$$

3.3.1 Load Distribution on the Axles:

- To select the position of center of gravity of the vehicle by using assumption of :

  c = 60% of total weight.

  b = 40% of total weight.

c= 600 kg

= 5.886 kN

b= 900 kg

= 8.829 kN

$$c = \frac{W_{fs} \times L}{W_{total}} = 0.5144 \text{ m}$$

$$b = \frac{W_{rs} \times L}{W_{total}} = 0.73952 \text{ m} \tag{3.3}$$

Where:

c : The distance between the center of gravity and rear axle.

b : The distance between the center of gravity and front axle.

W_{fs} : Weight distributed on the front axle.

W_{rs} : Weight distributed on the rear axle.

L: Wheel base.

$$W_{total} = W_{fs} + W_{rs} \tag{3.4}$$

3.3.2 Power calculations :

At first we want to determine the acceleration of the vehicle by:

$$a_x = 550 \frac{g}{v} \frac{HP}{w} \ (ft/s^2) \tag{3.5}$$

Where:

a_x : Acceleration of the vehicle.

g: Standard gravity = 32.2 (ft/s^2).

v: maximum speed of the vehicle (ft/s).

HP: Horse power, we assume the vehicle gives 16 horse power.

w: weight of the vehicle (lb).

v_{max} =30km\h

= 30000\3600 = 8.3333 m/s

= 27.3 ft/s

$$a_x = 550 \times \frac{32.2}{27.3} \times \frac{16}{3306}$$

$a_x = 3.31 \ (ft/s^2)$

$= 1.0088 \ m/s^2$

For Tractive force at drive wheels (F_x):

$$F_x = M \, a_x \tag{3.6}$$

$F_x = 1513.2$ N

Torque of the vehicle (T):

$T = F_x \times r$

Where:

r = radius of the wheel (m) = 0.22m

T = 332.904 N-m

= 0.3329 kN-m

3.3.3 Dynamics state analysis:

Forces acting on the vehicle can be expressed based on classical dependencies:

$$F_T = F_{AD} + F_{XR} + F_{grade} + F_R + F_{IN} \quad (3.7)$$

Where F_T is the total resistance of the vehicle (N), F_{AD} is the total aerodynamic drag force (N), F_{XR} is the total rolling resistance (N).
The forces of aerodynamic drag of vehicle were determined from the following dependence:

$$F_{AD} = C_d . A . \frac{\rho . V^2}{2} \quad (3.8)$$

where C_d is the vehicle drag coefficient, A is the frontal area of the vehicle (m^2), ρ is the ambient air density $\frac{kg}{m^3}$, and V is the vehicle speed(m/s). And the value of F_{AD} equal zero, because the speed of the vehicle is low and there is no effect of the air on the vehicle.

The rolling resistance of a vehicle can be determined based on:

$$F_{RX} = f_r \ w$$
$$= 0.12 \times 14.715 \quad (3.9)$$
$$= 1.765 \text{ kN}$$

Where w is the weight of the vehicle and f_r is the coefficient of rolling resistance shown in **figure 3.2** and its 0.12 for Graphite (we took the value from the vehicle dynamics).

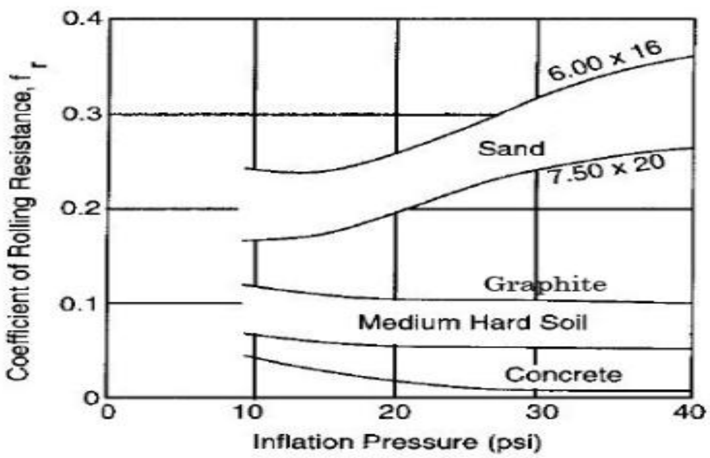


Figure 3.2 coefficient of rolling resistance

The sliding forces acting on the vehicle are based on equation:

$$F_{grade} = m.g.\sin(\theta) \quad (3.10)$$

$$= 0.355 \text{ kN}$$

Inertia resistance forces arising from the acceleration and braking of the vehicle were determined based on:

$$F_{motor} - F_T = m.a \quad (3.11)$$

$$F_{motor} = m.a + F_T$$
$$= 6.112 \text{ kN}$$

Where m is the vehicle mass (kg) and a is the vehicle acceleration $\left(\frac{m}{s^2}\right)$.

3.4 Brake calculations:

- To calculate the declaration for braking system:

$$m \times D_x = - F_{bf} - F_{br} - F_{grade} - F_{rolling} - F_{aerodyn} \quad (3.12)$$

$$F_{grade} = w \times \sin\theta \quad (3.13)$$

$$= 1500 \times 0.2 = 0.3 \text{ kN}$$

$$F_{Rolling} = f \times m \times g, \tag{3.14}$$

$$= 0.12 \times 1500 \times 9.81 = 1.765 \text{ kN}$$

Where f : friction of rolling resistance = 0.12

$$F_{aerodyn} = 0$$

So;

$$D_x = \frac{F_{bf} + F_{br} + F_{grade} + F_{rolling}}{m} \tag{3.15}$$

$$D_x = -7.412 \text{ m/s}^2$$

- To determine maximum brake force on each axle:
  - For the maximum force on front axle:

$$F_{xmf} = \mu \left(W_{fs} + \frac{h}{L}\ \frac{w}{g}\ D_x\right)$$

$$= -16870.568 \text{ N}$$

$$= -16.870 \text{ kN} \tag{3.16}$$

  - For the maximum force on rear axle:

$$F_{xmr} = \mu \left(W_{rs} + \frac{h}{L}\ \frac{w}{g}\ D_x\right)$$

$$= -14339.588 \text{ N}$$

$$= -14.339 \text{ kN} \tag{3.17}$$

Where:

F_{xmf} : Maximum brake force on front axle.

F_{xmr} : Maximum brake force on rear axle.

a_x : Acceleration of the vehicle.

μ : Coefficient of friction between rubber and graphite (μ = 0.85 calculated in the lab shown in figure 3.3).

Figure 3.3 lab test friction experiment

- To Determine stopping distance(SSD):

$$SSD = \frac{v^2}{2D_x} + (v \times t_r) \tag{3.18}$$

Where:

t_r : The reaction time = 0.3 (From vehicle dynamics).

$$SSD = \frac{8.33^2}{7.68} + (8.333 \times 0.3)$$

$$= 9.956 \text{ m}$$

- Braking energy:

- The energy absorbed by the brake system is the kinetic energy of motion.

$$E = \frac{M}{2} \times (V_i^2 - V_f^2) \tag{3.19}$$

$$E = 40.306 \text{ kJ}$$

3.5 Steering calculation:

Figure 3.4 shows the bicycle model of the vehicle (From vehicle dynamics book), in our project we will use steering system calculation to determine suitable steering which we can used to keep stability of the vehicle while steering and cornering.

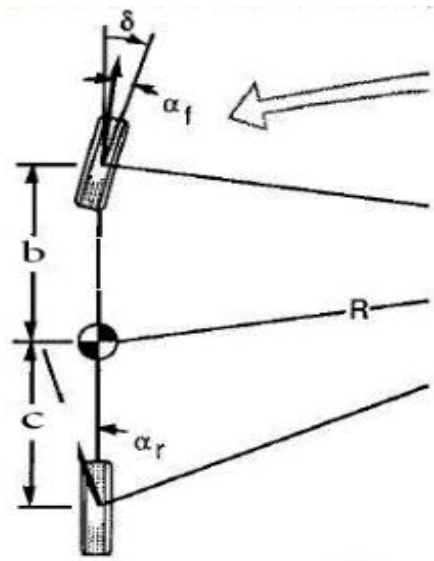


Figure 3.4 bicycle mode of the vehicle

$$\sum F_y = F_{yf} + F_{yr} = \frac{\mathrm{m\,v^2}}{R} \tag{3.20}$$

$$F_{yf} = \frac{\mathrm{c}}{b} F_{yr} \quad , \quad (1+\frac{\mathrm{c}}{b}) = \frac{\mathrm{b}}{b} + \frac{c}{b} = \frac{\mathrm{L}}{b}$$

So;

$$F_{yr} = \frac{\mathrm{b}}{L}\,\frac{\mathrm{m\,v^2}}{R}, F_{yf} = \frac{\mathrm{b}}{L}\,\frac{\mathrm{m\,v^2}}{R}$$

$$\alpha_f = \frac{F_{yf}}{C_{\alpha f}} \quad , \quad \alpha_r = \frac{F_{yr}}{C_{\alpha r}} \tag{3.21}$$

So;

$$\alpha_f = \frac{\mathrm{m\,b\,v^2}}{R\,\mathrm{L\,C}_{\alpha f}} \quad , \quad \alpha_r = \frac{\mathrm{m\,b\,v^2}}{R\,\mathrm{L\,C}_{\alpha r}}$$

$$\delta = \frac{\mathrm{L}}{R} + \alpha_f - \alpha_r$$

$$\delta = \frac{L}{R} + \left(\frac{c}{C_{\alpha f}} - \frac{b}{C_{\alpha r}} \right) \frac{m\,v^2}{R\,L}$$

$$\delta = \frac{1.283}{2.74} + \left(\frac{0.51452}{1.0231} - \frac{0.73955}{0.845162} \right) \frac{(1450) \times (8.33)^2}{(1.293) \times (2.74)}$$

$$\delta = 10.6578 \text{ deg}$$

Where:

m: Mass of vehicle

v: Vehicle speed

L: Wheel base

R: Radius of curvature

c: Distance between rear axle and center of gravity

b: Distance between front axle and center of gravity

$C_{\alpha f}$: Front cornering stiffness = 1.0231 kN/deg

$C_{\alpha r}$: Rear cornering stiffness = 0.845162 kN/deg

δ : Steering Angle

3.6 Pump calculations:

First: Total head

$$H = H_s + H_f + H_p \quad (3.22)$$

H : Total head (m)

H_s : Static head from high water in the tank to the last point that can fluid reach(m)

H_f : Friction head in pipes (m)

H_p : Head from flow pressure in the end of the nozzle

H_s = $h_{Building}$ - $h_{\text{water in the tank}}$ = 12-1.2 = 10.8 m

$$H_f = \textit{pipe length} \times \textit{friction coef} + \textit{pipe length} \times \textit{fitting coef} \quad (3.23)$$

In eqn3.23 finding friction head by find the sum of multiplied pipe lengths with coefficient of friction and pipe lengths with coefficient of fitting by using **table 1** and **table2** in APPINEX and applying lengths and diameters and dividing the length to 0.3 to convert to feet, the output is as follows:

$H_f = H_{f1} + H_{f2}$

$$H_f = (1/0.3) \times 0.26 + 0.3 \times (1/0.3) + (25/0.3) \times 0.48 + 0.3\ (25/0.3)$$

=66.866 ft

= 20.38 m

P_{pump} = 8.5 bar = 85 m head

$H_{pump} = 87\ m$

H = 13.7 + 20.04 + 87 = 120.84 m

Second : Pump power:

calculate of the ability of the pump (power) according to the following law:

$$P = Q \times H \times g \times \rho \times \zeta \quad (3.24)$$

$P = 0.0016 \times 120.84 \times 9.8 \times 1000 \times 0.7$

P= 1.32 KW

P= 1.32 x 1000 / 746 = 1.78 hp.

Where:

Q: flow rate(m^3 / s)

H: total head(m)

ρ: Intensity of fluid (N/m^2)

g: gravity (m/s^2)

ζ: Efficiency

Figure3.5 shows the components of the system and shows the point where there is change in the flow of the water , the main points where the procure calculation have been done is :

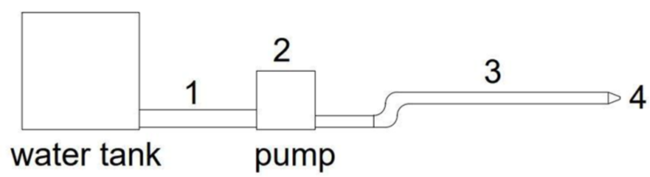


Figure 3.5 components of the hydraulic system

1 –The flowed between the water tank and the pump

2 - Water Pump

3 - The fluid between pump and nozzle

4 – Nozzle

pressure and velocity calculation :

At point 4 :

Q = 100 L/s

D 3 = 25 mm

D 4 = 2 mm

V4 = 5.38

P_4 = 0 bar

Velocity in point 3:

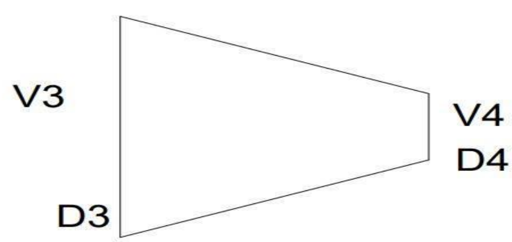


Figure 3.6 Flow rate of nozzle

Velocity at point 4 :figure 3.6 shows the flow rate of nozzle

$$V_3 = Q_1/A_3$$
$$A_3 = \pi \times d^2/4$$
$$=(\pi \times 0.025)/4$$
$$A_3 = 4.9 \times 10.^{-4} m^2 \quad (3.25)$$

So;

$$V_3 = 100/(6000 \times 4.9 \times 10^4)$$
$$V_3 = 3.4 \text{ m/s}$$

pressure in point 3 : We obtain pressure at point 3 by applying the Bernoulli equation as follows :

$$P_3 / \rho X g + V^2_3 / 2 X g = P_4 / \rho X g + V^2_4 / 2 X g \qquad (3.26)$$

P_3 = 8.7 bar

Velocity at point 1:

Q = V × A

$$V = \frac{Q}{A} \qquad (3.27)$$

V_1 = ((100 L /min) x (1 m^3 / 1000 L) x (1 min / 60 sec)) / 11.04 x 10^{-4}

V_1 = 0.00166 / 11.04 x 10^{-4} = 2.21 m /s

$$A1 = \frac{\pi}{4} \times d1^2 \qquad (3.28)$$

A1 = π x $(0.037)^2$ = 11.04 x 10^{-4} m^2

Where:

A: space segment of the pipeline

V: Speed of the fluid in the tube

Pressure at point 1 :

The pressure can be calculated at the point 1, the hydrostatic pressure is the pressure exerted by the fluid in the ballast suit because of the strength of gravitational pressure can be calculated according to the following equation:

$$P_1 = h \times \rho \times g \qquad (3.29)$$

P_1= 0.8 * 1000 * 9.8

P_1 = 7.840 KPa

= 0.0784 bar

Where:

h : the rise of fluid in the reservoir

4. Chapter four: Selection components

4.1 Overview.

4.2 motor.

4.3 Microcontroller.

4.4 Chassis.

4.5 Brake.

4.6 Steering.

4.7 Suspension.

4.8 Tires.

4.9 Batteries

4.10 Firefighting unit.

4.11 Screen.

4.12 Sensors and switches.

4.1 Overview:

After defining the problem, needs, the conceptual design for the project and project requirements in the previous chapters, now this chapter explains the components of the system, principle of operation, specification and usage. All components should be well integrated into the system.

4.2 Motors:

4.2.1 Brushless DC Motor (BLDC):

Figure 4.1 shows a Brushless DC (BLDC) motor is a Permanent Magnet Synchronous Motor with unique back EMF waveform brushless DC motor does not directly operate of a DC voltage source. However, the basic principle of operation is similar to a DC motor.

A Brushless DC Motor has:

- A rotor with permanent magnets and a stator with windings.
- A BLDC motor is essentially a DC motor turned inside out.
- Brushes and commutator have been eliminated and the windings are connected to the control electronics.
- Control electronics replace the function of the commutator and energize the proper winding.
- Windings are energized in a pattern which rotates around the stator.
- The energized stator winding leads the rotor magnet and switches just as the rotor aligns with the stator.[8]

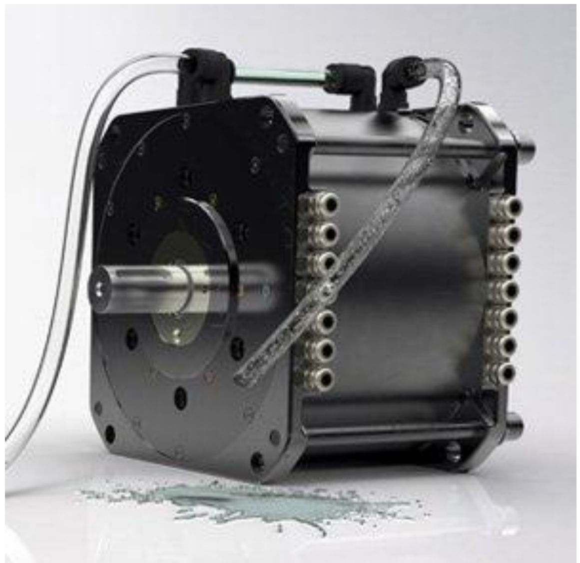


Figure 4.1 BLDC Motor

Specification:

- Model: HPM-20KW - High Power BLDC Motor
- Voltage:72V/96V/120V
- Voltages: 72V-120Vdc
- Rated power: 20-25KW
- Peak power: 50KW
- Speed: 3200-6000rpm
- Rated torque: 80 Nm
- Peak torque: 160 Nm
- Efficiency: >90%
- Dimensions: 30x30x25cm
- Weight: 39kgs
- Cooling: liquid cooling
- Number of Poles: 8

4.2.2 BLDC Driver:

3-Phase Brushless DC Sinusoidal Motor Driver

Figure 4.2 BLDC driver

Specification:

- Long working life (>20,000 hours)
- Low noise, high torque
- Excellent performance characteristics
- High efficiency (>90%)
- High reliability
- Rated voltage : 48V-120 VDC
- Rated power : 20KW
- Rated speed: 3200-6000 rpm
- Steeples speed control, dual-direction

4.3 Microcontroller:

Arduino shown in **figure 4.3** is an open-source microcontroller. Hence one can easily program it in (C++). Arduino provides high speed transfer of information to the motors. It is also used to control the system parts which includes sensors, swiches and the motors movement and speed.

Figure 4.3 Arduino microcontroller

Arduino specifications:

- Operating voltage: 5 V
- Digital I/O Pins: 14 (6 provide PWM)
- Analog input pins: 6
- DC current per I/O pins: 40 mA
- Dc current for 3.3 V pin: 50 mA
- Flash memory: 32 KB
- SRAM:2 KB
- Clock speed: 16 MHz

4.4 Chassis:

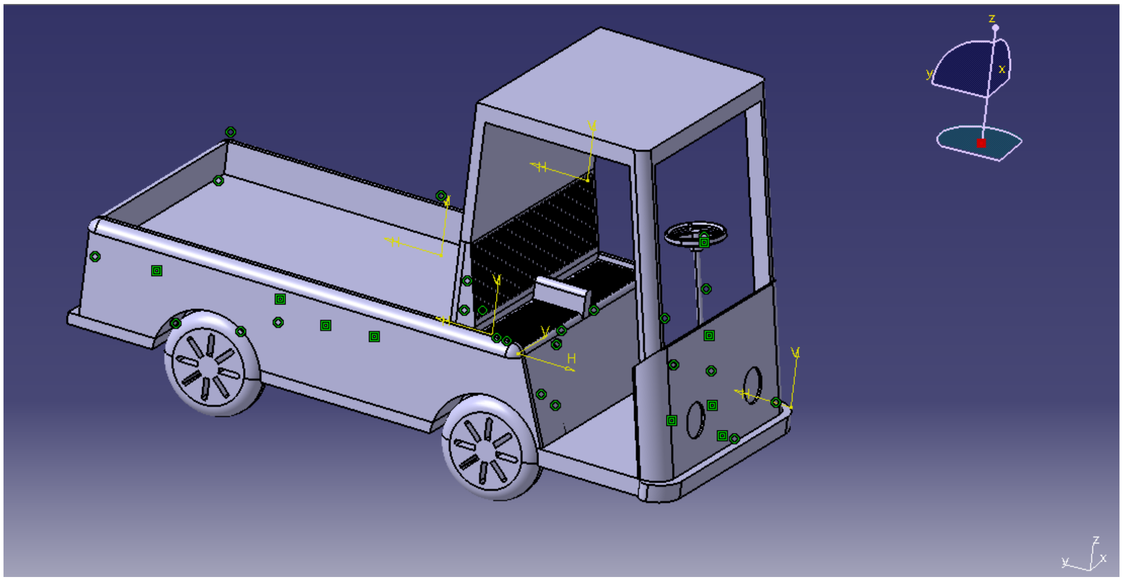


Figure 4.4 Chassis

Chassis shows in **figure 4.4**. It`s Unitized Fully Welded 16 Gauge Diamond Plate Steel.

4.5 Brake

In this project we used brake by wire system. Brake-by-wire is a frontier technology that will allow many braking functions to switch to electronic actuation. Its deployment will lead to more effective and safe braking systems, elimination of hydraulic technology, release of space and reduction of maintenance shown in **figure 4.5**.[9]

Figure 4.5 brake by wire

- Brake by wire components shown in **figures 4.6**

1) Electro-Mechanical Caliper:

•Supply Voltage: 12 V
•Max current: 15 A

Figure 4.6 caliper which operate by electric motor

2) Brake by Wire Brake Pedal :

•Position sensors: 3
•Force feedback passive

Figure 4.7 Brake by Wire Brake Pedal

3) Control ECU :

•On board BLDC driver (25A @ 12 Volt)
•Time Triggered Network

Figure 4.8 ECU controller

4.6 Suspension

Figure 4.9 shows the suspension .Suspension is the system of tires, tire air, springs, shock absorbers ad linkages that connects a vehicle to its wheels and allows relative motion between the two.

Figure 4.9 suspension

4.7 Steering

Figure 4.10 shows electric power steering (EPS), This system uses an electric motor to assist the driver while steering. Sensor detect the position and torque of the steering column, and a computer module applies assistive torque via the motor, which connects to either the steering gear or steering column. This allows varying amounts of assistance to be applied depending on driving conditions. It work by taking the signal from the torque sensor and analyze the data by the control unit and give the stepper motor the direction of turning and the motor turn the wheel by a ratio of gear box (1:12).

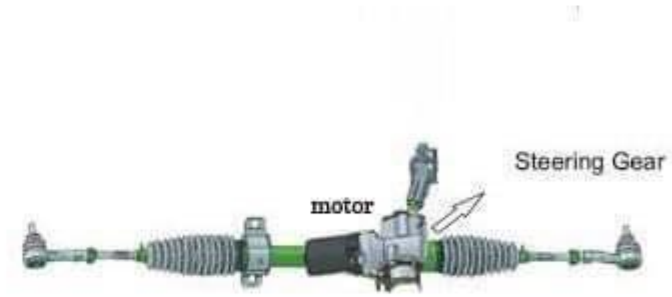


Figure 4.10 steering

4.8 Tires

Figure 4.11 shows the tire that used in the project.

Figure 4.11 tires

- We used tires with outer diameter equal 45.72 cm (when inflated), with section width equal 14.732 cm.
- Maximum load of these tires is 487.61 kg at 6.89 bars.
- Great for off-road and agricultural use.

4.9 Batteries

Lithium polymer battery modules in parallel or in series, can be used in electric ve hicle, E-bike, UPS, energy storage system, telecommunication base station, E-scooter, Etools, unmanned airplane, golf cart, fork lift, cleaning car, electric wheelchair, etc which shown in **figure 4.12**.

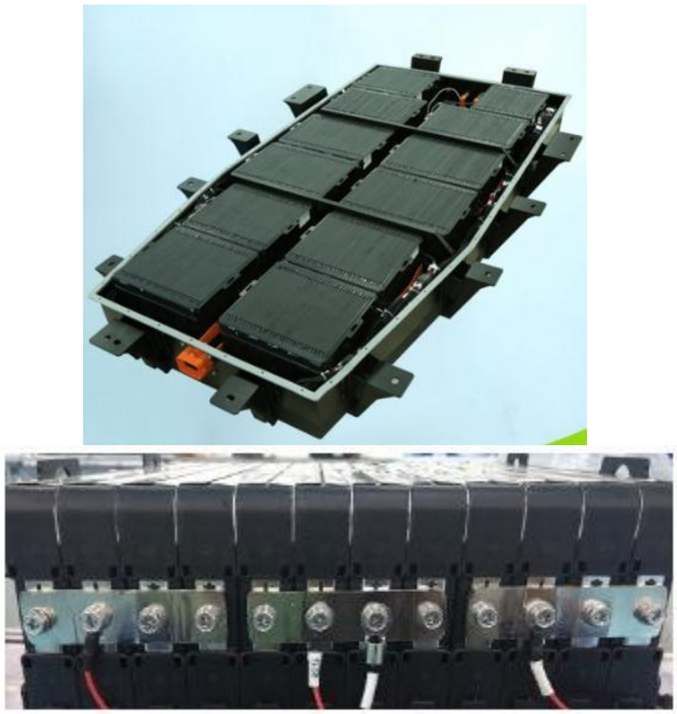


Figure 4.12 batteries

- Model NO.: Lithium Battery.
- Capacity: 12.5ah-200ah
- Weight: 1-200kg
- Voltage: 3.2V-400V(Increase Voltage in Series)
- Warranty: 2years
- Protection: PCB/PCM/BMS
- Case: Blue Film or Metal Case
- Company Type: Certificated Factory

4.10 Fire fighting unit:

4.10.1 Water Tank:

Figure 4.13 shows a Tank containing a liquid, a mixture of water 94-96.5%, and the foam by 3.5-6% of the liquid in the tank and be connected to the fire engine and be on wheels to be easy to drag with the fire engine, and must contain a reservoir of liquid quantity of 0.5 m^3 [11]

Figure 4.13 tank

4.10.2 Water Pump:

Pump is a tool used to move the fluids within the pipe system and raise the pressure of the liquid, a machine that uses multiple means to transfer energy to increase the working fluid pressure.[6]

Selecting the pump:

at the beginning of the process of selecting the pump, the required flow rate (Q) and the head(H) must be determined .

This is the quantity of the most important quantities to assist in the selection of the pump and which is expected to work well in the system.[7]

Figure 4.14 shows an electric pump was used the complete design of the car so it have to work with electricity.

Figure 4.14 Electric centrifugal pump

Pump specification :

- Model :JETSON HYDROMINI
- Flow: 5 m^3/h (176.5733 ft^3/h)
- Pressure: 8.7 bar (126.18 psi)
- Head: 87 m

4.10.3 Nozzle

Figure 4.15 shows a two-port nozzle that converts low-speed and high-pressure fluid into high-speed fluid and low pressure. The flow is the result of multiplying the velocity in the area. Since the relation between speed and space is inverse, when the area of the section decreases, the velocity increases.

Figure 4.15 Two port nozzle

4.10.4 generator

Figure 4.16 shows the power source that gives the pump power to work , the generator workes at 220 v

Figure 4.16 Generator

4.11 Sensors and switches

4.11.1.1 SST Liquid Level Sensor

Figure 4.16 shows an optical liquid level sensor, this sensor provides single point liquid detection via a TTL compatible push/pull output. An infra-red LED and phototransistor accurately positioned at the base of the sensing tip ensure good optical coupling between the two when the sensor is in air. When the sensing tip is immersed in liquid, the infra-red light escapes from the cone, causing a change in the amount of light present at the phototransistor, which makes the output change state , in this project it will be used to detect the water in the tank.

Figure 4.17 SST Sensor

Specification:

- Supply Voltage: + 4.5Vdc to +15.4Vdc
- Output Current: 100mA
- Temperature Range: -25 to +80^{0}C
- Polysulfone Housing Tip
- M12 threaded connector (mounted from outside)

4.11.2 On/Off Switch

Figure 4.17 shows the switch that have been used in the system. Switch is an electrical component that can "make" or "break" an electrical circuit, interrupting the current or diverting it from one conductor to another

Figure 4.18 ON/OFF Switch

4.11.3 Limit switch

In this work the limit switch which is shown in **figure4.18**is used to detect the existing of the driver sitting on the driver seat, the vehicle cannot be drive without sitting on the seat**.**

Figure Error! Use the Home tab to apply عنوان 1 to the text that you want to appear here.**.18 limit switch**

4.12 Charger

Figure 4.21 shows the charger for our system .

4. 19 charger

Charger specifications:

- Size: 230*135*70mm
- Weight: 3.5kg
- Input Voltage: 85VAC-250VAC
- Max Wattage: 900W
- Ambient Temperature: -20 °C To +50°C
- Protection: SCP,OVP,OCP,OTP
- Warranty: 18 Months

5. Chapter five: Control and electrical design

5.1. Overview.

5.2. Mathematical model.

5.3. Electric design.

5.1 Overview:

Previous chapters explained the purpose of using motor and Arduino , this section will explain the control modeling of the system and the schematic diagram of connection between electrical components, and explain the relationship between electrical components .

5.2 Mathematical model:

It is important to consider that there is a one-to-one correspondence between w_r and w_l and the actual velocity inputs and of the right and left wheel, respectively, as follow

$$v = \frac{R(l_R \omega_R + l_L \omega_L)}{l_R + l_L}$$

$$\omega = \frac{R(-\omega_L + \omega_R)}{l_R + l_L} \quad (5.1)$$

Where R is the radius of the wheels and l_L and L_R is the distance between left and right and the vehicle center. v and ω are the linear velocity and angular velocity of the vehicle.[9]

5.2.1 Mathematical model:

Figure 5.1 described vehicle which is driven by two DC motors with common voltage source and independent control of each motor. Motors are connected with driving wheels . Loses in motor and also in gear-box are proportional to rotation speed. Chassis is equipped with caster wheel with no influence to chassis motion (its influence is included in resistance coefficients acting against motion).

The dynamic part of the model consists from four differential equations describing the behavior of both motors, two differential equations describing the dynamics of the chassis and two algebraic equations with dependency of linear and angular chassis speed on the peripheral speeds of the driving wheels. We can find in these equations eight state variables describing the current state of the left motor (current i_L, angular velocity of the rotor ω_L, loading moment M_L) and the right motor (current i_R, angular velocity of the rotor ω_R, loading moment M_R) and the movement of the chassis (linear speed vB and angular velocity of rotation ω_B). [9]

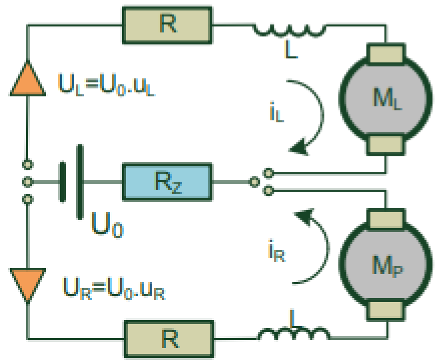


Figure 5.1 DC motor wiring

Eqn 5.1 describes motor behavior through balancing of voltages (Kirhoff's laws)

$$U_R + U_L = U_0 - U_M$$

$$Ri + L\frac{di}{dt} = U_0 - K\omega \qquad (5.2)$$

where
R [Ω] is motor winding resistivity,
L [H] is motor inductance,
K [kg.m2.s-2.A-1] is electromotor constant,
U_0 [V] is source voltage,
ω[rad.s-1] is rotor angular velocity and
i[A] is current flowing through winding.

Eqn5.3 is balance of moments (electric energy)-moment of inertia *M*s, rotation resistance proportional to rotation speed (mechanical loses) *M*o, load moment of the motor *M*x and moment *M*M caused by magnetic field which is proportional to current

$$M_s + M_0 + M_X = M_M$$

$$J\frac{d\omega}{dt} + k_r\omega + M_X = Ki \qquad (5.3)$$

where
J [kg.m2] is moment of inertia,
kr[kg.m2.s-1] is coefficient of rotation resistance and
*M*x [kg.m2.s-2] is load moment.

Chassis dynamics is defined with vector of translation speed v_B acting in selected chassis point and with rotation of this vector with angular velocity ω_B (constant for all chassis points). It is possible to calculate trajectory of arbitrary chassis point from these variables. Point B for which the equations are derived is centre of gravity normal projection to join between wheels – see Fig. 3. This leads according to authors to simplest set of equation for whole model. We consider general centre of gravity T position – usually it is placed to centre of the join between wheels.

We consider forces balances as starting equations. It is possible to replace two forces F_L and F_R acting to chassis in left (L) and right (R) wheel ground contact points with one force F_B and torsion moment M_B acting in point B. Chassis is characterized with semi-diameter of the driving wheels r, total weight m, moment of inertia J_T with respect to centre of gravity located with parameters l_T, l_L, l_P.[9]

By the balance of forces causing linear motion we will consider except of forces F_L, F_R caused by drives and inertial force F_S also resistance force F_O proportional to speed v_B. The balance of forces influencing linear motion is

$$F_L + F_P + F_0 + F_S = 0$$

$$\frac{M_{GL}}{r} + \frac{M_{GR}}{r} - k_v v_B - m\frac{dv_B}{dt} = 0 \qquad (5.4)$$

where
m [kg] is vehicle mass,
kv[kg.s-1] is resistance coefficient against linear motion
M_{GL} [kg.m^2.s^{-2}] is moment of the left drive,
M_{GR} [kg.m^2.s^{-2}] is moment of the right drive,
v_B [m.s^{-1}] is linear motion speed and
r[m] is semi-diameter of the wheels.[9]

If we introduce substitution of the parameters according to following formulas
Assuming $l_L=l_R$

$$a_L = a_R = k_r + \frac{k_v l_R r^2}{l_L + l_R} \qquad (5.5)$$

$$b_L = b_R = J + \frac{m l_R r^2}{l_L + l_R} \qquad (5.6)$$

$$c_L = c_R = k_r l_L + \frac{k_v r^2}{l_L + l_R} \qquad (5.7)$$

$$d_L = d_R = J l_L + \frac{J_B r^2}{l_L + l_R} \qquad (5.8)$$

$$\frac{di_L}{dt} = \frac{u_L U_0 - k.\omega_L - (R + R_z) i_L - R_z i_R}{L} \qquad (5.9)$$

$$\frac{di_R}{dt} = \frac{u_L U_0 - k.\omega_L - (R + R_z) i_L - R_z i_L}{L} \qquad (5.10)$$

The reduced linear part of the model consists from set of equations(**eqn5.11** and **eqn5.12**)

$$\frac{d\omega_L}{dt} = \frac{K(d_R + b_R l_L)}{b_L d_R + b_L d_L} i_L + \frac{K(d_L - b_L l_L)}{b_L d_R + b_L d_L} i_R - \frac{d_R a_L + b_R c_L}{b_L d_R + b_L d_L}\omega_l - \frac{d_R a_R - b_R l_R}{b_L d_R + b_L d_L}\omega_R \qquad (5.11)$$

$$\frac{d\omega_R}{dt} = \frac{K(\mathrm{d}_L - \mathrm{b}_L \mathrm{l}_L)}{b_L d_R + b_L d_L} i_L + \frac{K(\mathrm{d}_L + \mathrm{b}_L \mathrm{l}_R)}{b_L d_R + b_L d_L} i_R - \frac{\mathrm{d}_L a_L - \mathrm{b}_L c_L}{b_L d_R + b_L d_L} \omega_l - \frac{\mathrm{d}_L \mathrm{a}_R - \mathrm{b}_L \mathrm{l}_R)}{b_L d_R + b_L d_L} \omega_R \tag{5.12}$$

The output variables are given by algebraic **eqn5. 12**. It is possible to write reduced linear part of the model as standard state-space model in matrix form as

$$\frac{dx}{dt} = Ax + Bu$$

$$y = Cx \tag{5.13}$$

$$x = \begin{bmatrix} i_L \\ i_R \\ \omega_L \\ \omega_R \end{bmatrix}; u = \begin{bmatrix} u_L \\ u_R \end{bmatrix}; y = \begin{bmatrix} \omega_L \\ \omega_R \end{bmatrix}$$

5.3 Electric design:

5.3.1 Motors:

Figure 5.2 shows the connection for each motor with the battery and microcontroller. The input for the controller is the steering angle and the feedback of the sensors for each motor.

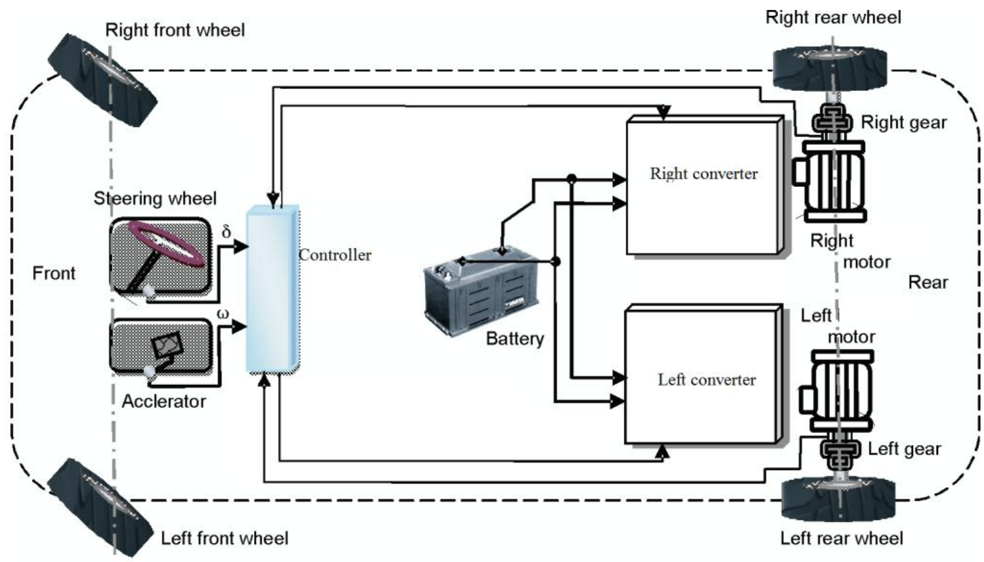


Figure 5.2 Electric design

Figure 5.3 shows motor driver connection and sensors with motors , the driver convert the batteries signal into sinusoidal to motor.

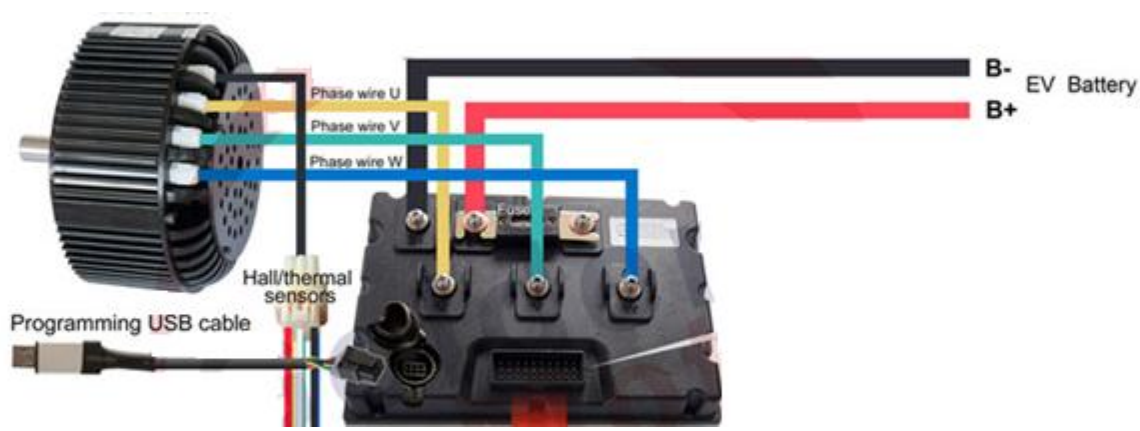


Figure 5.3 Motor driver connection

5.3.2 Brake by wire:

The **figure 5.4** show the schematic diagram of the brake module.

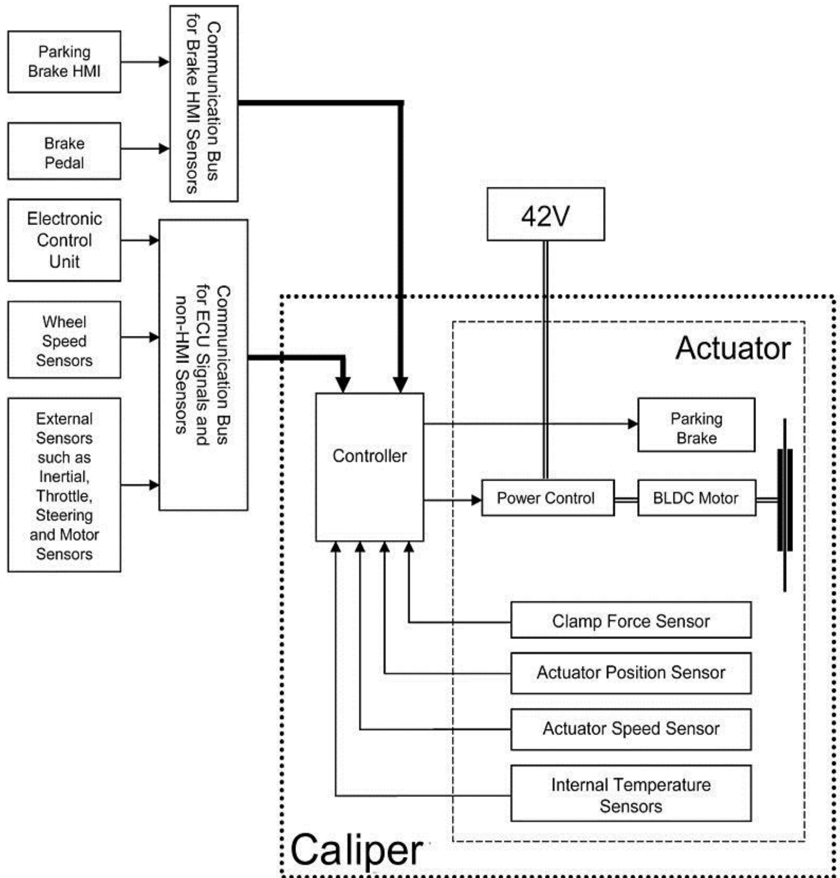


Figure 5.4 Brake By Wire Connection

5.3.3 Steering:

The **figure 5.5** shows the schematic diagram of the steering module.

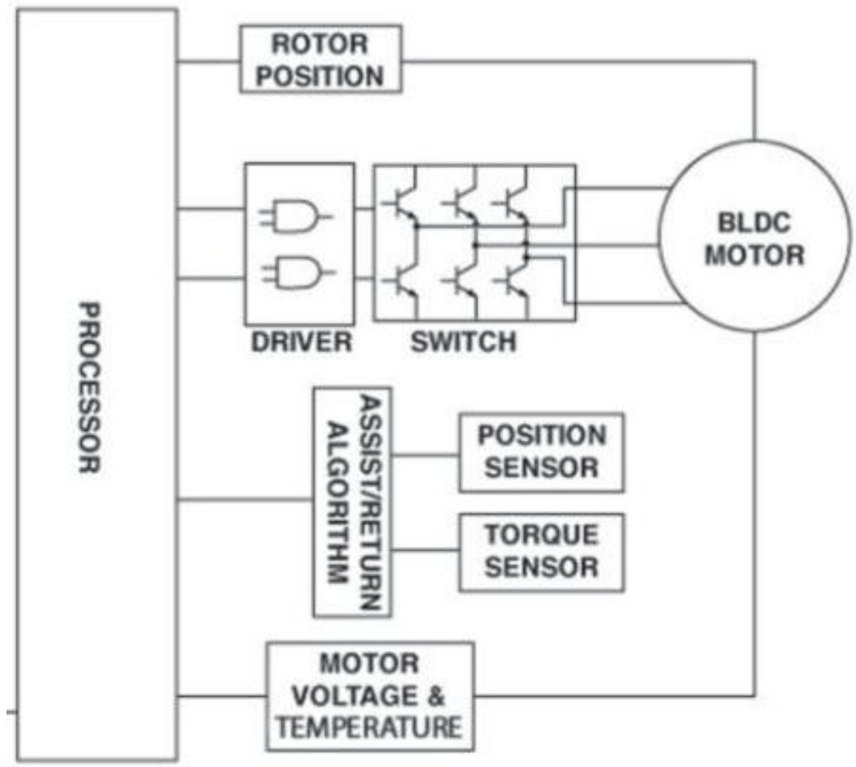


Figure 5.5 Steering Unit Connection

The steering unit have an encoder with the motor and connect to arduino and sent it the position of the steering it give a (+) sign degree when the steering rotates cw ,and a (-) sine degree when the steering rotate ccw .

5.3.4 Limit switch:

The limit switch sensor gives a digital signal, so it will be tied with pin in Arduino, the digital signal give the system a high signal if there is a driver sit on the seat and a low signal if nobody sitting on the seat its connection shown in **figure5.6.**

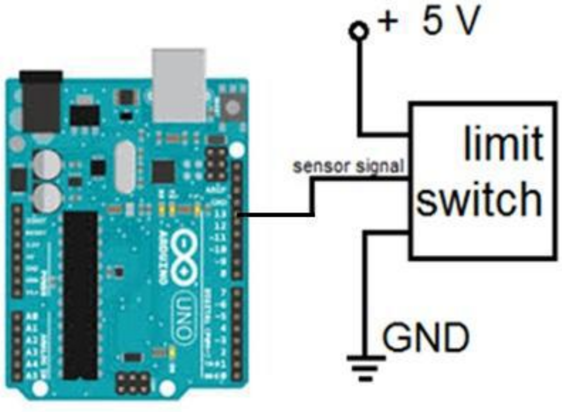


Figure 5.6 limit switch connection with arduino

5.3.5 SST Liquid Level Sensor:

This sensor send the level of the water in the tank by calculate length of laser out of the sensor. The microcontroller divide it by the height of tank to know the level of water. **figure 5.7** shows level sensor connection with arduino it connect with analog pin.

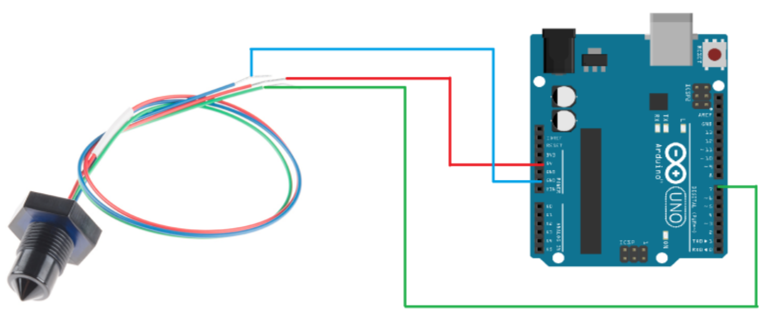


Figure 5.7 SST sensor connection with arduino

6. Chapter six : prototype

6.1 Overview.

6.2 Project Implementation.

6.3 Calculations.

6.4 Controller Design.

6.5 Electric connection

6.6 Budget .

6.7 system justification and calibration

6.8 Results.

6.1.Overview:

This chapter presents, a general description of the system prototyping, The final validation of the system is usually performed on the prototype. which describe the real process which can be operated together with the simulated control by using hardware other than the final hardware.

This Prototype build with Arduino platform and DC motors, Interface them together and use android application as an input device to control the speed through Bluetooth technology.

Specific objectives of this prototype are:

i. To design an electric deferential by using microcontroller.

ii. To implement PID controller to control speed of DC motors.

iii. To analyze output in term of speed of DC motor incorporating rotary encoder.

6.1.1. DC Motors

Permanent magnet brushed DC motors are the most common. These motors use permanent magnets to produce the stator field. They are generally used in applications needing fractional horsepower such as; Toys, Radio Control hobby applications, electric slot cars, appliances, etc. It is more cost effective to use permanent magnets than wound stators because they are cheaper to manufacture. The torque from a permanent magnet brushed DC motor is limited by its stator field, which gives it good low end (low speed) torque and a limited high end (high speed) torque. The permanent magnet brushed DC motor responds very quickly to changes in voltage. This is due to its constant stator field, thus giving it good speed control capabilities

6.2.Prototype implementation:

The first step when build a prototype is to document it with an accurate representation showing the relevant detail. to create a solid model or schematic representation of the part or assembly that were be planned to build to test it .

For this prototype a kids electric car have bought and required adjustment were be done for it to smellier to the designed project .

6.2.1. Hardware

The main shape of the prototype and its dimension shown in **Figure 6.1.**

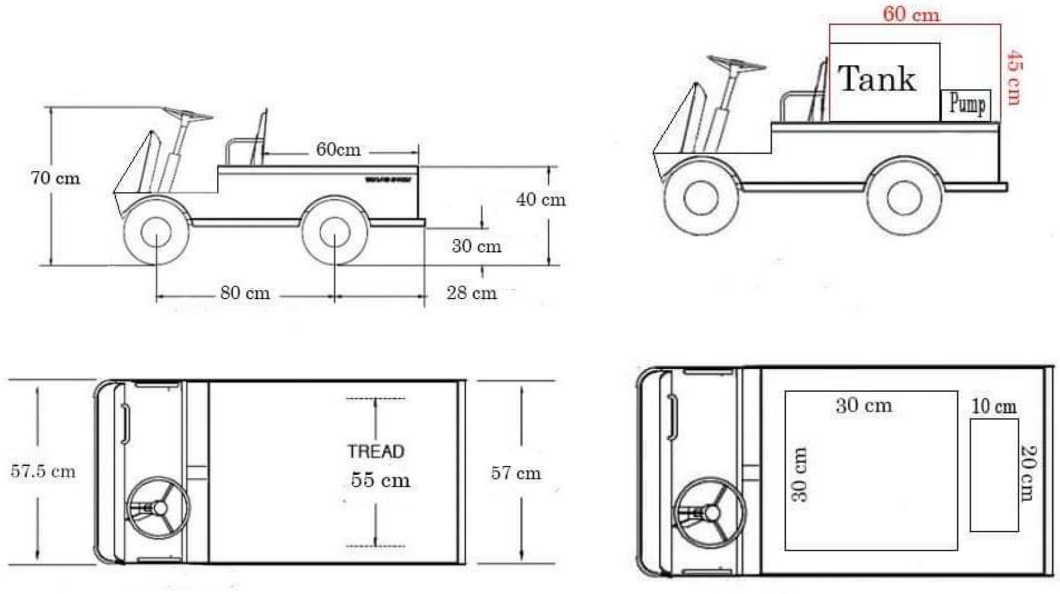


Figure 6.1the dimension and design of prototype

And the designed prototype on CATIA program shown in figure6.2 and figure 6.3

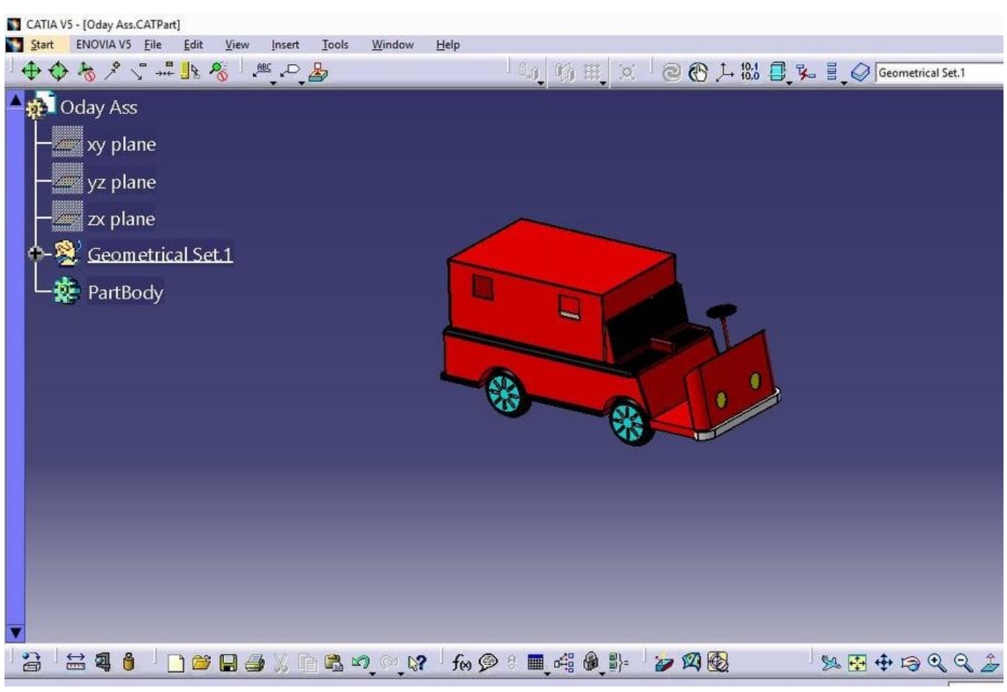


Figure 6.2 CATIA drowing1

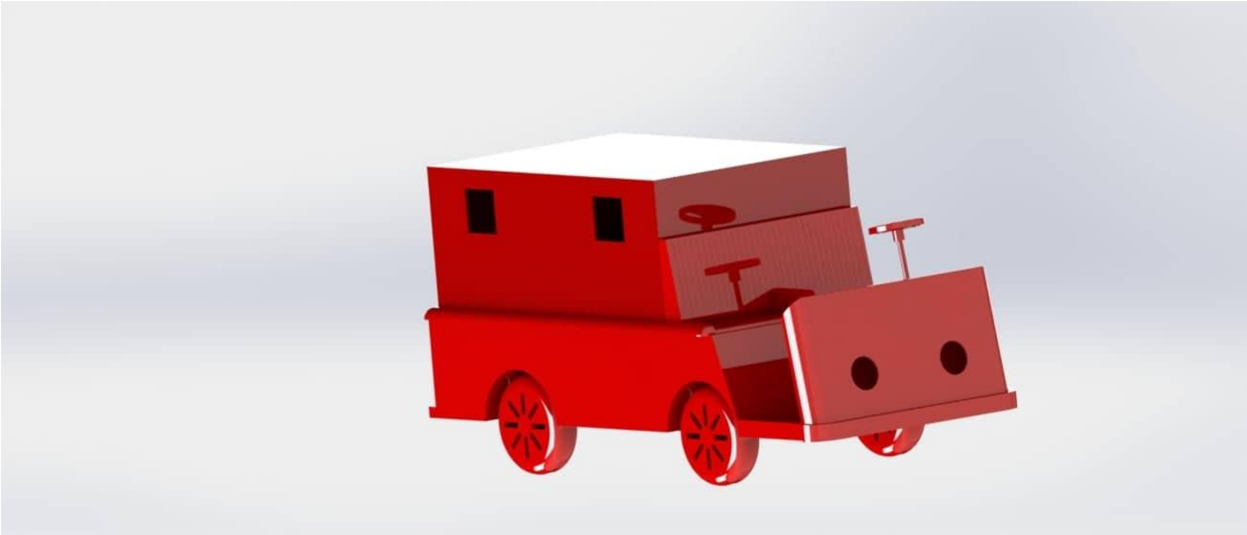


Figure 6.3 CATIA drowing2

As mentioned before the main objective of this project is to build small firefighting and design an electric differential, in order to apply this objective, we chose the following parts:

1) **Vehicle : Kids electric ride PlayActive**
   To build this prototype there is some specifications and constraints to be suitable for the project, when build a prototype the most similar and suitable toy vehicle was the Kids electric ride PlayActive which shown in **figure 6.4**, and by do some adjustment to its components to be as the project require.

Specifications and features :

- Rechargeable Battery: 12V 7Ah
- Charge time: 6-10 hours (Full Charge)
- Drive time: Approx 1 hour (Full Charge)
- Foot Accelerator: Auto Brake on Release
- Motor Model: 570#/15000RPM x 2
- Motor: 45W x 2
- Top Speed: 3-5km/h
- Age Group: 3 - 8 years old
- Max User Weight: 30kg
- Single Seat: Width 16cm
- Carton size: 113L x 64W x 46H (cm)
- G.W./N.W.: 30/25kgs
- Warranty: 12 Months
- Certificate: EN71, EN61125 EU toy safety standard

- Approx Dimensions: 116cm (L), 64cm (W), 80cm (H)
- EVA Soft Rubber Tires
- Charger (12V 1000mA)

The PlayActive vehicle shown below in **figure6.4**[11]

Figure 6.4 Kids electric ride PlayActive

After do the required change on the vehicle the final structure shown in **figure6.5**

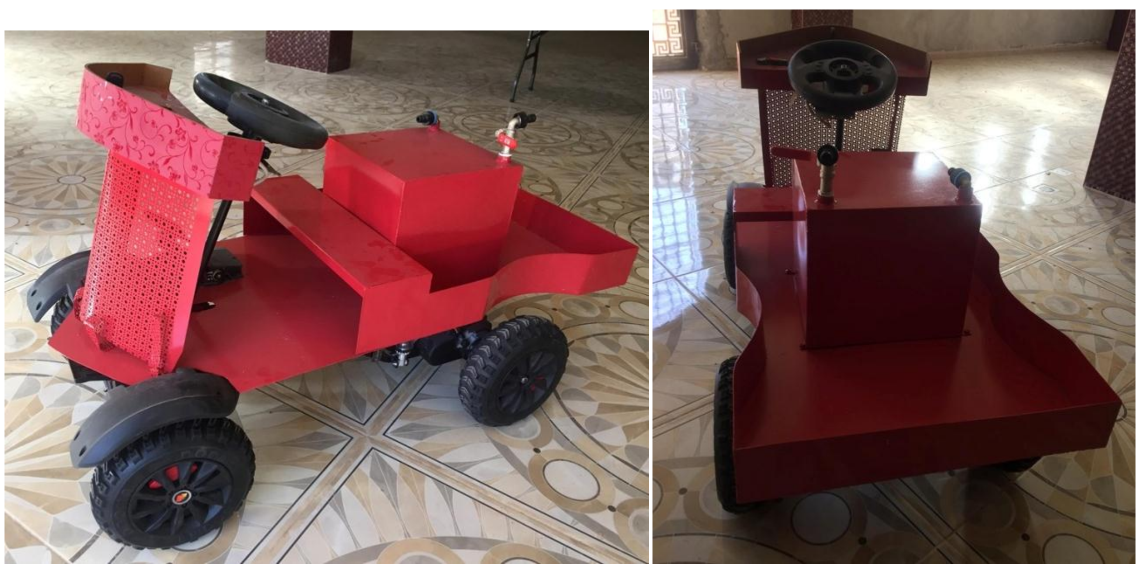


Figure 6.5 the prototype real structure

2) Controller : Arduino MEGA

The **Arduino Mega 2560** shown in **figure6.6** is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The MEGA 2560 is designed for more complex projects. With 54 digital I/O pins, 16 analog inputs and a larger space for your sketch it is the recommended board for 3D printers and robotics projects, the need of this type is because of the required interrupt pins (more than one pin) compared with UNO.

Figure 6.6 Arduino MEGA

SPEASIFICATION :

- Operating Voltage 5V
- Input Voltage (recommended) 7-12V
- Input Voltage (limit) 6-20V
- Digital I/O Pins 54 (of which 15 provide PWM output)
- Analog Input Pins 16
- DC Current per I/O Pin 20 mA
- DC Current for 3.3V Pin 50 mA
- Flash Memory 256 KB of which 8 KB used by bootloader
- SRAM 8 KB
- EEPROM 4 KB
- Clock Speed 16 MHz
- LED_BUILTIN 13
- Length 101.52 mm
- Width 53.3 mm
- Weight 37 g

3) Motor drivers: IB-2 DC MOTOR DRIVER

figure 6.7 shows IB-2 DC MOTOR DRIVER, This driver uses two high current half bridge for motor drive applications. Interfacing to a microcontroller is made easy using this driver which features current sensing, slew rate adjustment and protection against over temperature, overvoltage, under voltage, Over current and short circuit. This small size driver provides a cost optimized solution for protected high current PWM motor drives, this driver good for prototype because it handle current to 30A.

Figure 6.7 IB-2 DC MOTOR DRIVER

features:

- Operating Voltage 5 to 27V (B+)
- Control motor speed by PWM up to 25 kHz.
- Motor forward and backward motion control
- Switched mode current limitation! Or reduced power dissipation.
- Current limitation level of 30A Current sense capability
- Over temperature shut down Over voltage lock out.
- Size:4*5*1.2cm
- Weight:66 gm.

.

4) BLUETOOTH : HC-05 BLUETOOTH MODULE

As mentioned in the objective of the prototype, to make this prototype simulates and as much as similar to the real vehicle, a phone application used as graphical user interface and to make this work a Bluetooth need to connect the application with the microcontroller. **Figure 6.8** shows HC-05 BLUETOOTH MODULE which use for communication between ARDUINO and ANDROID APP by send the construction of user when activate the control of electric differential to ARDUINO .

Figure 6.8 HC-05 BLUETOOTH MODULE

Specification :

- Frequency: 2.4GHz ISM band
- Modulation: GFSK(Gaussian Frequency Shift Keying)
- Emission power: ≤4dBm, Class 2
- Sensitivity: ≤-84dBm at 0.1% BER
- Speed: Asynchronous: 2.1Mbps(Max) / 160 kbps, Synchronous: 1Mbps/1Mbps
- Security: Authentication and encryption
- Profiles: Bluetooth serial port
- Power supply: 3.3VDC 50mA
- Working temperature: -20 ~ 75Centigrade
- Dimension: 26.9mm x 13mm x 2.2 mm

5) Rotary encoder

To make the PID controller you must have a feedback , and for speed control the rotary encoder Shown in **figure6.9** used one for each motor ,it is an incremental rotary encoder that encodes the rotation by electronic pulse, each outputs encodes clockwise and counterclockwise with 20 pulses per circle. Unlike rotary potentiometer count, this rotation counts are not limited, and the outputs are digital. it can be also pressed, to generate another “knob” signal .

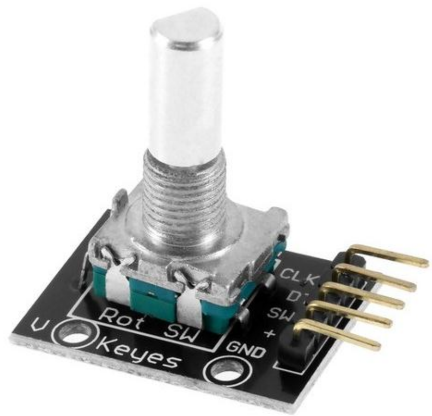


Figure 6.9 Rotary encoder

Specifications:

- Size: 31 x 19 x 29mm
- Working voltage: 5V
- Pulse circle: 20

6.2.2. Software

1) Android Software MIT App

MIT App Inventor shown in **figure6.10** is an intuitive, visual programming environment that allows everyone to build fully functional apps for smart phones and tablets. Those new to MIT App Inventor can have a simple first app up and running in less than 30 minutes. And what's more, our blocks-based tool facilitates the creation of complex, high-impact apps in significantly less time than traditional programming environments. The MIT App Inventor project seeks to democratize software development by empowering all people, especially young people, to move from technology consumption to technology creation.

Figure 6.10 **Android Software MIT App**

This project uses android devices as input device when need to activate the control of electric differential, to be able to do so there must be a graphical user interface on the android device that can send direction and speed of the motor and of course it sends the data through Bluetooth.

To create Such a GUI, we used MIT App. Inventor 2 and it created by the following android application.

This GUI Can do the following:

- Connect to Bluetooth and show the Connection States
- Increase and Decrease Speed and show the delay momentarily for troubleshooting
- Send the desired direction to the Arduino and show it on the screen momentarily

2) Arduino Software

The main controller in the project is Arduino MEGA it receives the data from Bluetooth on the serial port (pin0&pin1) -TX & RX-. It analyzes the data received and give the pulses and the direction to the driver. The working principle that taking by build ARDUINO code shown as flow chart in **figure 6.11 .**

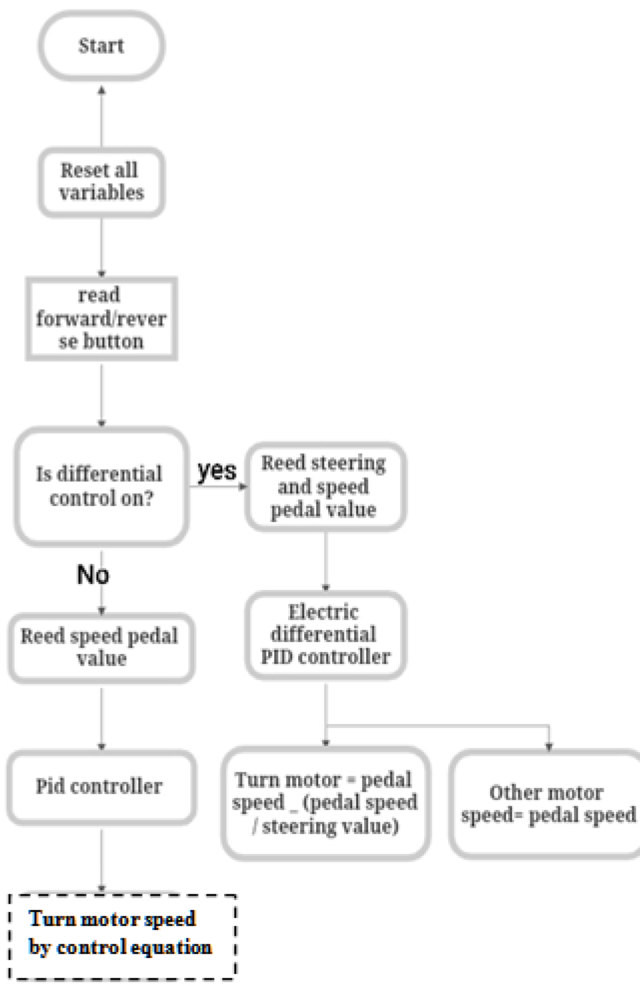


Figure 6.11 flow chart of prototype working principle

Note: the Arduino code is described in the appendix as a comment.

6.3. Calculations

6.3.1. Centre Of Gravity:

The maintenance of the vehicle stability in various conditions, and its stability on the road; is one of the fundamental procedures that the designer should build his calculations and theories on.

The designer should consider this procedure because it has a huge role in making the vehicle work properly and safe for the driver and passengers. Moreover, one of the fundamental things that the vehicle function should build on, is the Centre of gravity.

The Centre of gravity makes us know all of the forces that affect the vehicle to maintain its stability.There are some considers for the Center Of Gravity in various conditions.The main possible situations that may affect on the vehicle:

- Horizontal case
- Upgrade case
- Downgrade case

1- Horizontal case:

By using experiments for our project we determined some parameters:

Total mass = 86.7 kg

Front mass = 42.48 kg

Rear mass = 48.72 kg

Wheel base = 80 cm

To determine the Center Of Gravity and distance between CG and the front wheel (b), also between CG and rear wheel (c) we could use Newton low at static state:

$$c = \frac{w_{fs} \times L \times \cos\theta}{W} = 0.384 \text{ m} \quad (6.1)$$

$$b = \frac{w_{rs} \times L \times \cos\theta}{W} = 0.440 \text{ m}$$

At Dynamic state:

$$F_{xr} = M N \quad , \quad N = w_{rs} \tag{6.2}$$

$$F_{xr} = 0.015 \times 48.72 \times 9.81 = 7.169$$

$$F_{xf} = M N \quad , \quad N = w_{fs}$$

$$F_{xr} = 0.015 \times 42.48 \times 9.81 = 6.250$$

Where:

F_{xr} : Force on the front axle.

F_{xf} : Force on the rear axle.

w_{rs} : Rear weight of the vehicle.

w_{fs} : Front weight of the vehicle.

6.3.2. Design Calculations:

Structural design is the methodical investigation of the stability, strength and rigidity of structures. The basic objective in structural analysis and design is to produce a structure capable of resisting all applied loads without failure during its intended life. The primary purpose of a structure is to transmit or support loads. If the structure is improperly designed or fabricated, or if the actual applied loads exceed the design specifications, the device will probably fail to perform its intended function, with possible serious consequences. A well-engineered structure greatly minimizes the possibility of costly failures.

- Structural design process:

A structural design project may be divided into three phases, i.e. planning, design and construction. Planning: This phase involves consideration of the various requirements and factors affecting the general layout and dimensions of the structure and results in the choice of one or perhaps several alternative types of structure, which offer the best general solution. The primary consideration is the function of the structure. Secondary considerations such as aesthetics, sociology, law, economics and the environment may also be taken into account. In addition there are structural and constructional requirements and limitations, which may affect the type of structure to be designed, the structure load distribution of prototype shown if **figure 6.12** [11]

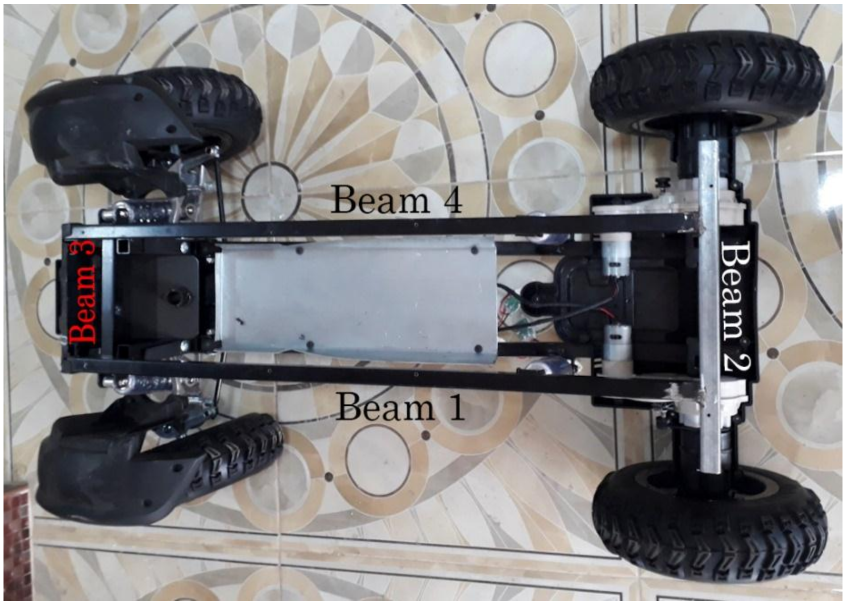


Figure 6.12 the structure of the prototype

- The Calculations for the First Beam: **Figure 6.13** shows the load distribution on the beam
-

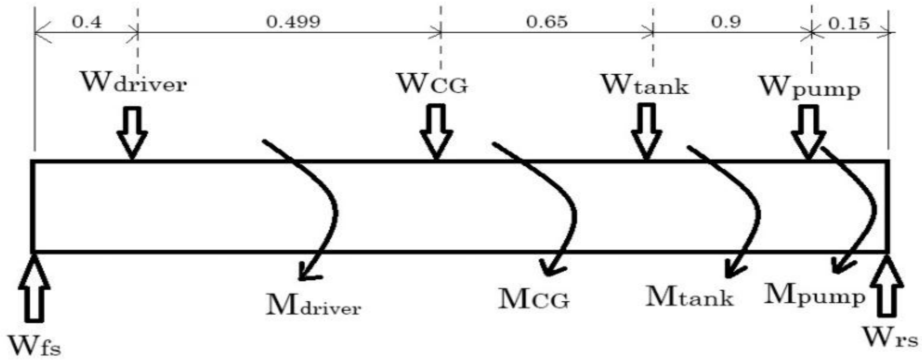


Figure 6.13 the load distribution of the first beam

$$\sum M_{total} = (W_{Driver} \times r_{Driver}) + M_{Driver} + (W_{CG} \times r_{CG}) + M_{CG} + (W_{Tank} \times r_{Tank}) + M_{Tank} + (W_{Pump} \times r_{Pump}) + M_{Pump} \quad (6.3)$$

Where:

W: The weight, $W = m \times g$

M: The moment, $M = W \times R$

r: The distance between W_{fs} and the article

Here R = 0.275 m

$$\sum M_{total} = (25 \times 9.81 \times 0.4) + 67.44 + (65.2 \times 9.81 \times 0.449) + 175.8 + (22 \times 9.81 \times 0.65) + 59.35 + (5 \times 9.81 \times 0.9) + 13.48$$

$$\sum M_{Total} = 885.885 \text{ N.m}$$

$$\sigma_x = \frac{M \times C}{I} \quad (6.5)$$

Where:

$$C = \frac{d}{2} = \frac{0.02}{2} = 0.01\ \text{m}$$

$$I = \frac{1}{12} \times b \times h^3 = \frac{1}{12} \times 0.02 \times 0.02^3 = 1.333 \times 10^{-8}\ \text{m}^4$$

$$\sigma_x = \frac{885.885 \times 0.01}{1.333 \times 10^{-8}} = 664.430\ \text{MPa}$$

σ_y = zero

$$\sigma_{1,2} = \frac{\sigma_x - \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^{\ 2}}$$

σ_1 = 664.430 MPa

σ_2 = zero

σ_3 = zero

$\sigma_{max} = \sigma_1$ = 664.430 MPa

σ_{min} = zero

$$\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2} = 332.215\ \text{MPa} \qquad (6.6)$$

Now, to determine the type of material for design the factor of safety (F_s) which assumed equal 1.5

$$F_s = \frac{S_y}{\tau_{max}} \qquad (6.7)$$

So; S_y = 498.322 MPa

From Table A-20 , The beams should be made by AISI 1045 CD:

S_y = 530 MPa and S_{ut} = 630 MPa

- Calculations for the Second Beam: **Figure 6.14** shows the load distribution on the beam

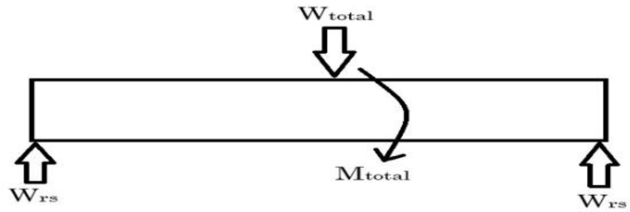


Figure 6.14 the load distribution of the second beam

$$\sum M = M_{Driver} + M_{CG} + M_{Tank} + M_{Pump} + (W_{Total} \times R) \qquad (6.8)$$

$$\sum M = (25 \times 9.81 \times 0.42) + (65.2 \times 9.81 \times 0.384) + (22 \times 9.81 \times 0.20) + (5 \times 9.81 \times 0.08) + (1.1526 \times 0.175)$$

$$\sum M = 596.911 \text{ N.m}$$

$$\sigma_x = \frac{M_{max} \times C}{I}$$

$$\sigma_x = 447.7 \text{ MPa}$$

$\sigma_{max} = \sigma_1 = 447.7$ MPa

σ_{min} = zero

$$\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2} = 223.847 \text{ MPa}$$

Now, to determine the type of material for design the factor of safety (F_s) which assumed equal 1.5

$$F_s = \frac{S_y}{\tau_{max}}$$

So; $S_y = 335.770$ MPa

From Table A-20, the beams should be made by AISI 1050 HR:

$S_y = 340$ MPa and $S_{ut} = 620$ MPa

- Calculations for the Third Beam: **Figure 6.15** shows the load distribution on the beam

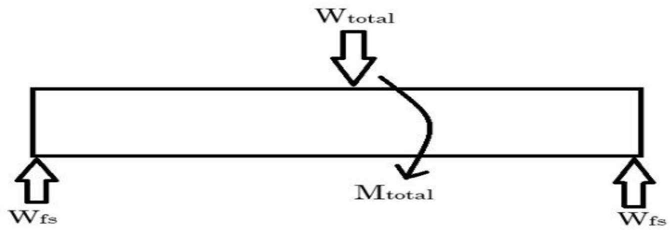


Figure 6.15 the load distribution of the third beam

$$\sum M = M_{Driver} + M_{CG} + M_{Tank} + M_{Pump} + (W_{Total} \times R)$$

$$\sum M = (25\times 9.81\times 0.4) + (65.2\times 9.81\times 0.449) + (22\times 9.81\times 0.65) + (5\times 9.81\times 0.9) + (1.1526\times 0.175)$$

$$\sum M = 770.916 \text{ N.m}$$

$$\sigma_x = \frac{M \times C}{I}$$

$$\sigma_x = 578.33 \text{ MPa}$$

$$\sigma_{max} = \sigma_1 = 578.33 \text{ MPa}$$

$$\sigma_{min} = \text{zero}$$

$$\tau_{max} = \frac{\sigma_{max} - \sigma_{min}}{2} = 289.125 \text{ MPa}$$

Now, to determine the type of material for design the factor of safety (F_s) which assumed equal 1.2

$$F_s = \frac{S_y}{\tau_{max}}$$

So; $S_y = 346.92$ MPa

From Table A-20 , The beams should be made by AISI 1018 CD:

$S_y = 370$ MPa and $S_{ut} = 440$ MPa

6.3.3. Welding calculations:

Welding is a fusion process in which metal parts are heated to the melting point and fused together, usually with a filler of the same material melted along with the parent material.[11]

- Welding analysis for beam 1 and beam 2:

Assumed the following pattern shown in **figure6.16**

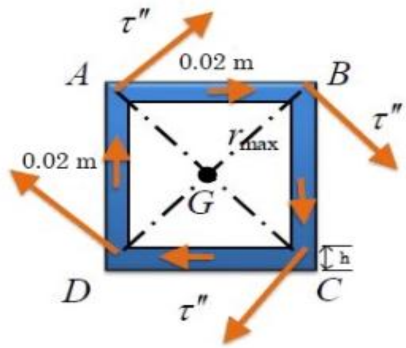


Figure 6.16 beam1 and 2 battern

From table 9-1:

$$A = 1.414\ h \times (b+d) = 0.0565\ h\ m^2$$

$$J_u = \frac{(b+d)^3}{6} = 1.0666\times10^{-5}\ m^3$$

- The upper right corner shown in figure below and the lower right corner are critical:

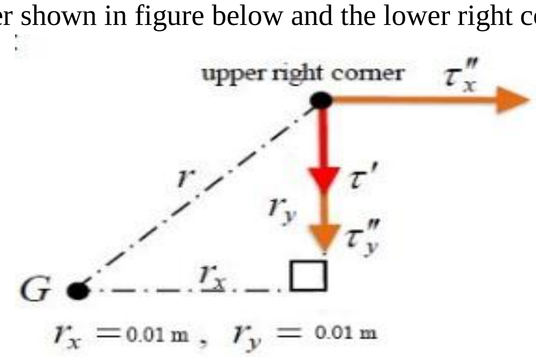


Figure 6.17 The upper right corner analysis

$$\tau' = \frac{F}{A} = \frac{3.819}{h}\ kPa \qquad (6.9)$$

$$\tau_x^{//} = \frac{M\,r_y}{J} = \frac{1.1747}{h}\ \text{MPa}$$

$$\tau_y^{//} = \frac{M\,r_x}{J} = \frac{1.1747}{h}\ \text{MPa}$$

Resultant stress at the critical point:

$$\tau = \sqrt{(\tau_x^{//})^2 + (\tau_y^{//} + \tau_y^{/})^2} = \frac{1.66}{h}\ \text{MPa} \qquad (6.10)$$

From table A-20:

For the first member $S_y = 530$ MPa

For the second member AISI 1050, $S_y = 340$ MPa

Allowable stresses:

$\tau_{all\,1} = 0.4S_y = 212$ MPa (Member)

$\tau_{all\,2} = 0.4S_y = 136$ MPa (Attachment)

Note that the attachment is weaker than the member, it's the critical part.

Therefore, select an electrode not weaker than the attachment.

$\tau_{all\ Electrode} = 0.3S_{ut}$
$= 144.6$ MPa

Which is greater than the attachment. So; E70XX is a suitable Electrode.

Now, for the entire joint, we have:

$\tau_{all} = \min(212, 136, 144.6) = 136$ MPa

$\tau_{max} = \tau_{all}$

$$\frac{1.66}{h} = 136$$

h = 12.235 mm

- For beam 1 and beam 3:

After following the same steps, the difference were shown in **table 6.1** and **table 6.2**:

$\tau_{all\ 1}$ = 212 MPa

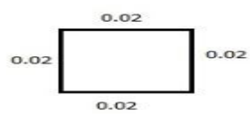
$\tau_{all\ 2}$ = 148 MPa

$\tau_{Electrode}$ = 165 MPa

h = 11.23 mm

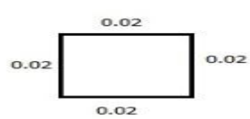
- For beam 1 and beam 2:

Table 6.1 **specifications of beam 1 and beam 2**

Pattern	
Electrode	E70XX
Type	Fillet weld
Size	h = 12 mm
Total length	2 cm

- For beam 1 and beam 3:

Table 6.2 specifications of beam 1 and beam 3

Pattern	
Electrode	E80XX
Type	Fillet weld
Size	h = 11 mm
Total length	2 cm

6.3.4. Steering calculations:

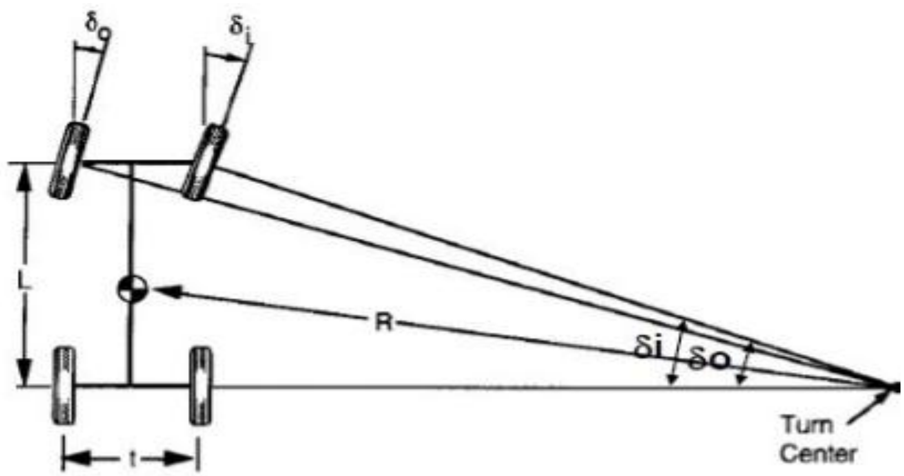


Figure 6.18 **the vehicle analysis when turning**

Figure 6.18 shows the vehicle when turn with respect to turn center.

- For low speed turning:

No centrifugal force

No lateral forces on tires

No slip angle on rear wheels

$$R_{out} = \frac{L}{\delta_{out}} - \frac{t}{2} = 0.257 \text{ m}$$

$$R_{in} = \frac{L}{\delta_{in}} + \frac{t}{2} = 0.292 \text{ m} \quad (6.11)$$

Then the radius of curvature for the allover vehicle equal

$$R = \frac{R_{in} + R_{out}}{2} = 0.274 \text{ m} \quad (6.12)$$

Where:

δ_{out} , δ_{in} : steer angles of inner and outer wheels.

L: Wheel base.

t: the distance between the left and right rear wheels.

6.3.5. Pump calculation:

1. **Total head**

$H_T = H_s + H_f + H_p$ (6.13)

H_T : Total head (m)

H_s: Static head from high water in the tank to the last point that can fluid reach(m)

H_f: Friction head in pipes (m)

H_P: Head from flow pressure in the end of the nozzle

$$H_S = h_{Building} - h_{water\ in\ the\ tank} = 3 - 0.8 = 2.2$$

$$H_f = pipe\ length \times friction\ coef + pipe\ length \times fitting\ coef \quad (6.14)$$

In eqn6.14: Finding friction head by find the sum of multiplied pipe lengths with coefficient of friction and pipe lengths with coefficient of fitting by using **table 1** and **table 2** in APPINEX and applying lengths and diameters and dividing the length to 0.3 to convert to feet, the output is as follows:

$H_f = H_{f1} + H_{f2}$

$H_f = (0.3/0.3) \times 1.08 + 0.3 \times (0.3/0.3) + (1/0.3) \times 1.08 + 0.3\,(1/0.3)$

$= 1.38 + 4.6 = 5.98$ ft

$= 1.82$ m

$P_{pump} = 2.65$ bar = 26.5 m head

$H_P = 26.5$ m

$H = 2.2 + 1.82 + 26.5 = 31.52$ m

2. **Pump power**:
   calculate of the ability of the pump (power) according to the following law:
   $P = Q \times H \times g \times \rho \times \zeta$ (6.15)

   $P = 4.5 \times 10^{-3} \times 31.52 \times 9.8 \times 1000 \times 0.7$

   $P = 0.84$ kW

   $P = 0.84 \times 1000 / 746 = 1.12$ hp.

Where:

Q: flow rate [m/s]

H: total head [m]

ρ: Intensity of fluid [kg/m^3]

g: gravity [m/s^2]

ζ: Efficiency

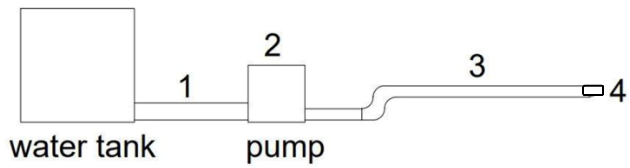


Figure 6.19 the hydrolic system block digram

The **figure6.19** shows the components of the system and shows the point where there is change in the flow of the water , the main points where the procure calculation have been done is :

1 - The flowed between the water tank and the pump

2 - Water Pump

3 - The fluid between pump and nozzle

4 –Nozzle

pressure and velocity calculation :

For point 4 :

Q = 2.7 L/ min

D 3 = 10 mm

D 4 = 2 mm

V4 = 2.65 m /s

P_4 = 0 bar

Velocity in point 3:

$V_3 = Q_1/A_3$

$A_3 = 0.78*10^{-4}\ m^2$

Then $V_3 = 2.21\ m/s$

pressure in point 3 : We obtain pressure at point 3 by applying the Bernoulli equation as follows :

$$P_3 / \rho X g + V^2{}_3 / 2 X g = P_4 / \rho X g + V^2{}_4 / 2 X g \quad (6.17)$$

$P_3 =$ 2.72 bar

For point 1:

Velocity at point 1:

$$Q = V \times A$$

$$V = \frac{Q}{A} \qquad (6.17)$$

$V_1 = V_1 = ((2.7\ L/min) \times (1\ m^3 / 1000\ L) \times (1\ min / 60\ sec)) / 0.78 \times 10^{-4}$

$V_1 = 0.00166 / 11.04 \times 10^{-4} = 2.21\ m/s$

Where:

A: space segment of the pipeline

$$A = \frac{\pi}{4} \times d_2$$

$A_1 = 0.78 * 10^{-4}\ m^2$

V: Speed of the fluid in the tube

The hydrostatic pressure is the pressure exerted by the fluid in the ballast suit because of the strength of gravitational pressure can be calculate according to the following equation:

$$P_1 = h \times \rho \times g \qquad (6.16)$$

$P_1 = 0.3 * 1000 * 9.8$

$P_1 = 2.94$ Kpa

$= 0.0294$ bar

Where:

h : The rise of fluid in the reservoir

$Cv_{for\ nozzle} = V_{act} / V_{ideal}$

$C_{act} = Cv * V_{ideal} = 0.8 * 2.65 = 2.12$ m/s

6.4.Controller design

6.4.1. Transfer Function

In this project the transfer function contain both the car and the motor , In chapter four there is a mathematical model for this project.

A motor is an electromechanical component that yields a displacement output for a voltage input, that is, a mechanical output generated by an electrical input. The schematic and block diagram of the system shown in **figure 6.20**

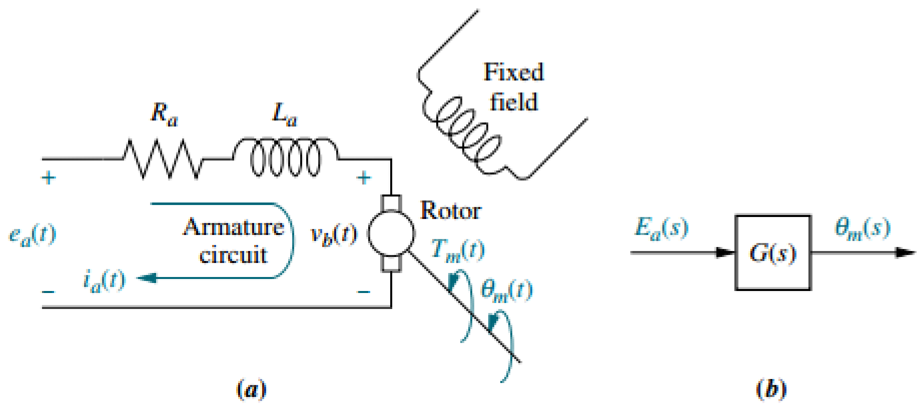


Figure 6.20 a)schematic ,b)block diagram

The relationship between the armature current$i_a(t)$, the applied armature voltage,$E_a(t)$, and the back emf,$v_b(t)$, is found by writing a loop equation around the Laplace transformed armature circuit

$$R_aI_a(s) + L_aSI_a(s) + Vb(s) = E_a(s) \tag{6.18}$$

The torque developed by the motor is proportional to the armature current; thus,

$$T_m(s) = K_tI_a(s) \tag{6.19}$$

Where $T_m$is the torque developed by the motor, and K_t is a constant of proportionality, called the motor torque constant, which depends on the motor and magnetic field characteristics. In a consistent set of units, the value of K_t is equal to the value of K_b Rearranging Eq. (6.19) yields

$$I_a(s) = \frac{1}{K_t}T_m(s) \tag{6.20}$$

To find the transfer function of the motor

$$\frac{R_a + L_a s(s)}{K_t} + K_b s\theta_m(s) = Ea(s) \tag{6.21}$$

Now it must foundTm(s)in terms of Ѳm(s) if we are to separate the input andoutput variables and obtain the transfer function,Ѳm(s)/Ea(s)

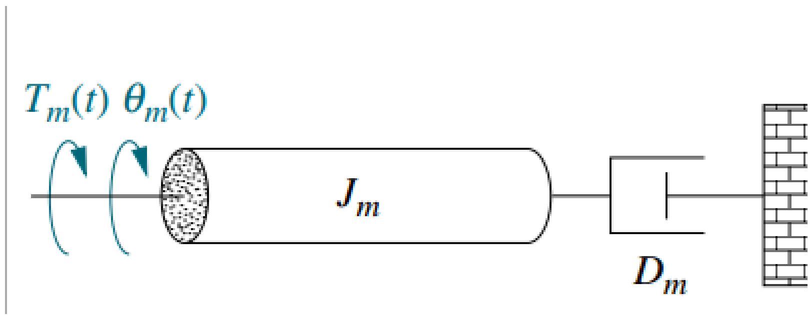


Figure 6.21 Typical equivalent mechanical loading on a motor

Figure 6.21 shows the typical equivalent mechanical loading on a motor where Jm is the equivalent inertia at the armature and includes both the armatureinertia and, as we will see later, the load inertia reflected to the armature, and Dm is the equivalent viscous damping at the armature and includes both thearmature viscous damping and, as we will see later, the load viscous dampingreflected to the armature

$$T_m(s) = (J_m s^2 + D_m s)\theta_m(s) \tag{6.22}$$

Tm(s)=(Jms^2+Dms)Ѳm(s)………………..()

Substituing last two eq.22 yields

$$\frac{(R_a + L_a s)(J_m s^2 + D_m s)\Theta_m(s)}{Kt} + K_b s\theta_m(s) = E_a(s) \tag{6.23}$$

If we assume that the armature inductance,La, is small compared to the armatureresistance,Ra, which is usual for a dc motor

$$(\frac{K_a}{Kt}(J_m s + D_m) + K_b)s\theta_m(s) = E_a(s) \tag{6.24}$$

After simplification, the desired transfer function

$$\frac{\Theta_m(s)}{E_a(s)} = \frac{K_t/(R_a J_m)}{2[s + \frac{1}{J_m}\left(D_m + \frac{K_t K_b}{R_a}\right)]} \tag{6.25}$$

in this project two DC motor that have the same specifications we used , and to control them , many details needed and cannot be found , so to find the transfer function of the motor it will assume that it is an first order system whose transfer function is :

$$G(t) = \frac{k}{(s+a)}$$

And its step response is :

$$c(t) = \frac{k}{s(s+a)}$$

To identify *K* and *a (* the exponential frequency) from laboratory testing for the motor that it has the first-order characteristics, by connect the motor with a small motor (the motor should have very small inertia compared with the selected motor) and by present the output of generator (small motor) on the oscilloscope, such as no overshoot and nonzero initial slope. , assume the unit step response given in Figure 6.22

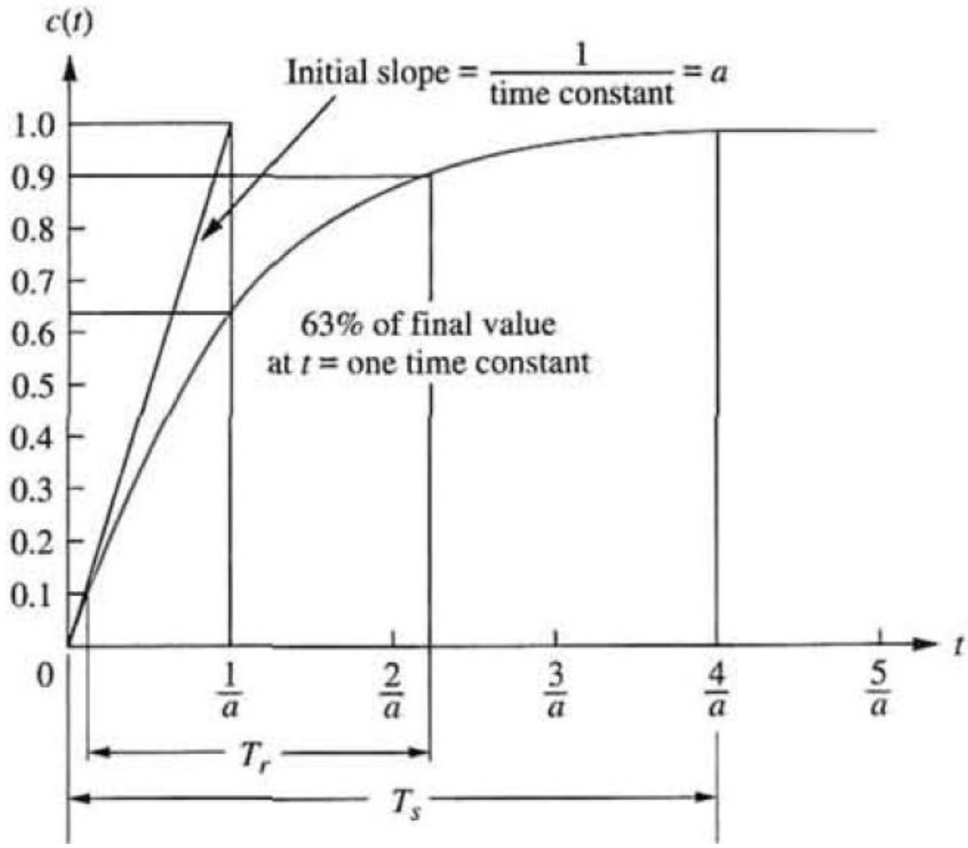


Figure 6.22 first order system

From the response, the time constant could be measured , the time constant is the time it takes for the step response to rise to 63% of its final value

$$time\ constant = 1/a$$

To find *K*, the forced response reaches a steady state value of :

$$\frac{k}{a} = \text{final value}$$

The step response of a laboratory test was as shown in **figure 6.23**

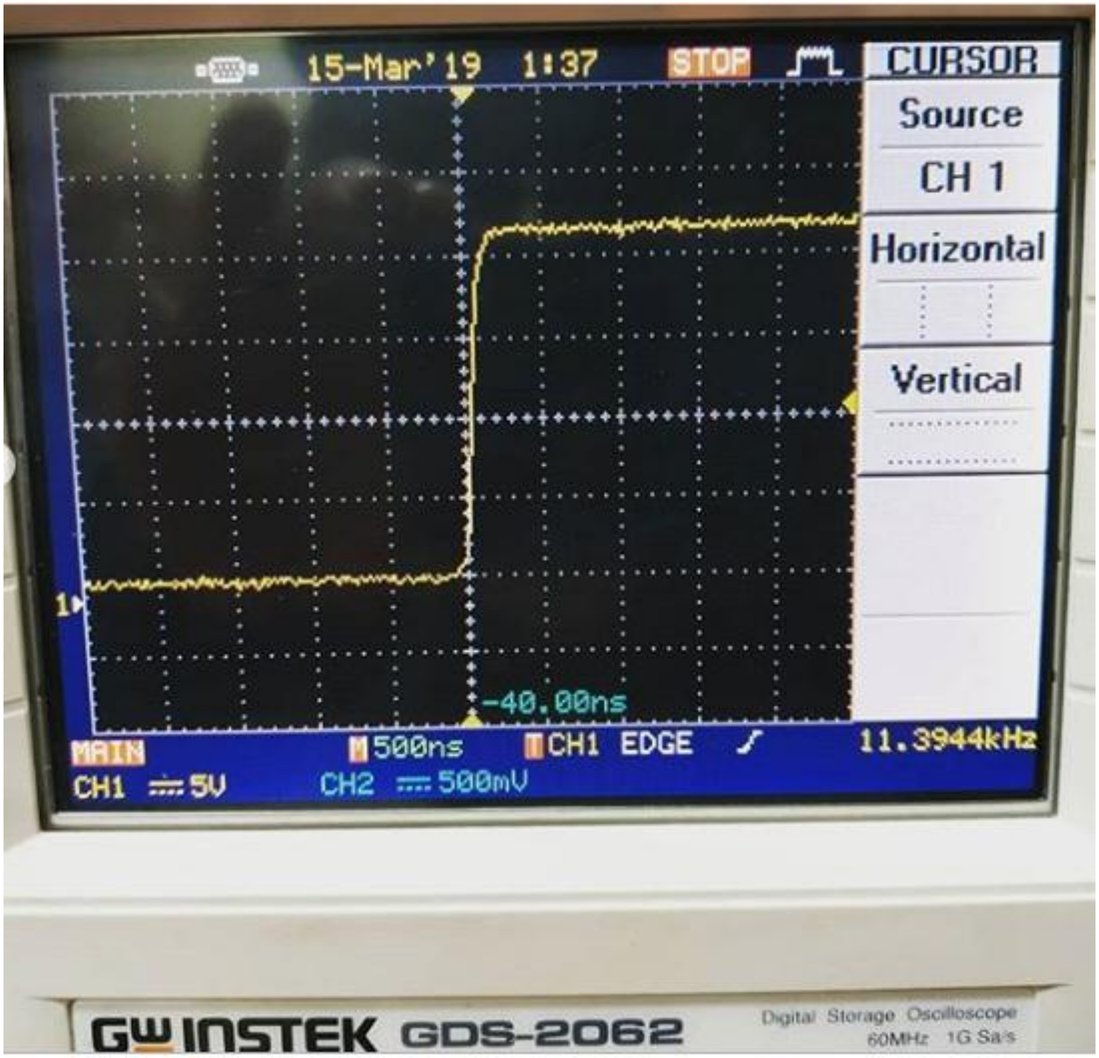


Figure 6.23 Laboratory results of a system step response test

Since the final value is about 120 time constant is evaluated where the curve reaches 0.63 x 120 = 75.6, or about 0.5 s. Hence, a = 1/0.5 = 20 μs. And k=2.4

Then the transfer function of the motor is

$$G(t) = \frac{2.4}{(s + 20)}$$

6.4.2. Speed PID controller

A proportional–integral–derivative controller (PID controller or three term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control, APID controller continuously calculates an error value as the difference between a desired set point (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively) which give the controller its name. **Figure6.24** shows the block diagram of PID controller

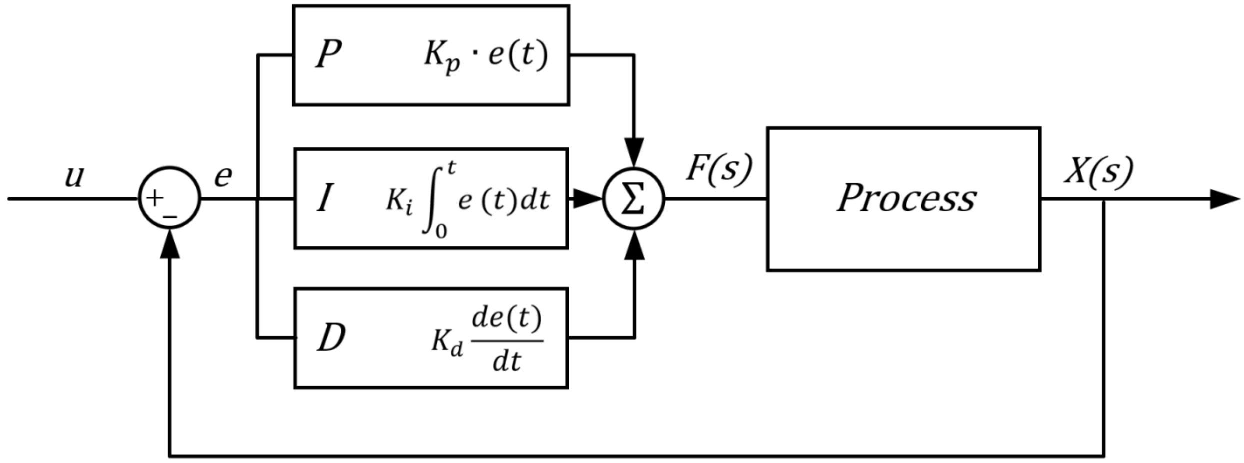


Figure 6.24 block diagram of PID controller

The transfer function of the PID controller is:

$$G(s) = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s} \tag{6.26}$$

6.4.3. MATLAB and SIMULINK

Matlab code:

```
syms ll lr lt lk rs m kv jt kw r l k rz u0 j kr pg rg jb al bl cl dl ar br cr dr
ll=0.225;%[m]distance of the left wheel from point B
lr=0.225;%[m]distance of the right wheel from point B
lt=0.384;%[m]distance of the centre of gravity from join between wheels
lk=0.85;%[m]distance of caster wheel from join between wheels
rs=0.30;%[m]semi-diameter of driving wheel
m=56.20;%[kg]total weight
kv=1.200;%[kg/s]coefficient of the resistance against car linear motion
jt=0.026582;%[kg.m^2]moment of inertia of car with respect to centre of gravity
kw=1.350;%[kg.m^2/s]coefficient of the resistance against car rotating
r=12.000;%[?]motor winding resistivity
l=0.50;%[H]motor inductance
k=0.0066;%[kg.m2.s-2.A-1]electromotoric constant
rz=0.200;%[?]source resistance
u0=12.00;% [V] source voltage
j=0.025;% [kg.m2] total moment of inertia of rotor and gearbox
kr=0.002;%[kg.m2.s-1] coefficient of the resistance against rotating of rotor and gearbox
```

```
pg=26;% gearbox transmission ratio
rg=rs/pg;
jb=jt+(m*(lt)^2);
al=kr+((kv*lr*(rg)^2)/(ll+lr));
bl=j+((m*lr*(rg)^2)/(ll+lr));
cl=(kr*ll)+((kw*(rg)^2)/(ll+lr));
dl=(j*ll)+((jb*(rg)^2)/(ll+lr));
ar=kr+((kv*ll*(rg)^2)/(ll+lr));
br=j+((m*ll*(rg)^2)/(ll+lr));
cr=(kr*lr)+((kw*(rg)^2)/(ll+lr));
dr=(j*lr)+((jb*(rg)^2)/(ll+lr));
A=[(-1*(r+rz)/l) (-1*(rz/l)) (-1*(k/l)) 0;(-1*(rz/l)) (-1*((r+rz)/l)) 0 (-
1*(k/l));((k*(dr+(br*ll)))/((bl*dr)+(br*dl))) ((k*(dr-(br*lr)))/((bl*dr)+(br*dl))) (-
1*((dr*al)+(br*cl))/((bl*dr)+(br*dl))) (-1*((dr*ar)-(br*cr))/((bl*dr)+(br*dl)));((k*(dl-
(bl*ll)))/((bl*dr)+(br*dl))) ((k*(dl+(bl*lr)))/((bl*dr)+(br*dl))) (-1*((dl*al)-(bl*cl))/((bl*dr)+(br*dl))) (-
((dl*ar)+(bl*cr))/((bl*dr)+(br*dl)))]
B=[(u0/l) 0;0 (u0/l);0 0;0 0]
C=[0 0 (lr*rg)/(ll+lr) (ll*rg)/(ll+lr);0 0 -(rg)/(ll+lr) (rg)/(ll+lr)]
D=eye(2)

sys=ss(A,B,C,D)
TF=tf(sys)
num1=[-0.113 -2.811 -0.2032]
den1=[1 48.98 603.9 106.1 4.537]
g1=tf(num1,den1)
TT=min(roots(den1))
Ts=-3.14/(TT*100)
```

And the SIMULINK model for the plant(in green color) and the PID controller shown in **figure6.25**

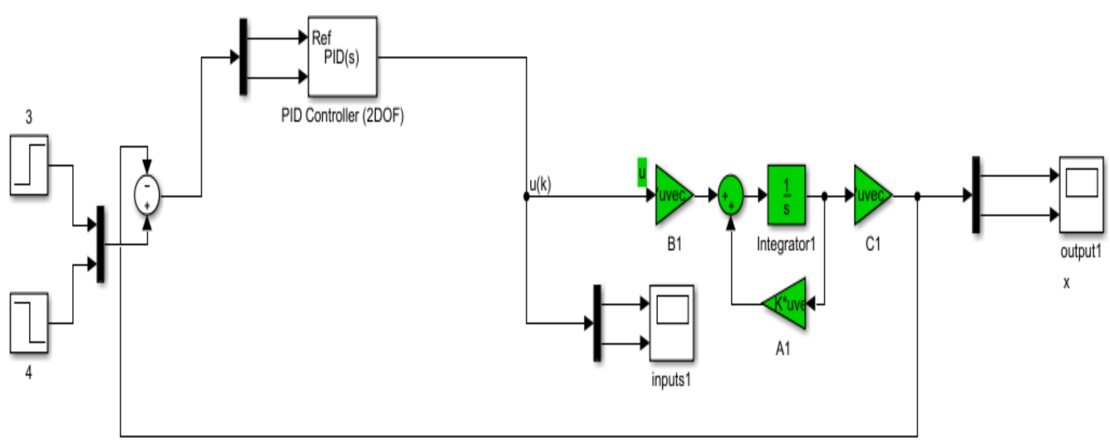


Figure 6.25 the simulink model

The response of the motor was as shown in **figure6.26** which go to the desired value without taking long time the over shoot of the curve is acceptable and the steady state error equal zero.

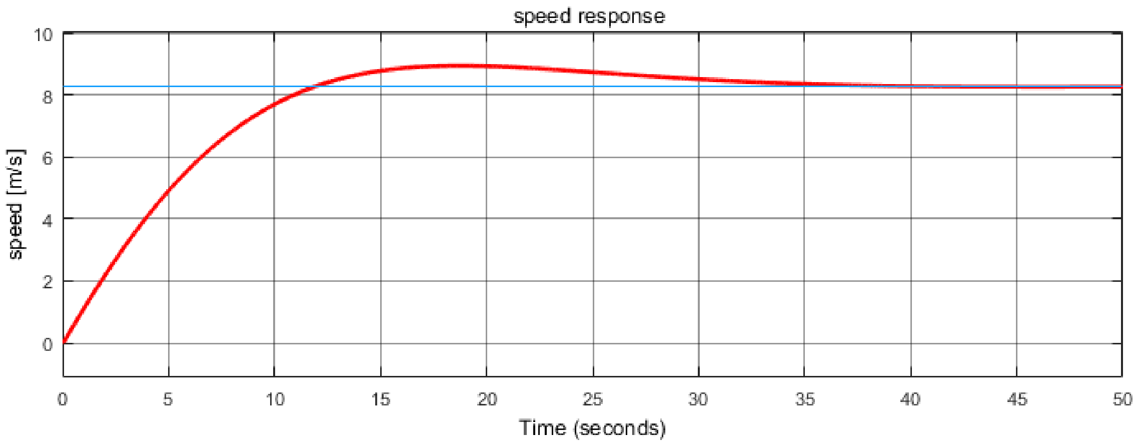


Figure 6.26 speed response

6.4.4. Android Application :

This project uses android devices as main input device, so there must be a graphical user interface on the android device that can send the speed of each motor and of course it sends the data through Bluetooth.

To create Such a GUI, we used MIT App. Inventor 2 and we created the following android application shown in **figure6.27**.

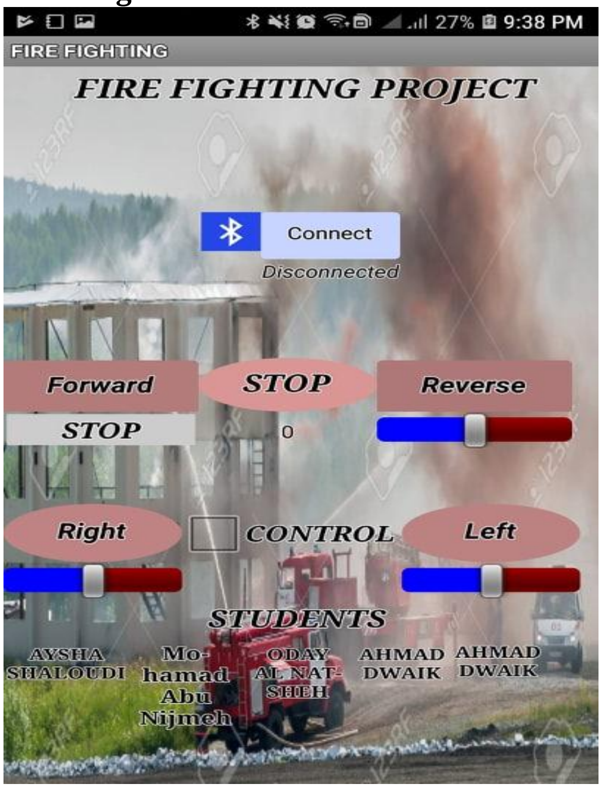


Figure 6.27 GUI of MIT ANDROID APP

This GUI Can do the following:

- Connect to Bluetooth and show the Connection States
- Increase and Decrease Speed of the firefighting .
- Activate the control to change the speed of each motor individually .

Application code :

First of all , initiate the Bluetooth and the change when connect and disconnect, and take the require data when connect , the code shown if **figure6.28 figure 6.29** :

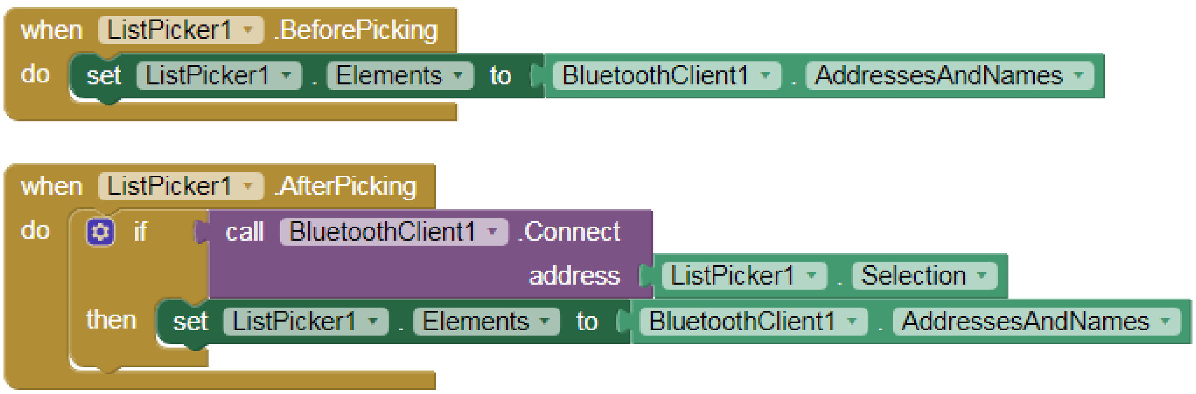


Figure 6.28 mit app code 1

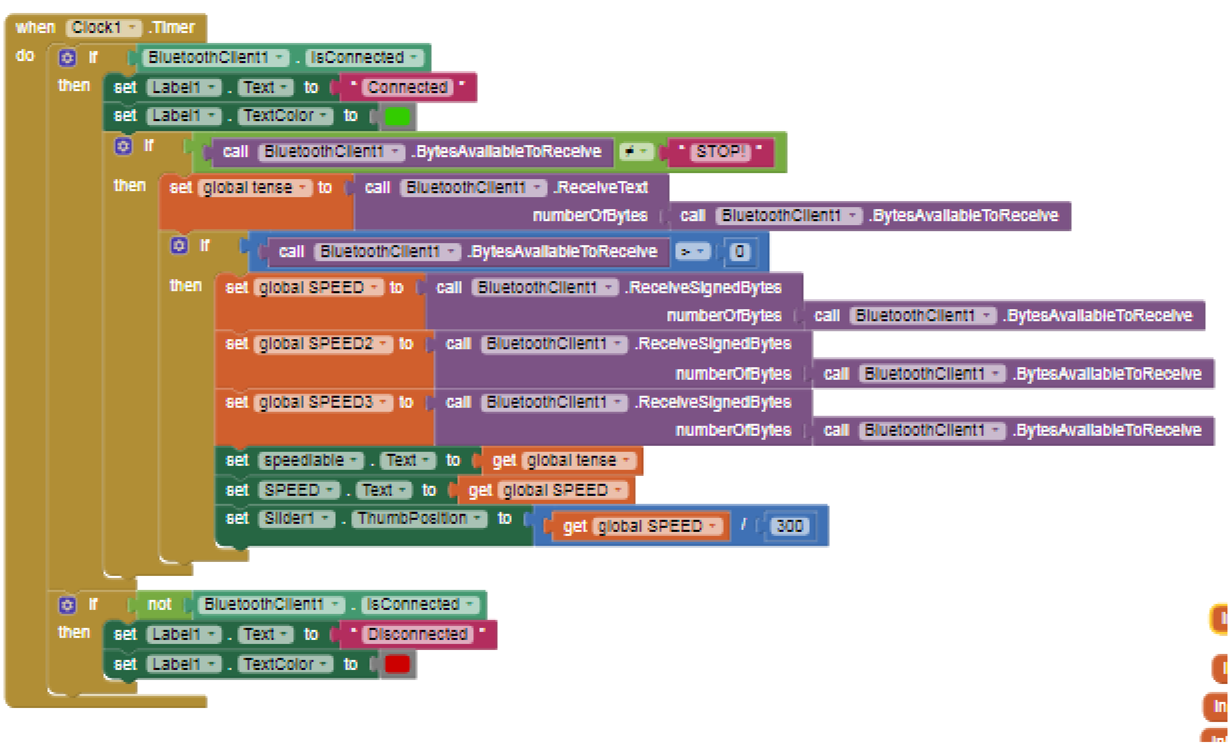


Figure 6.29 mit APP code 2

Set the variables code shown in **figure6.30**:

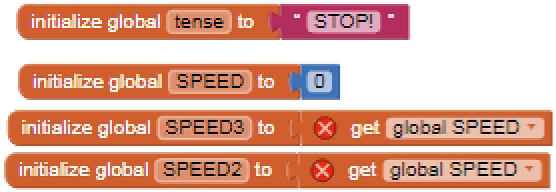


Figure 6.30 mit APP code 3

Then choose the construction when click the buttons code shown in **figure 6.31**

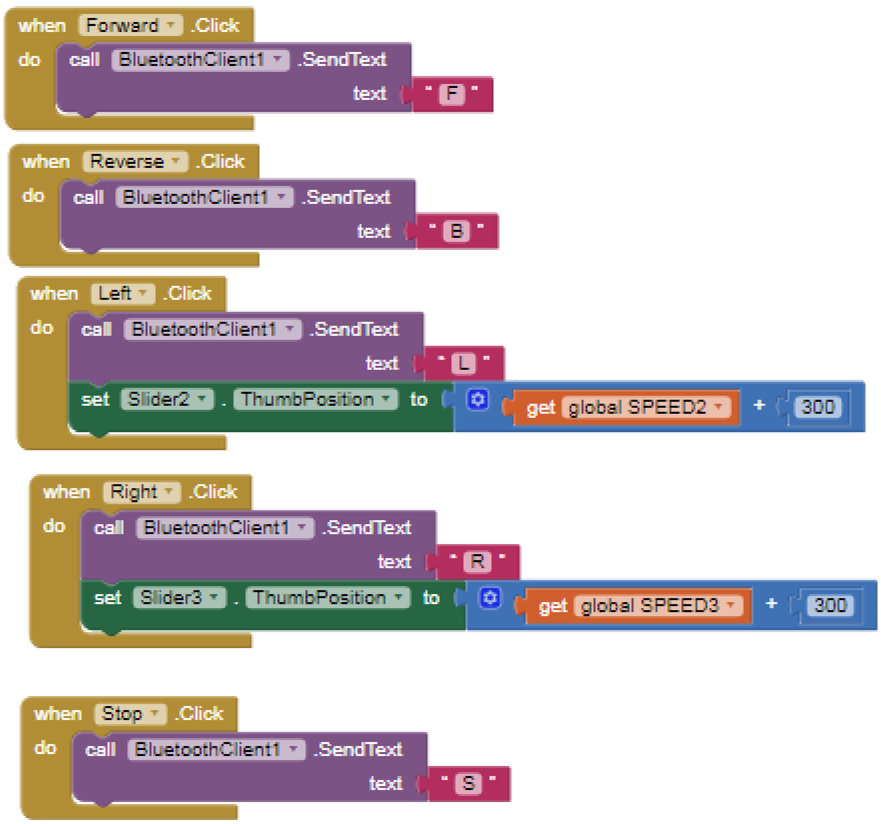


Figure 6.31 mit app code 4

When choose the control check text , and activate the control tense , changing left and right speed slider code shown in **figure 6.32** :

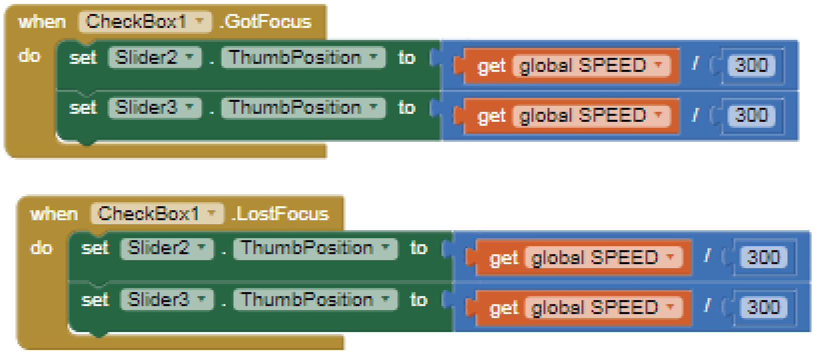


Figure 6.32 mit app code4

6.4.5. Arduino Software

The main controller in the project is Arduino mega it receives the data from the steering angle and the speed pedal and Bluetooth on the serial port (-TX & RX-.) It analyzes the data received and give the pulse width modulation and the direction to the motor driver.

Note: the Arduino code is described in the appendix as a comment.

6.5.System connections :

- **PROTEOS Software**

Whenever build a code for control , the best way to test it before the real test is to simulate the code , and PROTOES is one of simulation program to know how its work. For each motor there is a driver and a feedback(rotary encoder) to controller and absolutely a power supply the prototype schematic diagram shown in **figure 6.33**

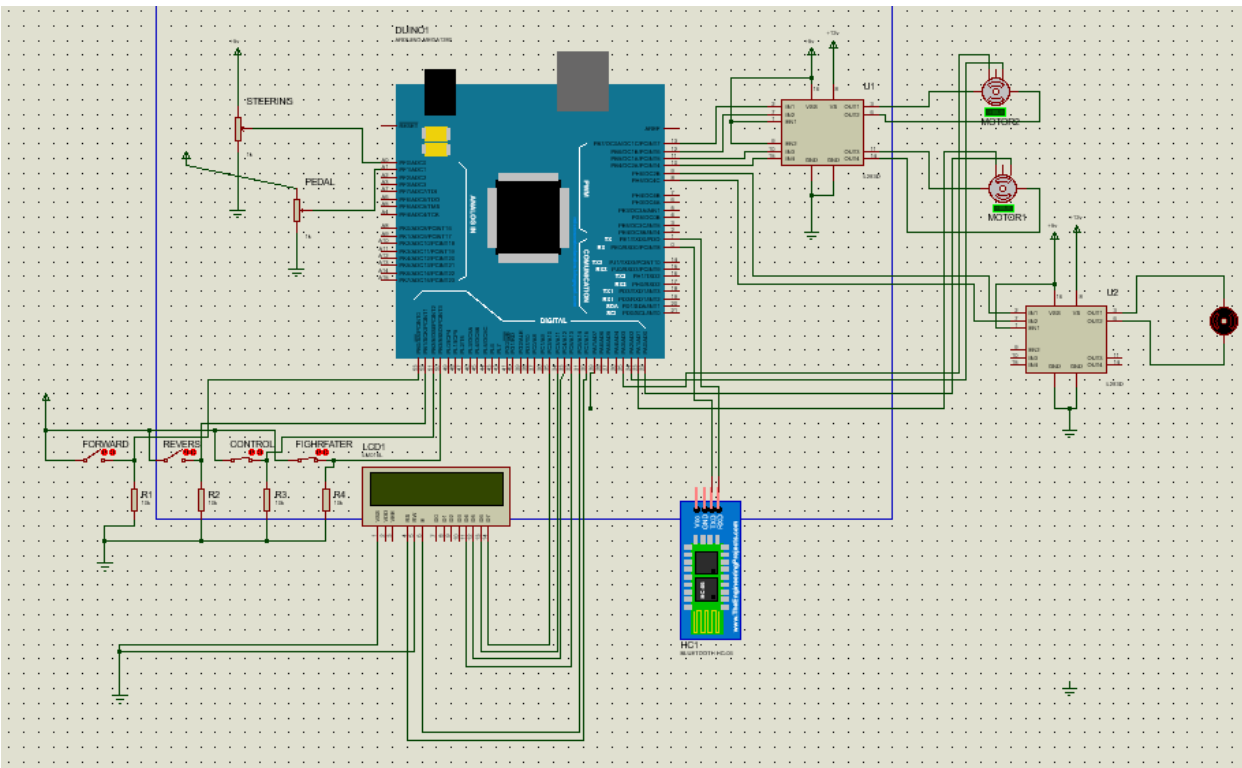


Figure 6.33 prototype schematic diagram

- **Block diagram of prototype shown in figure 6.34**

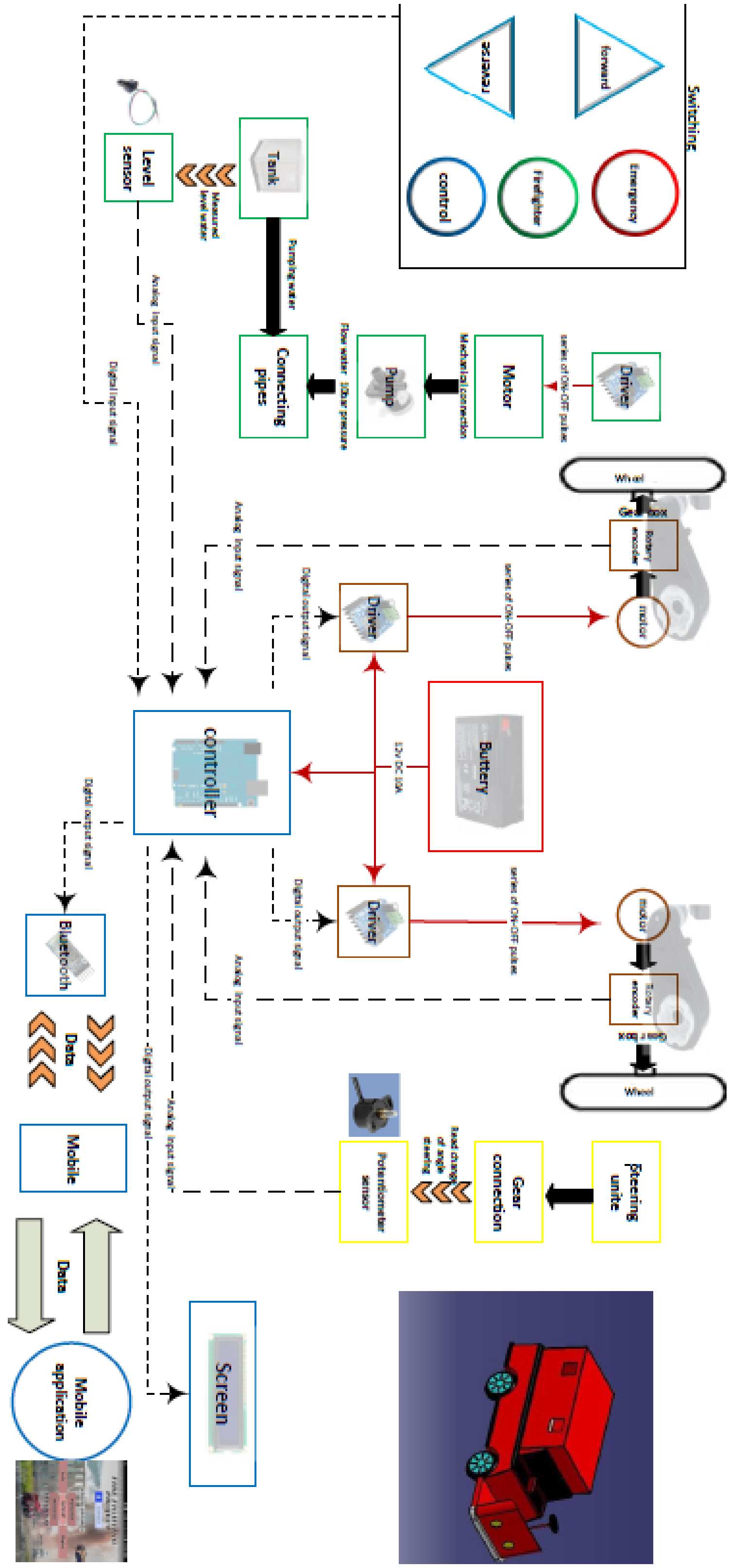


Figure 6.34 block diagram of prototype

6.6. System justification and calibration:

Rotary encoder :

In this project a PID controller designed for the speed control of the motors , then this kind of control is an closed loop control and need a signal for the feedback, an rotary encoder shown in **figure 6.35** added to the prototype to be the feedback of the system.

Figure 6.35 rotary encoder installation

Figure6.35 shows the rotary encoder installation in the vehicle , it have been added after the gear box to make a good calibration, we calculate the gain of this feedback by ratio shown in **figure6.36**, in this project there is a gain ratio of 38 .

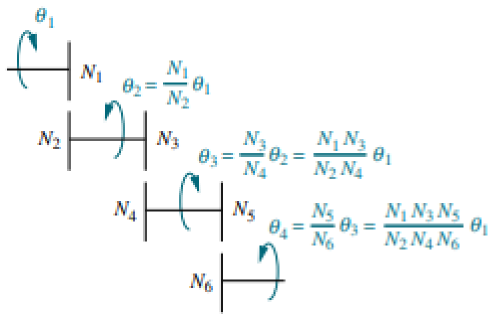


Figure 6.36 gear box turn ratio

- **Speed pedal :**

Figure 6.37 speed pedal

Figure6.37 shows a speed pedal, which connect to an potentiometer , this pedal simulate the real cars pedal , it allow the driver to change the speed by push his foot on it , any change in the pressure make a change in the resistance of potentiometer and change the voltage of it which connect an analog pin in the ARDUINO ,so the output voltage of the pedal potentiometer is an analog input for ARDUINO , in the code of ARDUINO as shown in APPENDIX a mapping done to the input value of pedal potentiometer and convert to a reference speed for the PID controller , when the differential control is off both motor have a speed from this speed pedal , but in differential control tense the side turn motor have the speed from speed pedal.

- **Steering turn sensor:**

To make the electric differential control on the prototype , it must be measure the degree and direction of the steering , to know how much speed much be defer between the two motors .

Figure 6.38 steering sensor

Figure 6.38 shows the potentiometer connect with a gear with steering ,the steering have a turn of 45 degree for both direction, when change the degree of steering it make a change in the resistance of the potentiometer which change the output voltage of it , when the differential control off there is no need for the signal of the steering turn sensor but in differential control tense it must mapping the value of potentiometer and convert it to a decreasing speed for the turn side motor while the other motor speed depends on the speed pedal .

6.7.Result :

- **Turning radius :**

In this project, the main objective is to make an electric which make the different in the speed of the left and the right motors depends on this equation :

$$turn\ motor\ speed = \left(1 - \left(\frac{|steering\ degree|}{45}\right)\right) * pedal\ speed$$

And for the turning radius with different speed for the two motors we have this equation :

$$turning\ radius = axle\ width * \left(\frac{pedal\ speed - turning\ motor\ speed}{pedal\ speed}\right)$$

Axle width =56.2cm

Table 6.1 shows the speed of both motor in differential control tense.

Table 6.3 speed results

Steering angle [deg]	Pedal speed [m/s]	Turn motor speed [m/s]	Other motor speed [m/s]	Turning radius[cm]
10	0.38	0.25	0.38	24.5
20	0.38	0.20	0.38	30.7
30	0.38	0.15	0.38	48.8
45	0.38	0.05	0.38	54.6

- Fire fighting result :

For prototype a tank of (3.*3.*27)m^3 used for the fire fighting unit**, figure6.39** shows the distance that the pump could flow the water , by testing it reach almost 5m.

Figure 6.39 distance of water flowed from pump

6.8.Budget

Table 6.3 shows the budget of the prototype

6.1budget of prototype

No.	Component name	Quality	Price (₪)
1	Vehicle	1	1500
2	Motors drivers	2	500
3	Electric steering	1	150
4	Arduino	3	75
5	Pump	1	300
6	Tank	1	100
7	Rotary encoders	2	300
8	Sensors and switches		75
	TOTAL		3000

APPINDIX

1. TABLE 1: the loss coefficient for pipes
2. TABLE 2: Flow rate and friction head loss for tubing and pipe size
3. ARDUINO CODE

TABLE 1shows the loss coefficient for pipes :

Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$ **(Data from Refs. 5, 10, 27)**

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210

90° elbow

45° elbow

180° return bend

Tee

Tee

Union

Table 2 shows the Flow rate and friction head loss for tubing and pipe size

Nom Dia (in)	Inside Dia (in)	Flow rate (gpm)	Fraction head loss (ft of head per feet pipe)
¼	0.311	2.4	2.15
½	0.527	6.8	1.08
¾	0.745	13.6	0.69
1	0.995	24	0.48
1 ½	1.6	63	0.26
2	2.067	105	0.19
2 ½	2.469	149	0.15
3	3.068	230	0.117
4	4.026	400	0.084
6	6.065	900	0.051
8	8.125	1615	0.036
10	10.25	2570	0.027
12	12.25	3675	0.022
14	13.5	4460	0.0194

Table 2 loss coefficient for pipe component

ARDUINO CODE

```
//bluetooth bins 0 & 1

int RPWM_Output = 5; // Arduino PWM output pin 5; connect to IBT-2 pin 1 (RPWM)

int LPWM_Output = 6; // Arduino PWM output pin 6; connect to IBT-2 pin 2 (LPWM)


int RPWM_Output2 = 9; // Arduino PWM output pin 9; connect to IBT-2 pin 1
(RPWM)MOTOR2

int LPWM_Output2 = 10; // Arduino PWM output pin 10; connect to IBT-2 pin 2
(LPWM)MOTOR2


int state;

int flag=0;        //makes sure that the serial only prints once the state


int stateStop=0;


boolean motor_start = false;

boolean motor_start2 = false;


const byte pin_a = 3; //for encoder pulse A

const byte pin_b = 18; //for encoder pulse B


const byte pin_a2 =21; //for encoder pulse A MOTOR2

const byte pin_b2 = 16; //for encoder pulse B MOTOR2


int encoder = 0;

int encoder2 = 0;
```

```
int m_direction = 0;
int sv_speed = 200; //this value is 0~255
double pv_speed = 0;
double pv_speedn = 0;
double set_speed = 0;
double e_speed = 0; //error of speed = set_speed - pv_speed
double e_speed_pre = 0; //last error of speed
double e_speed_sum = 0; //sum error of speed
double pwm_pulse = 0; //this value is 0~255

int m_direction2 = 0;
int sv_speed2 = 200; //this value is 0~255
double pv_speed2 = 0;
double pv_speedn2 = 0;
double set_speed2 = 0;
double e_speed2 = 0; //error of speed = set_speed - pv_speed
double e_speed_pre2 = 0; //last error of speed
double e_speed_sum2 = 0; //sum error of speed
double pwm_pulse2 = 0; //this value is 0~255

double kp = 0.348;
double ki = 2.28;
double kd = 0.0132;
int r=0;
```

```
int timer1_counter; //for timer

int timer2_counter; //for timer

int value;

int SENSOR_PIN = A0; // center pin of the potentiometer A0 pin

int outputValue = 0;        // value output to the PWM (analog out)

int sw = 26; //on/off switch

int cont=5;  //control switch

int f=11;

int b=10;

int steering=A1;

int degree;

void setup() {

  pinMode (b,INPUT);

  pinMode (f,INPUT);

  pinMode (sw,INPUT);

  pinMode(cont,INPUT);

  pinMode (pin_a,INPUT);

  pinMode (pin_b,INPUT);

  pinMode (pin_a2,INPUT);

  pinMode (pin_b2,INPUT);

 //--------------------------timer setup

noInterrupts(); // disable all interrupts

TCCR1A = 0;

TCCR1B = 0;
```

```
timer1_counter = 59286; // preload timer 65536-16MHz/256/2Hz (34286 for 0.5sec) (59286
for 0.1sec)

TCNT1 = timer1_counter; // preload timer

TCCR1B |= (1 << CS12); // 256 prescaler

TIMSK1 |= (1 << TOIE1); // enable timer overflow interrupt


interrupts(); // enable all interrupts

    // sets the pins :

  pinMode(RPWM_Output, OUTPUT);

  pinMode(LPWM_Output, OUTPUT);

  pinMode(RPWM_Output2, OUTPUT);

  pinMode(LPWM_Output2, OUTPUT);


    // initialize serial communication at 9600 bits per second:

    Serial.begin(9600);

}


void loop() {




    //if some date is sent, reads it and saves in state

    if(Serial.available() > 0){

      state = Serial.read();
```

```
    }

if(sw==HIGH){

    // if the state is 'F' the DC motor will go forward
    if (state == 'F'|| f==HIGH ) {

        Serial.println("Go Forward!");

      r=2;   //run motor run forward

      analogWrite(RPWM_Output, 0);
      analogWrite(RPWM_Output2, 0);

      motor_start = true;

    }

    // if the state is 'S' the motor will Stop
    else if (state == 'S' || stateStop == 1) {
```

```
      Serial.println("STOP!");

      analogWrite(RPWM_Output, 0);
      analogWrite(LPWM_Output, 0);
      analogWrite(RPWM_Output2, 0);
      analogWrite(LPWM_Output2, 0);

    motor_start = false;

  }

    // if the state is 'L' the motor will turn right
  else if (state == 'L' && cont==HIGH) {
    degree=analogRead(steering);
    degree = map(degree, 0, 1023, 0, 255);
    r=4;
    analogWrite(RPWM_Output2, 0);
    analogWrite(RPWM_Output, 0);
     motor_start = true;
      Serial.println("Turn RIGHT");
```

```
  }

// if the state is 'R' the motor will turn left
  else if (state == 'R'&& cont==HIGH) {

      degree=analogRead(steering);
      degree = map(degree, 0, 1023, 0, 255);
      r=3;
      analogWrite(RPWM_Output, 0);
      analogWrite(RPWM_Output2, 0);

       motor_start = true;
        Serial.println("Turn LEFT");

  }
  // if the state is 'B' the motor will Reverse
  else if (state == 'B' || b==HIGH) {

      r=1;   //run motor run backward



        Serial.println("Reverse!");
```

```
        analogWrite(LPWM_Output, 0);

        analogWrite(LPWM_Output2, 0);


        motor_start = true;




    }

    //For debugging purpose

    //Serial.println(state);

      value = analogRead(SENSOR_PIN);

    outputValue = map(value, 0, 1023, 0, 255);


  Serial.println(outputValue);

}

}

void detect_a() {

encoder+=1; //increasing encoder at new pulse

m_direction = digitalRead(pin_b); //read direction of motor

}

ISR(TIMER1_OVF_vect) // interrupt service routine - tick every 0.1sec

{

TCNT1 = timer1_counter; // set timer

pv_speed = 60.0*(encoder/200.0)/0.1; //calculate motor speed, unit is rpm
```

```
pv_speedn=pv_speed/0.00866;
encoder=0;
Serial.println(pv_speed);

//PID program
if (motor_start){
      value = analogRead(SENSOR_PIN);
    outputValue = map(value, 0, 1023, 0, 255);
int set_speed=outputValue;

e_speed = set_speed - pv_speedn;
pwm_pulse = e_speed*kp + e_speed_sum*ki + (e_speed - e_speed_pre)*kd;
e_speed_pre = e_speed; //save last (previous) error
e_speed_sum += e_speed; //sum of error
if (e_speed_sum >4000) e_speed_sum = 4000;
if (e_speed_sum <-4000) e_speed_sum = -4000;
}
else{
e_speed = 0;
e_speed_pre = 0;
e_speed_sum = 0;
pwm_pulse = 0;
}
//update new speed
if(r==1){
```

```
if (pwm_pulse <255 & pwm_pulse >0){

analogWrite(RPWM_Output,pwm_pulse); //set motor speed
analogWrite(RPWM_Output2,pwm_pulse);
}
else{
if (pwm_pulse>255){
analogWrite(RPWM_Output,255);
analogWrite(RPWM_Output2,255);
}
else{
analogWrite(RPWM_Output,0);
analogWrite(RPWM_Output2,0);
}
}
}
if(r==2){
if (pwm_pulse <255 & pwm_pulse >0){

analogWrite(LPWM_Output,pwm_pulse); //set motor speed
analogWrite(LPWM_Output2,pwm_pulse);
}
else{
if (pwm_pulse>255){
analogWrite(LPWM_Output,255);
```

```
analogWrite(LPWM_Output2,255);
}
else{
analogWrite(LPWM_Output,0);
analogWrite(LPWM_Output2,0);
}
}
}
if(r==3){
if (pwm_pulse <255 & pwm_pulse >0){

analogWrite(LPWM_Output,pwm_pulse); //set motor speed
analogWrite(LPWM_Output2,pwm_pulse*(degree/1024));
}
else{
if (pwm_pulse>255){
analogWrite(LPWM_Output,255);
analogWrite(LPWM_Output2,127);
}
else{
analogWrite(LPWM_Output,0);
analogWrite(LPWM_Output2,0);
}
}
}
```

```
if(r==4){
if (pwm_pulse <255 & pwm_pulse >0){

analogWrite(LPWM_Output,pwm_pulse*(degree/1024)); //set motor speed
analogWrite(LPWM_Output2,pwm_pulse);
}
else{
if (pwm_pulse>255){
analogWrite(LPWM_Output,127);
analogWrite(LPWM_Output2,255);
}
else{
analogWrite(LPWM_Output,0);
analogWrite(LPWM_Output2,0);
}
}
}
}
```

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