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Worker Electric Vehicle

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July 2020

ACKNOWLEDGMENT

Frist, I would like to thank CIC (Canadian International Collage) for their continuous support for student by providing them with scientific material that helps students to improve their skills and knowledge.

Second, I would like to thank Dr. Mahmoud Mohamed El Sayed, Head of mechanical engineering department for providing continuous support and necessary technical data that helped in making that project possible.

ABSTRACT

The world nowadays is headed towards electrical vehicles since they are environmental friendly, less expensive that I.C.E (internal combustion engine) vehicles in terms of operation, maintenance, more durable and last but not least easy and safe to use and develop, therefore many companies are developing vehicles for off-road application but unfortunately there is less regard for workers and employees that work in large landscapes as Harbors, manufacturing facilities, agricultural projects, sport clubs, construction sites and amusement parks that requires regular maintenance work in different areas. Therefore the project tends to design and develop an electrical vehicle for workers with low cost, easy to use and high durability to allow them to transport around these landscapes fast allowing them to perform their work efficiently.

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List of symbols

C : Shaft Center Distance in pitches
L : Length of chain in pitches
N : Number of teeth in larger sprocket
n : Number of teeth in smaller sprocket
π : 3.1416
P : Pitch of chain
k : stiffness
m : mass
c : damping
W_r : W rear
W_f : x front
c,f : front linear distance from center of gravity
d,r : rear linear distance from center of gravity
θ : angle
x : positional displacement
ω : natural frequency
μ : coefficient of friction
$\Delta\theta$: change in angle
a_x : acceleration in x axis
P_a : pressure
p : power
t : time
V_o : initial speed
ΔT : change in temperature
C_v : specific heat
I : mass moment of inertia
ω_o : initial angular speed
F : braking force
W : weight

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CHAPTER ONE

INTRODUCTION

Chapter One: Introduction

Introduction

Vehicles nowadays are the main mean of transportation; however, internal combustion engine (I.C.E.) vehicles have lots of disadvantages including:

1. Using of non-renewable source (petroleum products)
2. Low efficiency
3. Requires a lots of maintenance work
4. Waste of resources and materials
5. High production cost affecting selling price
6. Requires special and experienced employment
7. Environmental pollution
8. Low level safety
9. Lots of design considerations and limitations
10. Requires user prior knowledge of operation of such vehicles

That's why the world is working to develop electrical vehicles since they are environmental friendly, and highly efficient compared to I.C.E vehicles; however electrical vehicles never got the proper attention they deserve until tesla released their roadster in 2008 that can achieved 245 miles (394 km) on a single charge, accelerate from 0 to 60 miles (96 km) per hour in less than 4 seconds and could reach a top speed of 125 miles (200 km) per hour that could rival that of many gasoline-powered sports cars at the time which caused lots of countries to fund researches about electrical vehicles.

FIGURE 1 2008 Tesla roadster

That's why this project will try to design an electrical vehicle that assists workers in their work areas but the vehicle is not designed to operate in off-road conditions. That's why it's highly un recommended to use the vehicle in public roads.

Objectives

Since the project is still in progress, it will be inappropriate to state a clear list of objectives that may not be achieved due to academic and/or financial limitations, however the project will tend to:

1. Design a 100% direct current vehicle that relies on direct current components other than alternating current components.
2. Create power management system that optimizes the usage of power based on real-time data.
3. Design an environmental friendly vehicle.
4. Design an easy to use vehicle that doesn't need prior training to use.
5. Easy in maintenance that doesn't require special technicians.
6. Manufactured from components that are available in the local market.
7. The Design will tend to reach the following specifications:
    - Maximum Loading capacity: 200 kilograms
    - Maximum speed: up to 25 km/h
    - Operating time: 60 minutes (at 50 km/h)
    - Vertical step: 0.3 meters
    - Side slope: 20%
    - Gradient: 40%
    - Fording: 0.23 meters

    Note that any of these specifications may be altered depending on real-time testing of the project and components, market availability and reliability.

Methodology

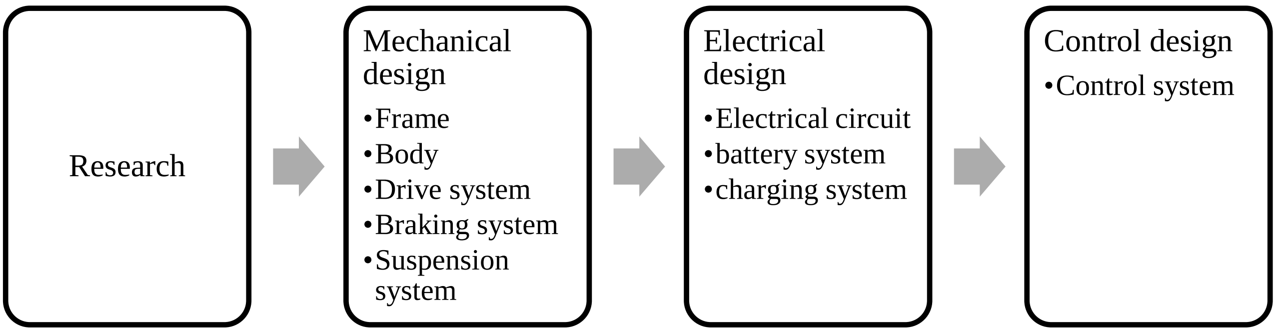


FIGURE 2 Methodology diagram

The project will start with research. This research implemented methodology of research as follow:

- Market research and collect date
- Analysis data an get the alternative
- Selection of row materials (components, sensors, software, and…..)
- Design of (WEV) Worker Electric Vehicle
- Experiment work and measurement

The project will proceed with mechanical design which will define how the vehicle will look like along with providing clear details about how system will move mechanically and which system will be used in driving it and stopping it.

After mechanical parameters and limitation are set, an electrical system will be used to turn that mechanical static elements into dynamic system in terms of electrical elements will be used as motor, batteries and user interface unit and how each connect with each other along with stating how batteries will be charged.

Control design will provide system with control using control unit that controls all electrical elements using control parameters that will be provided via system's mathematical model to determine the desired performance, also control design will provide system with some features as power management system and speed control.

Finally, implementing all of the design elements together to fit into final product that also will help determining its cost as prototype and what additions can be added in the future.

This research contains eight chapters as follows:

- Chapter one : Introduction
- Chapter two : Literature review
- Chapter three : Design
- Chapter four : Modeling, simulation and calculations
- Chapter five : Hardware implementation
- Chapter six : Conclusion

CHAPTER TWO

LITERATURE REVIEW

Chapter Two: Literature review

Introduction

This chapter will discuss the history of electrical vehicles

Historical review

Electrical vehicles passed through different historical periods that made it clear to the world that electrical vehicles are the future of transportation starting from 19th century until today, these periods are:

1832 ~ 1839: Robert Anderson of Scotland built the first prototype electric carriage.

1834: Thomas Davenport of the USA invented the first direct current electrical motor in a car that operates on a circular electrified track.

1888: German engineer Andreas Flocken built the first four-wheeled electric car.

1897: The first commercial EVs entered the New York City taxi fleet. The Pope Manufacturing Company became the first large-scale EV manufacturer in the USA.

1899: The 'La Jamais Contente' (The Never Happy!), built in France, became the first electric vehicle to travel over 100 km/h.

FIGURE 3 La jamais contente vehicle

1900: Electricity-powered cars were the bestselling road vehicle in the USA with about 28% of the market.

1908: The petrol-powered Ford Model T was introduced to the market.

1909: William Taft was the first US President to buy an automobile, a Baker Electric.

FIGURE 4 William taft’s baker electric vehicle

1912: The electric starter motor was invented by Charles Kettering. This made it easier to drive petrol cars because hand cranking was not now necessary. The global stock of EVs reached around 30,000.

1930 ~ 1935 : the number of EVs dropped almost to zero and ICE vehicles dominated because of cheap petrol.

1947: Oil rationing in Japan led carmaker Tama to release a 4.5 horsepower electric car. It used a 40V lead-acid battery.

1966: US Congress introduced legislation recommending EVs as a way of reducing air pollution.

1973: The OPEC oil embargo caused high oil prices, long delays at fuel stations, and therefore renewed interest in EVs.

1976: The French government launched the ‘PREDIT’, which was a programme accelerating EV research and development.

1996: To comply with California’s Zero Emission Vehicle (ZEV) requirements of 1990, GM produced the EV1 electric car.

1997: In Japan, Toyota began sales of the Prius, the world's first commercial hybrid car. Eighteen thousand were sold in the first year.

2008: Oil prices reached record highs.

2010: The Nissan LEAF was launched.

FIGURE 5 NISSAN LEAF

2011:

1. The world's largest electric car sharing service, Autolib, was launched in Paris with a targeted stock of 3,000 vehicles.
2. The global stock of EVs reached around 50,000. The French government fleet consortium committed to purchase 50,000 EVs over four years. Nissan LEAF won the European Car of the Year award.

2012: The Chevrolet Volt PHEV outsold half the car models on the US market. The global stock of EVs reached around 180,000.

FIGURE 6 Chevrolet volt

2014: Tesla Model S, Euro NCAP 5-star safety rating, autopilot-equipped, available all-wheel drive dual motor with 0–60 mph in as little as 2.8 seconds and a range of up to 330 miles.

2015: Car manufacturers were caught cheating emission regulations making EVs more prominent in people's minds as perhaps the best way to reduce consumption and emissions. The global stock of EVs reached around 700,000 and continues to grow (22,000 in the UK and 275,000 in the USA).

Electrical vehicles in the period late 19th century till beginning of 20th century where viewed as city vehicles although some of these vehicles have functionality to recharge on the road. The speed was controlled using lever mechanism that allows them to switch between different power modes. The drive system can be divided into direct drive (motor shaft is connected to the main shaft of the vehicle) and chain drive (motor is connected to the main shaft of the vehicle using sprocket - chain system).

As for modern vehicles, each aspect of them will be discussed prior to how it is designed.

CHAPTER THREE

DESIGN

Chapter Three: Design

Introduction

This chapter will be divided into:

CHAPTER 3.1 Mechanical design

CHAPTER 3.2 Electrical design

CHAPTER 3.3 Control design

3.1 Mechanical design

Introduction

This chapter will discuss mechanical design of the vehicle which includes how vehicle is designed mechanically and analyzed mathematically. The parts are divided into:

1. Static Elements (elements that aren't directly involved in vehicle's motion):
   i) Frame
   ii) Body
2. Dynamic Elements (elements that are directly involved in vehicle's motion):
   i) Drive system
   ii) Braking system
   iii) Suspension system

The standard ANSI/ILTVA Z130.1-2012 considerations were taken in mind while designing the vehicle. Each element will be discussed in details.
Please be noted that the project is still in design phase therefore some of technical data might be missing due to some factors including market availability and uncertain technical data provided by market's suppliers.

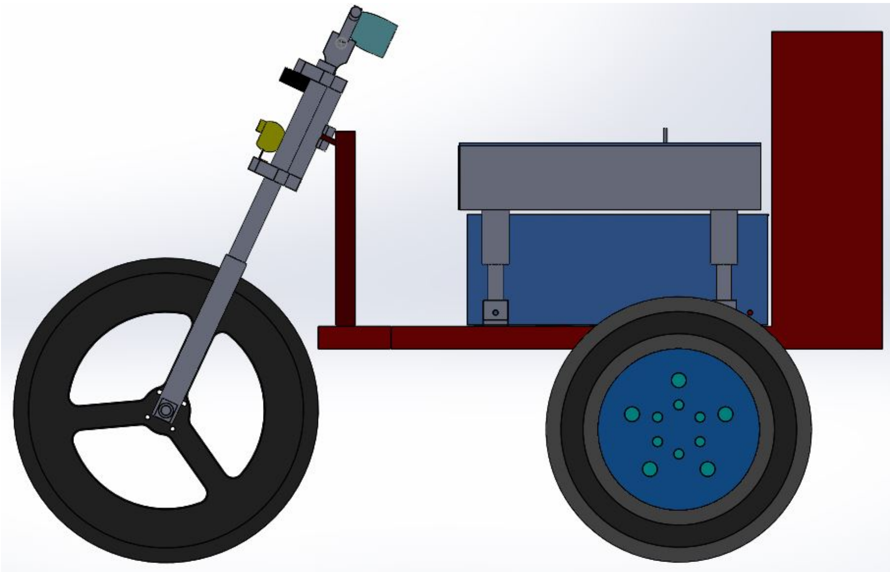


FIGURE 7 Vehicle side view

Static elements

Frame

Theory

- A frame is the main structure of vehicle. All other components fasten to it.
- The frames are made of the following steel sections:
    (1) Channel section
    - Channel section is used in long members of the frame.
    - The channel section is good for bending stress.

    (2) Box section
    - Box section is used in short members of the frame.
    - The box section is good for both bending and torsion stresses.

    (3) Tubular section.
    - Tubular section is used these days in three-wheelers, scooters and matadors, pick-ups frames.
    - The tubular section is good for torsion stress.
- Frames can classified into:
    (1) Conventional Frame:
    - It is also known as non-load carrying frame.
    - The loads on the vehicles are transferred to the suspensions by frame.
    - It is not suited to resist torsion.

    (1) Semi Integral Frame:
    - In this type of frame load is transferred to the body structure also.
    - It has the advantage when the vehicle is met with accident the Front frame can be taken easily to replace the damaged chassis frame.
    - Half frame is fixed in the front end on which engine gear box and front suspension is mounted.

    (2) Integral Frame:
    - In this type of construction there is no frame and all assembly units are attached to the body.
    - The chassis, floor and body are assembled by from a large number of mild steel pressings.
    - All the functions of the frame carried out by the body itself.

- Due to elimination of long frame, it is cheaper and due to less weight most economical.

- Types of frames are:
  (a) Ladder Frame
    - It consists of two symmetrical rails, or beams, and cross member connecting them.
    - This design offers good beam resistance because of its continuous rails from front to rear, but poor resistance to torsion.
    - the vehicle's overall height will be higher due to the floor pan sitting above the frame instead of inside it

  (b) Backbone Frame
    - A type of an automobile construction frame that is similar to the body-on frame design.
    - it consists of a strong tubular backbone (usually rectangular in cross section) that connects the front and rear suspension attachment areas.
    - The whole drivetrain, engine & suspensions are connected to both ends of the backbone.
    - Easy to be manufactured by hand thus heap for low volume production.
    - Does not provide protection against side impact or crash.

  (c) X-frame
    - The rails from alongside the engine seemed to cross in the passenger compartment, each continuing to the opposite end of the cross member at the extreme rear of the vehicle.
    - Decreases the overall height of the vehicles, and to increase in the space for transmission.

  (d) Perimeter Frame
    - Similar to a ladder frame, but the middle sections of the frame rails sit outboard of the front and rear rails.
    - This was done to allow for a lower floor pan, and therefore lower overall vehicle in passenger cars.
    - Perimeter frame allows lower seating positions when that is desirable, and offers better safety in the event of a side impact.
    - The design lacks stiffness, because the transition areas from front to center and center to rear reduce beam and torsional resistance.

  (e) Platform Frame

- This is a modification of the perimeter frame in which the passenger compartment floor and often the luggage compartment floor were permanently attached to the frame, for extra strength.
- Neither floor pieces were sheet metal straight off the roll, but had been stamped with ridges and hollows for extra strength.

(f) Uni-body or Unit body

- The frame and body are constructed as a single unit.
- This became the preferred construction for mass market automobiles

(g) Sub Frame

- A sub frame is a structural component of a vehicle.
- It uses a separate structure within a larger body-on-frame or unit body to carry certain components, such as the engine, drivetrain, or suspension.
- The sub frame is bolted and/or welded to the vehicle.
- Spread high chassis loads over a wide area of relatively thin sheet metal of a monocoque body shell, and to isolate vibration and harshness from the rest of the body.
- Separate front and rear sub frames are used to reduce the overall weight and cost.

Design

The frame is made of two 3 mm sheet metal and reinforced in a structure similar to Sandwich-structured composite using 40*40*2 mm box section galvanized steel bars along be connected by welding or mechanical joints. The frame type is platform since the entire vehicle body is based a platform.

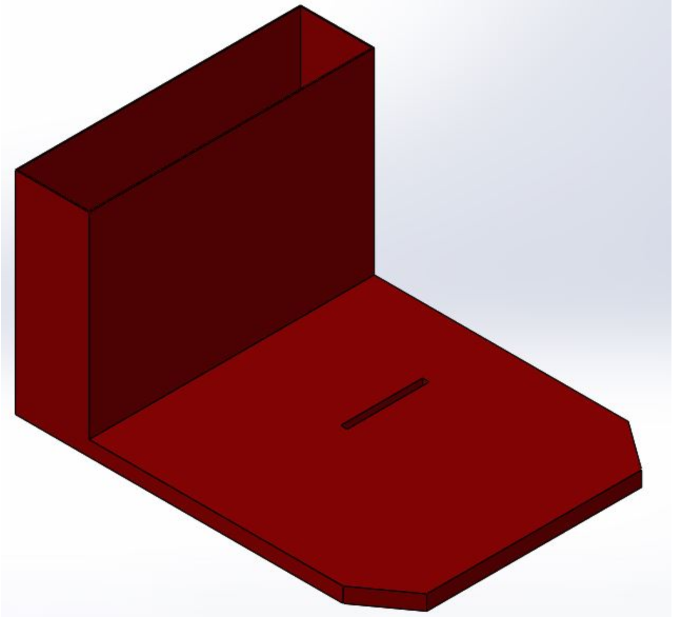


FIGURE 8 Vehicle frame

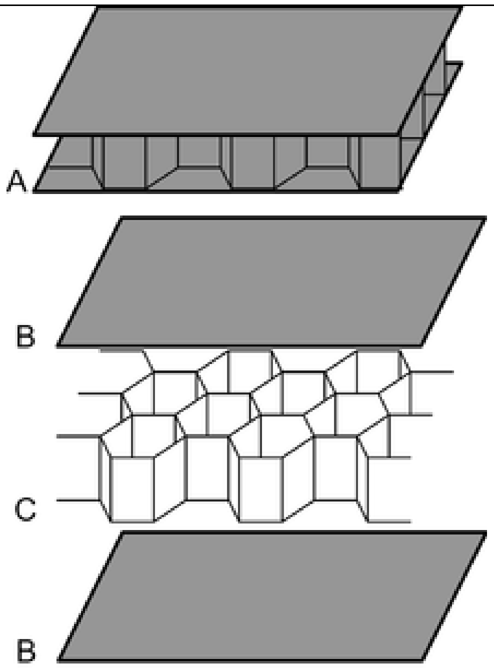


FIGURE 9 Sandwich-structured composite concept (honeycomb structured foam)

Body

Design

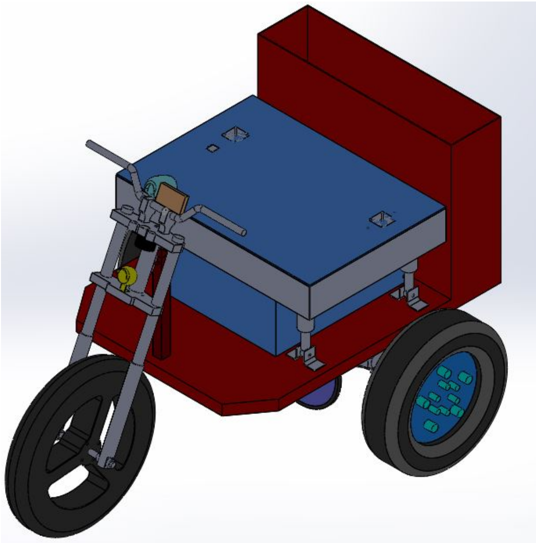


FIGURE 10 Vehicle assembled

Althought the frame type is platform , it is also the frame ;however , there are some elements are needed including:

1. A large toolbox that allows user to place their tools
2. Seat with design considerations:
   i. Knee angle (smaller number means more bent)
   ii. Hip angle: (smaller number means more crouched)
   iii. User's height
   iv. Rider's triangle which is the distance between driver seat point and handle bar point and the ground

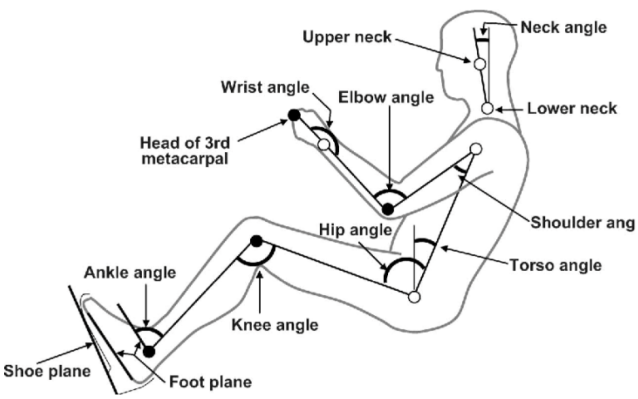


FIGURE 11 Passenger seat angles

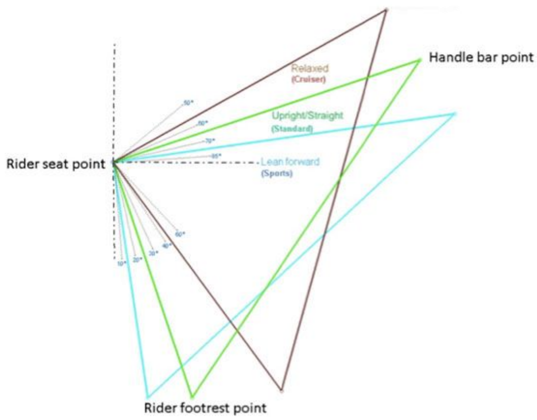


FIGURE 12 Rider triangle

3. Positon of front fork with the following considerations:
    v. Rake angle (usually between 17^o to 25^o)
    vi. Trail (usually between 55 to 75 mm)

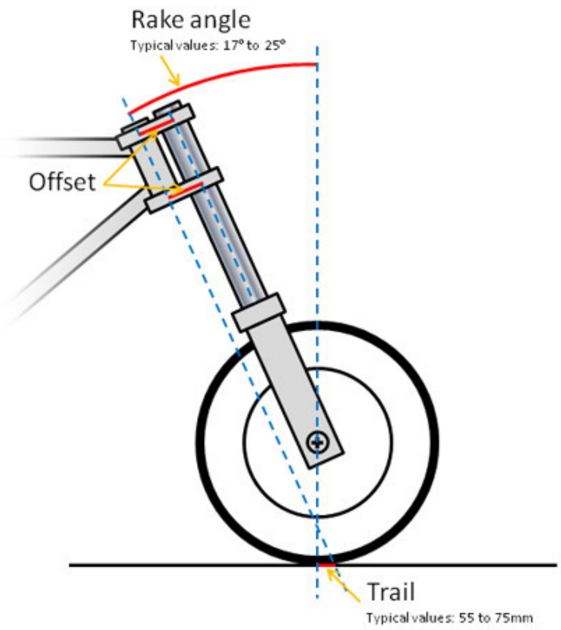


FIGURE 13 Front fork (used for steering)

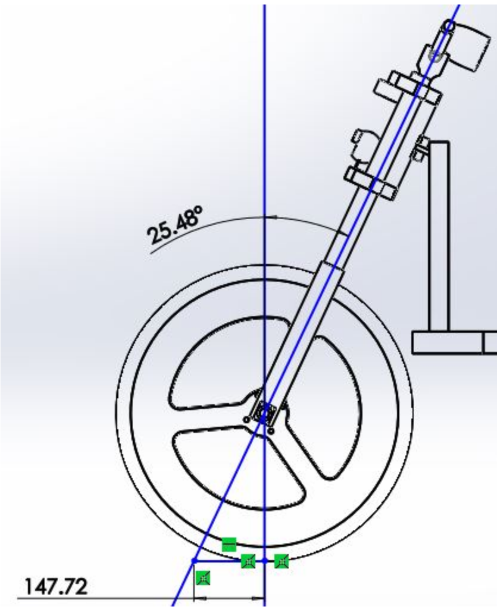


FIGURE 14 Vehicle front fork

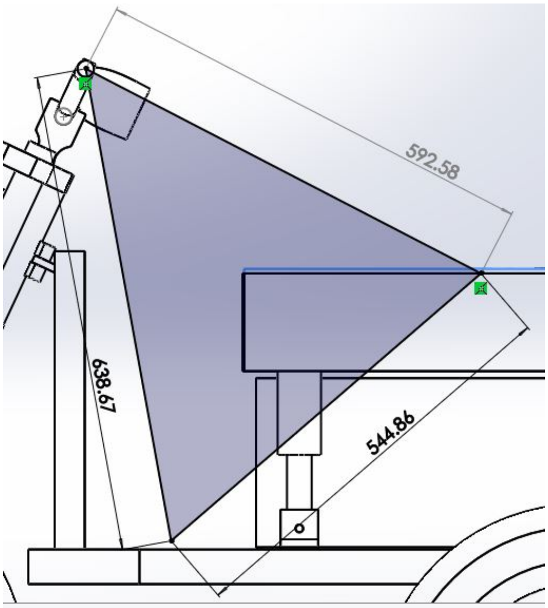


FIGURE 15 Vehicle's rider triangle

Dynamic elements

Drive system

Theory

There are two types of drive systems that are used in vehicles:

Table 1 Comparison between gear drive and chain drive

Gear Drive	Chain Drive
Gear drive is one engagement type mechanical drive as power and motion are transferred by means of successive engagement and disengagement of teeth of mating gears.	Chain drive is also one engagement type mechanical drive but power and motion are transferred by means of successive engagement and disengagement of chain with sprocket.
No additional element is required in gear drive (only two gears are sufficient for power transmission).	In chain drive, apart from two sprockets, a chain is indispensably necessary for power transmission.
It is not one flexible drive. Thus, it cannot protect the driver unit from vibrations induced in driven unit.	Presence of flexible element like chain makes it one flexible drive. It can easily isolate vibrations, and thus can protect the driver.
Gear drive is suitable for small center distance between driver and driven shafts	Chain drive can be employed for short as well as medium center distances between driver and driven shafts.
For the same center distance, gear drive requires more space. The drive unit is also heavy.	Chain drive is compact and thus space efficient. Drive unit is light in weight
Gear dive requires precise center distance otherwise performance will degrade sharply	Centre distance is not so critical for chain drive. A small error is tolerable without much effect.
Gear drive requires full lubrication. For best performance and longer life in heavy duty applications, gears must be partially immersed into lubricating oil.	Chain drive also requires lubrication to reduce noise and wear of joints; however, it does not require full lubrication (periodic lubrication is sufficient).
Gear drive can be utilized for parallel (spur and helical gears), intersecting (bevel gear), and non-intersecting non-coplanar (worm gear) shafts.	Chain drive is suitable for parallel shafts only.
Operation of gear drive is quiet.	Operation of chain drive is noisy.
A wide range of velocity reduction (1:1 to 1:40) is possible with gear	Chain drive is not suitable for high velocity reduction. It can be used when

drive	reduction is up to 1:10.
Gear drive offers positive drive and velocity ratio remains constant.	Chain drive is not true positive drive. Although it is free from slip, but velocity ratio may vary due to polygonal effect.
With gear drive, the driver and driven shafts rotate in opposite direction.	With chain drive, the driver and driven shafts rotate in same direction.
They are not ideal for large velocities	It allows high speed ratio of 8 to 10 in one single step
They give a low transmission efficiency due to fiction between gears teeth	They give a high transmission efficiency of up to 98 percent

- Chain drive was selected as main drive due to:
    (a) It allows high speed ratio of 8 to 10 in one single step
    (b) it does not require full lubrication
    (c) it is compact and light in weight
    (d) It can easily isolate vibrations, and thus can protect the driver.
- Chain and Sprocket Selection Procedure Steps:

1. Determine class of driven load.

Table 2 Types of load

Uniform Load	Moderate Shock Load	Heavy Shock Load
• Agitators, Liquid • Generators • Blowers, Centrifugal • Line Shafts, Even Load • Conveyors, Even Load • Machines, Even Load, • Elevators, Even Load • Non-reversing Pumps, Centrifugal • Fans, Centrifugal	• Beaters • Laundry - Washers and Tumblers • Compressors, Centrifugal • Line Shafts, Uneven Load • Machines, Pulsating • Load, Non-reversing • Pumps, Reciprocating, Triplex • Screens, Rotary, Even Load • Woodworking Machinery • Kilns and Dryers • Grinders, Pulp • Elevators, Uneven Load • Conveyors, Uneven Load	• Brick Machines • Machines, Reversing or Impact Loads • Presses • Crushers • Compressors, Reciprocating • Mills, Hammer, Rolling or Drawing • Pumps, Reciprocating, Simplex or Duplex • Machines, Reversing or Impact Loads

2. Select service factor.

Table 3 Service factor

SERVICE CLASSIFICATION	TYPE OF INPUT POWER		
	Internal Combustion Engine with Hydraulic Drive	Electric Motor or Turbine	Internal Combustion Engine with Mechanical Drive
Uniform Load	1.0	1.0	1.2
Moderate Shock Load	1.2	1.3	1.4
Heavy Shock Load	1.4	1.5	1.7

3. Calculate design horsepower.
   - Multiply the normal operating horsepower of the drive by the Compensated Service Factor to obtain Service Horsepower.
4. Select chain pitch.
   - From table (5) in appendix A
5. Select number of teeth in small sprocket.
   - Usually it is assumed value within 7 to 27 teeth range
   - If small sprocket teeth are less than 20 teeth, teeth hardening is required
6. Determine number of teeth in larger sprocket.
   - Reduction ration= larger sprocket teeth / small sprocket small sprocket.
   - After calculating reduction ration can be found from table (6) in appendix A
7. Determine center distance.

$$C = \frac{P}{8}\left\{ 2L - N - n + \sqrt{(2L - N - n)^2 - 0.810\,(N - n)^2} \right\}$$

8. Calculate chain length.

$$L = 2C + \frac{N + n}{2} + \frac{.1013\,(N - n)^2}{4C}$$

Braking system

Theory

- There are two types of braking systems used in motorcycles/ 3-wheeled vehicles:
    1. Disc Brakes: Disc brake systems employ a round, solid steel plate or disc attached to the rotating wheel. Two fiber brake pads or “pucks” are located in a caliper assembly that is attached firmly to the fork or swing arm. When the brakes are applied these pads are squeezed together against both sides of the disc, creating the friction and heat needed to stop the bike. The disc brake is superior to the drum brake because it is fade resistant, smoother operating, self-cleaning, and easier to service. Most disc brakes employ a “floating calipers where the caliper can slide on its bracket. This enables the caliper to move sideways during engagement to insure firm contact by both brake pads even though only one pad is activated.

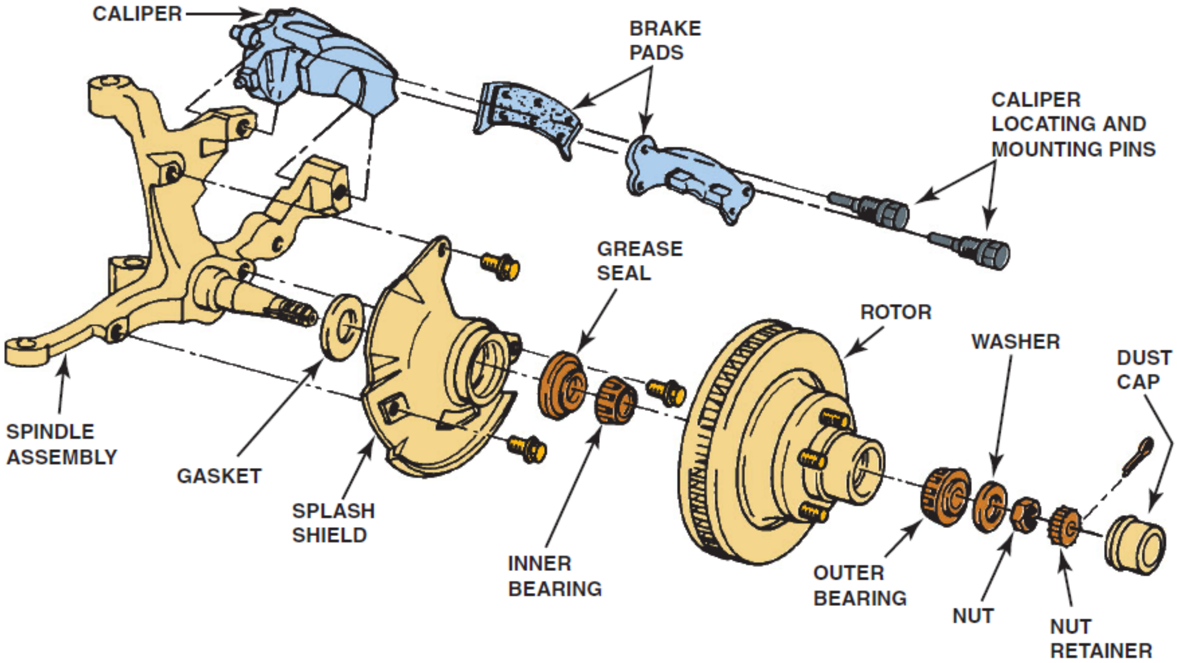


FIGURE 16 Disc brake exploded view

2. Drum Brakes: Drum brake operation is fairly simple. The most important feature contributing to the effectiveness of the braking force supplied by the drum brake is the brake shoe pressure or force directed against the drum. With the vehicle moving in either the forward or reverse direction with the brakes on, the applied force of the brake shoe pressing against the brake drum increasingly multiplies itself (called self-energizing) because the brake's anchor pin acts as a brake shoe stop and prohibits the brake shoe from its tendency to follow the movement of the rotating drum. The result is a wedging action between the brake shoe and brake drum. The wedging action combined with the applied brake force creates a self-multiplied brake force.

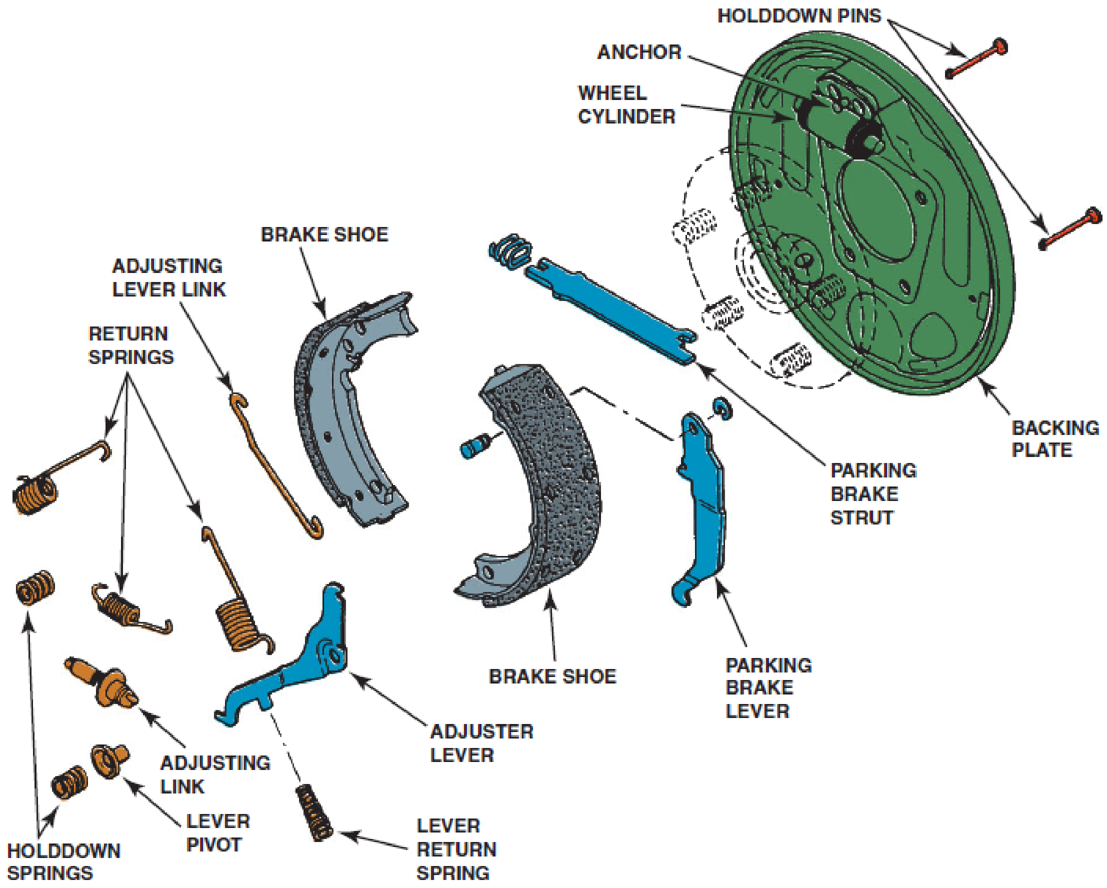


FIGURE 17 Drum brake exploded view

- Disk brake was selected although drum brakes have the advantages of self-energization and ease of parking brake incorporation, they suffer from several disadvantages. Their heat dissipation is problematic, and drum brakes are prone to brake fade as the drum becomes hot due to extended or frequent heavy braking. Also, drum brakes are very sensitive to moisture or contamination inside the drum. Any water in the drum rapidly vaporizes under braking, causing the coefficient of friction of the shoe to become nearly zero.
- Disk brake analysis :

1- Calculate front and rear weight

$$W_r = \frac{mgc}{(c+d)} \quad , \quad W_f = \frac{mgd}{(c+d)}$$

2- Calculate braking front and rear weight

$$W_f' = \frac{mgd}{c+d} + \frac{ma_x h}{c+d}$$

$$W_r' = \frac{mgc}{c+d} - \frac{ma_x h}{c+d}$$

3- Calculate weight distribution

$$W_{dist,front} = \frac{W'_f}{mg} \, , W_{dist,rear} = \frac{W'_r}{mg}$$

4- Calculate Force

$$F = \frac{\Delta\theta}{4} p_a d(D-d)$$

5- Calculate Torque

$$T = \frac{F\mu}{4}(D+d)$$

$$T = \frac{\Delta\theta}{16}\mu p_a d\left(D^2 - d^2\right)$$

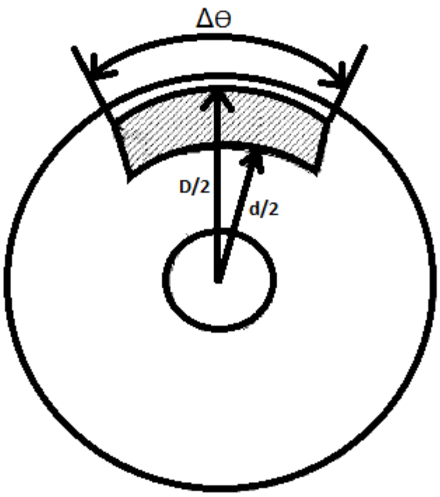


FIGURE 18 Disk brake diagram

6- Calculate vehicle's deceleration time and braking energy

$$t = \frac{V_o}{a} \quad , \quad E = P \times t \quad , \quad \Delta KE = \frac{1}{2} m V_o^2 + \frac{1}{2} I \omega_o^2$$

$$E_{\text{braking}} = E \times \frac{W'_{\text{dist,brakes}}}{no.\,of\text{wheels}}$$

7- Calculate change in temperature

$$\Delta T = \frac{E}{m c_v}$$

Suspension system

Theory

A vehicle suspension’s main function is to absorb the impact and vibration of the wheels that result from the uneven fluctuation of the road surface. It is used to transmit the force and torque from the handlebar to the wheels. It also plays an important role on the vehicle ride comfort and safety. The suspension is divided into:

1. Front suspension:

- It is maintained by front fork that is used in steering
- The most common used front fork is telescopic fork.
- There are other types of front fork as Telelever, Hossack, Double wishbone, and Hub Centre Steering (HCS).
- Telescopic fork consists of handlebar that end-user use to control vehicle direction (steer), triple trees that connects fork to the rest of vehicle, shock absorber that absorb vibration, and an axle where steering wheel is placed.

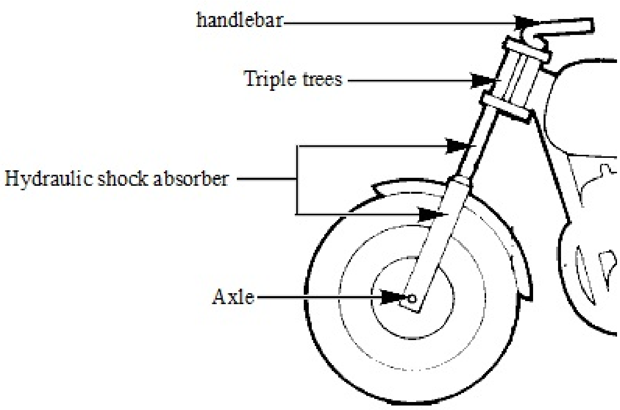


FIGURE 19 Telescopic fork components

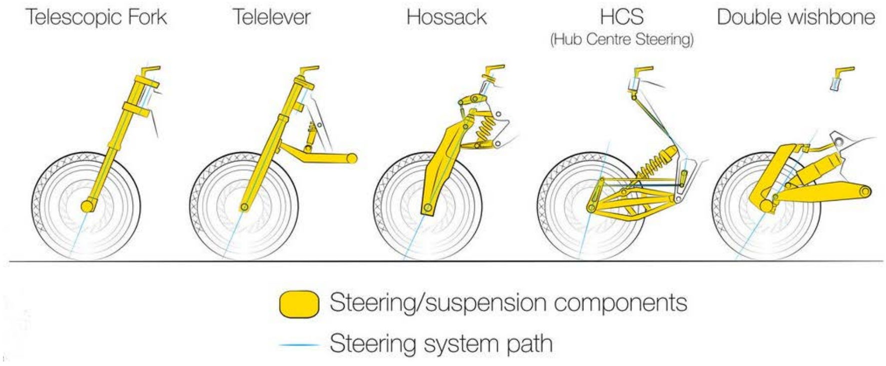
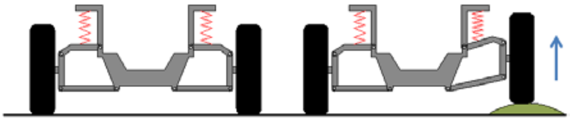


FIGURE 20 Types of front fork

2. Rear suspension:

- Suspension is placed on driver seat
- There are two types of suspension:

Table 4 Independent and dependent suspension

 FIGURE 21 Independent suspension	 FIGURE 22 Dependent suspension
Independent: Each wheel of an independent suspension system has a different reaction to road conditions, meaning that a bump on one side is not to cause a reaction on the other.	Dependent: a solid axle that goes across the width of the frame. It allows the wheels on both the left and the right side to be connected and operate together.

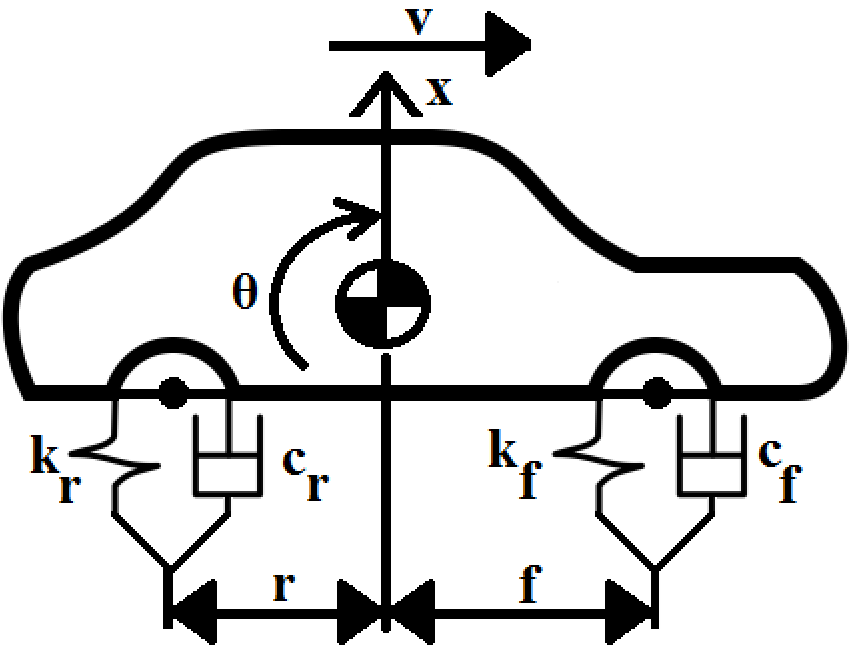


FIGURE 23 Car diagram for analysis

Vibrational Analysis of the vehicle will be made based on half car model which is two degree of freedom system which takes following steps:

1. Establish mathematical model for the system:

$$\begin{bmatrix} m & 0 \\ 0 & mk^2 \end{bmatrix} \begin{Bmatrix} \ddot{x} \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} c_f + c_r & c_f f - c_r r \\ c_f f - c_r r & c_f f^2 + c_r r^2 \end{bmatrix} \begin{Bmatrix} \dot{x} \\ \dot{\theta} \end{Bmatrix} + \begin{bmatrix} k_f + k_r & k_f f - k_r r \\ k_f f - k_r r & k_f f^2 + k_r r^2 \end{bmatrix} \begin{Bmatrix} x \\ \theta \end{Bmatrix} = \begin{Bmatrix} F(t) \\ M(t) \end{Bmatrix}$$

2. To calculate natural frequency and mode shapes , remove damping effect:

$$\begin{bmatrix} m & 0 \\ 0 & mk^2 \end{bmatrix} \begin{Bmatrix} \ddot{x} \\ \ddot{\theta} \end{Bmatrix} + \begin{bmatrix} k_f + k_r & k_f f - k_r r \\ k_f f - k_r r & k_f f^2 + k_r r^2 \end{bmatrix} \begin{Bmatrix} x \\ \theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}$$

3. the absence of damping, the solution to the equations of motion will be sinusoidal

$$x = X \sin(\omega t)$$
$$\theta = \Theta \sin(\omega t)$$

4. Differentiate the solutions twice and substitute them in mathematical model:

$$\begin{bmatrix} \frac{k_f + k_r}{m} - \omega^2 & \frac{k_f f - k_r r}{m} \\ \frac{k_f f - k_r r}{mk^2} & \frac{k_f f^2 + k_r r^2}{mk^2} - \omega^2 \end{bmatrix} \begin{Bmatrix} X \\ \Theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}$$

5. Assume the following equations for solution simplicity:

$$A = \frac{k_f + k_r}{m}, \quad B = \frac{k_f f - k_r r}{m}, \quad C = \frac{k_f f^2 + k_r r^2}{mk^2}, \qquad \begin{bmatrix} A - \omega^2 & B \\ \frac{B}{k^2} & C - \omega^2 \end{bmatrix} \begin{Bmatrix} X \\ \Theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix}$$

6. Solve the equation to find natural frequencies:

$$\omega^2 = \frac{(A + C) \pm \sqrt{(A + C)^2 - 4\left(AC - \frac{B^2}{k^2}\right)}}{2}$$

7. Calculate the mode shapes:

$$\left[[K] - [M]\omega_1^2\right]\{u_i\} = \{0\}, \qquad \{u_i\} = \begin{Bmatrix} X_i \\ \Theta_i \end{Bmatrix}$$

8. Mode shapes are:

$$(u)_1 = \begin{Bmatrix} 1 \\ \frac{\omega_1^2 - A}{B} \end{Bmatrix}, \qquad (u)_2 = \begin{Bmatrix} 1 \\ \frac{\omega_2^2 - A}{B} \end{Bmatrix}$$

Steering system

Theory

There are two types of steering configurations in three wheeled vehicles:

1. Tadpole configuration:

Typically have a lower center of gravity placing the rider "in" the vehicle more than "on." Having two wheels in front also makes them corner slightly better at speed, with two wheels offering more stability to resist cornering forces. However, being lower, they may not be as easy to get in and out of, so this is certainly a point to consider if your mobility is limited. They also typically have a larger turning radius than delta vehicle, so may not be the best choice if you need to maneuver in tighter places.

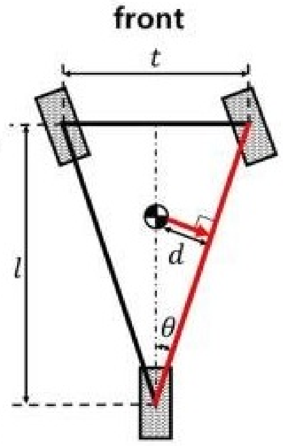


FIGURE 24 TADPOLE CONFIGURATION

To sum up, tadpoles are often a good choice when speed and stability is prioritized over maneuverability and when the rider can easily get in and out of the lower seated riding position.

2. Delta configuration:

Tend to be more versatile and maneuverable. The front wheel on most designs can turn almost 90 degrees, giving the trike a very tight turning circle; the radius is nearly its own length. They are also slightly easier to get on and off of, for those riders for whom mobility is a concern. More unique to the delta design is that they can also be linked together, providing more options for riders who may not be able to operate a single trike safely on their own.

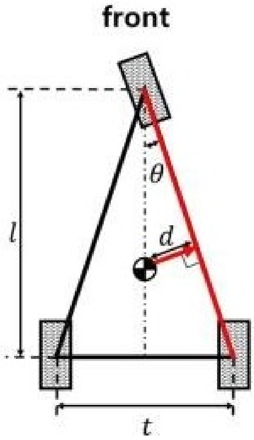


FIGURE 25 DELTA CONFIGURATION

Delta trikes are usually the best choice when maneuverability and versatility are a priority over all out speed. They are also better for individuals with limited mobility since they are very easy to get on and off.

- Delta steering configuration was selected since it provide wider steering angle than tadpole meaning that the vehicle will be able to turn in tight tracks and roads of any facility also provide easy riding position for any worker regardless of his medical condition lastly it’s the ideal configuration that allow to add a storage box in the back
- To calculate steer angle range (for low speed turns):

  $$\delta_o = \frac{L}{R+\frac{t}{2}} \ , \delta_i = \frac{L}{R-\frac{t}{2}}$$

  Where: $\delta_o \leq \delta \leq \delta_i$
- These equations gives you steering angle limits and get the average by calculating their mean or using Ackerman angle:

  $$\delta_{avg} = \frac{L}{R} \ (radians) \ , \delta_{avg} = \frac{5.73L}{R} \ (degrees)$$

3.2 Electrical design

Introduction

The electrical design of the vehicle is the design and selection of every individual electrical element that is going to be used in the embedded design chapter in order to control the vehicle, these elements are:

1. DC motor: The main driving element of the vehicle
2. Motor driver: the controlling element of the DC motor
3. Headlamp: The lighting element used to light up driver’s path during night
4. Throttle handlebar: The main element used to control the vehicle’s speed
5. Battery: The main power supply of the system
6. Battery’s Charging unit: The unit that is responsible for charging the vehicle’s battery

Each of these elements will discussed in this chapter in terms of theoretical approach.

DC motor

Theory

There are five types of motors that can be used to drive a vehicle:

1. Separately exited (Permanent Magnet) DC motor:

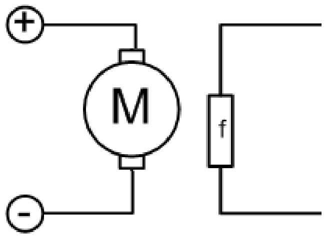


FIGURE 26 PM Motor circuit diagram

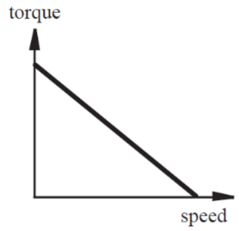


FIGURE 27 Speed-Torque curve (PM motor)

The most common BDC motors found in the world. These motors use permanent magnets to produce the stator field. PMDC motors are generally used in applications involving fractional horsepower because it is more cost effective to use permanent magnets than wound stators. The drawback of PMDC motors is that the magnets lose their magnetic properties over time. Some PMDC motors have windings built into them to prevent this from happening. The performance curve (voltage vs. speed), is very linear for PMDC motors. Current draw also varies linearly with torque. These motors respond to changes in voltage very quickly because the stator field is always constant.

2. Shunt-wound DC motor:

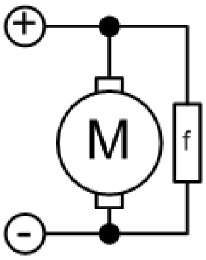


FIGURE 28 Shunt Motor circuit diagram

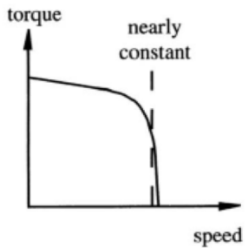


FIGURE 29 Speed-Torque curve (Shunt Motor)

Shunt-wound Brushed DC (SHWDC) motors have the field coil in parallel (shunt) with the armature. The current in the field coil and the armature are independent of one another. As a result, these motors have excellent speed control. SHWDC motors are typically used applications that require five or more horsepower. Loss of magnetism is not an issue in SHWDC motors so they are generally more robust than PMDC motors.

3. Series-wound DC motor:

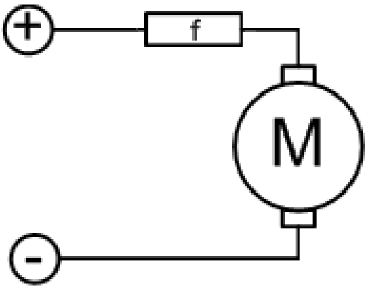


FIGURE 30 Series Motor circuit diagram

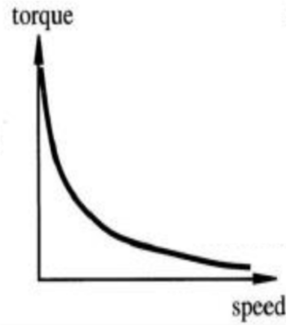


FIGURE 31 Speed-Torque curve (Series Motor)

Series-wound Brushed DC (SWDC) motors have the field coil in series with the armature. These motors are ideally suited for high-torque applications because the current in both the stator and armature increases under load. A drawback to SWDC motors is that they do not have precise speed control like PMDC and SHWDC motors have.

4. Compound DC motor:

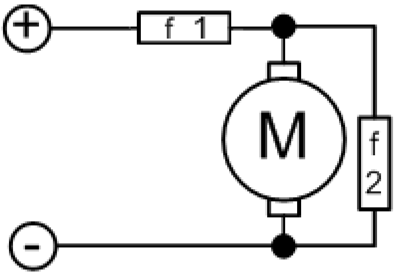


FIGURE 32 Compound Motor circuit diagram

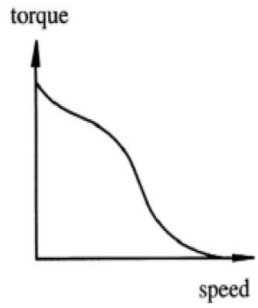


FIGURE 33 Speed-Torque curve (Compound Motor)

Compound Wound (CWDC) motors are a combination of shunt-wound and series-wound motors. As shown in Figure 5, CWDC motors employ both a series and a shunt field. The performance of a CWDC motor is a combination of SWDC and SHWDC motors. CWDC motors have higher torque than a SHWDC motor while offering better speed control than SWDC motor.

5. Universal motor

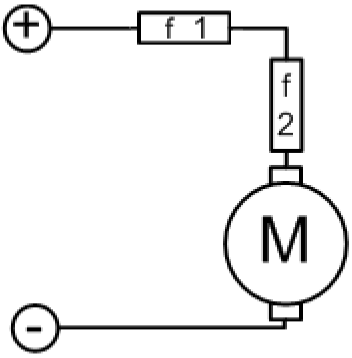


FIGURE 34 Universal Motor circuit diagram

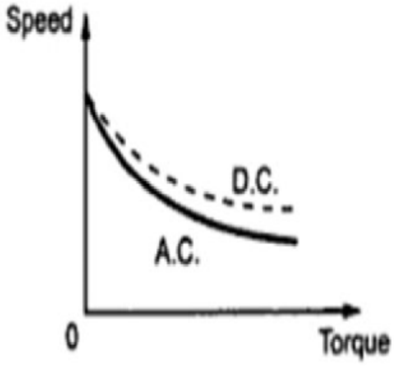


FIGURE 35 Speed-Torque curve (Universal Motor)

The universal motor is a type of electric motor that can operate on either AC or DC power and uses an electromagnet as its stator to create its magnetic field. It is a commutated series-wound motor where the stator's field coils are connected in series with the rotor windings through a commutator. It is often referred to as an AC series motor. The universal motor is very similar to a DC series motor in construction, but is modified slightly to allow the motor to operate properly on AC power. This type of electric motor can operate well on AC because the current in both the field coils and the armature (and the resultant magnetic fields) will alternate (reverse polarity) synchronously with the supply. Hence the resulting mechanical force will occur in a consistent direction of rotation, independent of the direction of applied voltage, but determined by the commutator and polarity of the field coils.

To calculate torque required for motor:

1. Calculate Rolling Resistance between the wheels and the ground:

$$RR = GVW \times C_{rr}$$

2. Determine Grade Resistance which is the resistance that the vehicle will oppose due to road's inclination:

$$GR = GVW \times \sin\theta_{road}$$

3. Determine Acceleration Force that the vehicle will take to reach desired speed:

$$FA = m \times a$$

Where: $m = GVW / g$

4. Determine Total Tractive Effort which is the sum of all forces affecting the motor:

$$TTE = RR + GR + FA$$

5. Determine Wheel Motor Torque:

$$\tau = R_f \times TTE \times r_{wheel}$$

6. Verification to make sure that the calculation is true:

$$\tau_{\max} = (\mu \times GVW \times f \times r_{wheel}) / 2$$

Where the calculations become true if: $\tau_{\max} \geq \tau$

Motor Driver

Theory

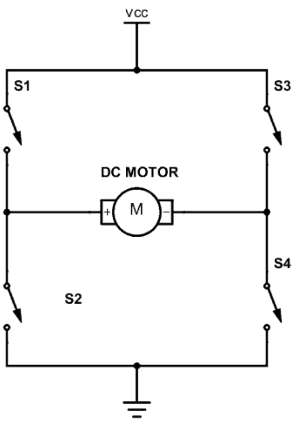


FIGURE 36 H-bridge diagram

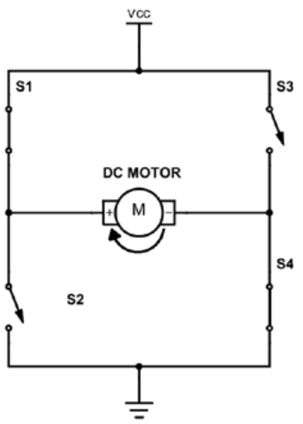


FIGURE 37 H-bridge operation diagram

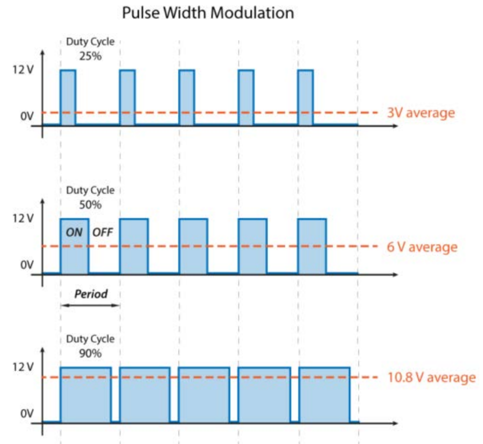


FIGURE 38 PWM (pulse width modulation) illustration

Any motor driver (also called H-bridge) consists of group of transistors (MOSFETS) that acts as switch controlling current path to the DC motor controlling its direction and uses PWM (pulse width modulation) to control speed.

PWM (pulse width modulation) is a technique which allows controller to adjust the average value of the voltage that's going to the DC motor by turning on and off the power at a fast rate sending a periodic pulse signal. The average voltage depends on the duty cycle, or the amount of time the signal is ON versus the amount of time the signal is OFF in a single period of time.

Electric vehicles usually use a motor controller which is motor driver along with a current sensor to measure motor usage, a protection circuit in case of overloading or overheating, and a simple control interface allowing control of the motor's speed by connecting a potentiometer or throttle and rotation direction by connecting a reverse switch.

Finally, the motor driver or controller is selected depending on motor rated voltage and maximum used current.

Headlamp

Theory

- A headlamp is a lamp attached to the front of a vehicle to illuminate the road ahead.

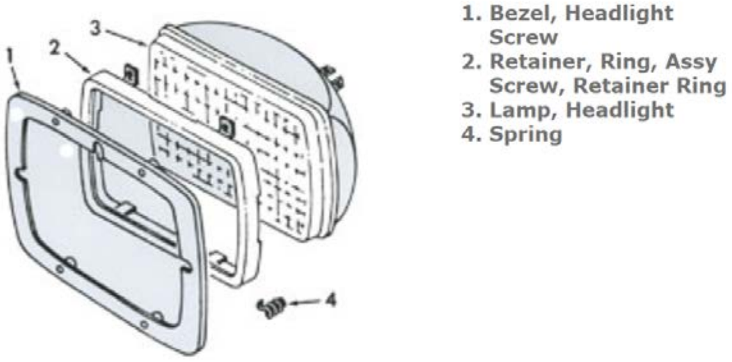


FIGURE 39 Headlamp exploded view

- There are three types of headlamps:
    1. Tungsten-halogen
        - The most common headlamps in production make use of Tungsten filaments contained in an inert gas with small amounts of halogen, such as iodine or bromine. The halogen stops the tungsten filament from blackening the glass of the headlamp meaning that the optimal lumens-per-watt ratio is achieved for the entirety of the life of the headlamp.

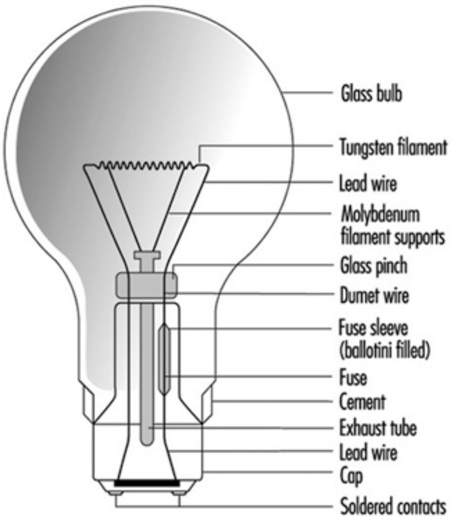


FIGURE 40 Tungsten lamp

2. High-intensity discharge (HID)
    - These headlamps vaporize metallic salts within an arc chamber containing xenon gas, creating the high intensity electrical arc for which the technology is named. The light from this electrical arc is reflected to provide forward illumination for the vehicle, and is more efficiently generated than the light produced by Tungsten Halogen headlamps. HID headlamps have been in production since 1991, and are subsequently in fairly common circulation in higher-end vehicles, despite complaints from other drivers about the glare they produce.

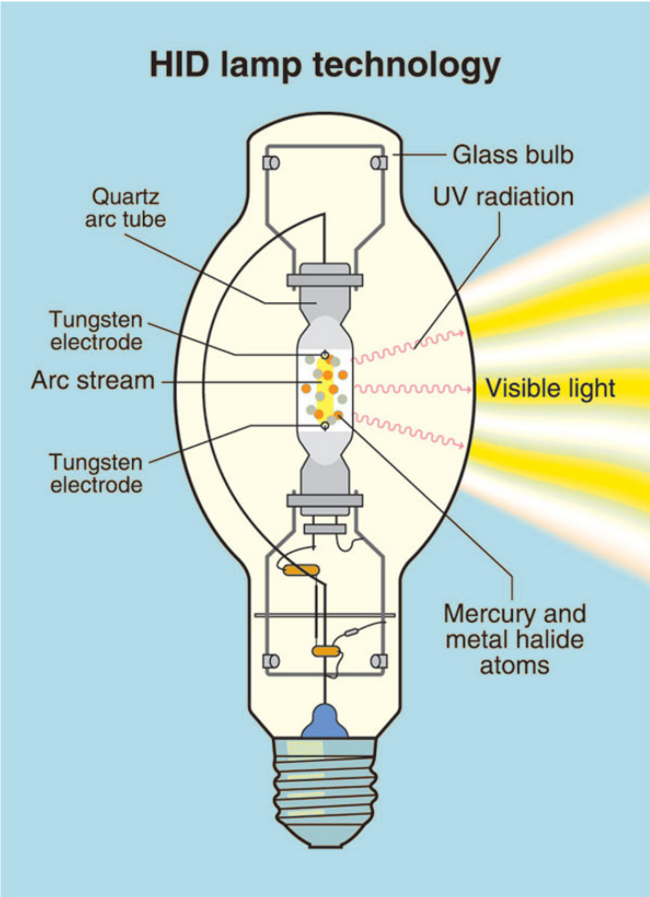


FIGURE 41 High-intensity discharge lamp

3. Light-emitting diode (LED)
    - Easily identifiable as strips or rings of smaller light sources in place of a single large light source, LEDs provide the lowest energy consumption, longest lifespan, and most flexible design possibilities when compared to other light sources. As the technology evolves, it is predicted that LEDs will eventually out-perform HID headlamps. Unfortunately, high production costs and engineering challenges around heat dissipation currently prevent LEDs from taking the pole market position. White LEDs give off a much colder light than that of Tungsten Halogen globes, without being quite as blue as HID.

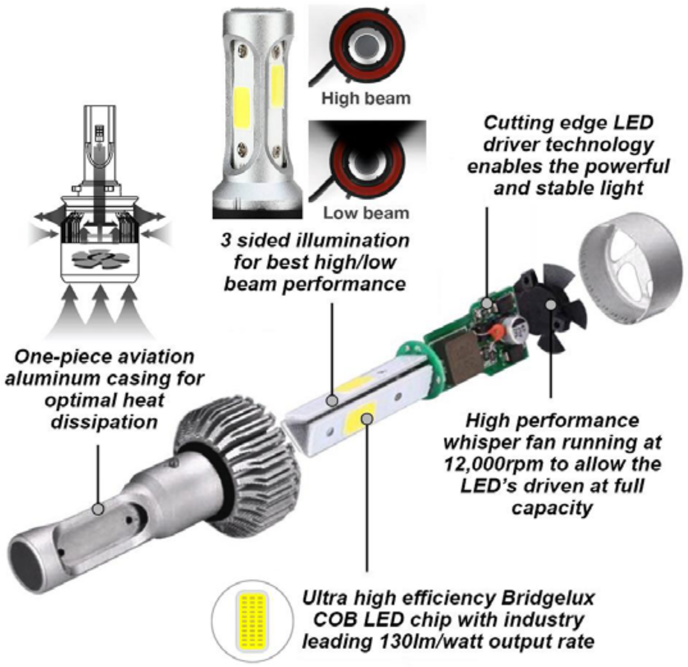


FIGURE 42 LED headlamp unit

Throttle handlebar

Theory

- Throttle in Internal combustion engine vehicles is used to control amount of fuel input to the engine by twisting throttle handlebar in counterclockwise direction to increase fuel input and twisting throttle handlebar in clockwise direction to decrease fuel input thus controls the speed of the vehicle.
- However throttle handlebar in an electric vehicle act as a variable resistance which by controlling the value of the resistance, you control the speed of the motor driving the drive system that controls the speed of the vehicle.
- Throttle handlebar in an electric vehicle operate the same way as in internal combustion engine vehicles.
- Throttle handlebar comes with multiple options as:
    1. Handlebar only without any additions
    2. Speed indicator that shows percentage of power inputted and battery indicator that shows charging percentage of the battery.
    3. Motor driver unit that controls speed of motor directly without a control unit.

FIGURE 43 Throttle handlebar with speed/battery indicator

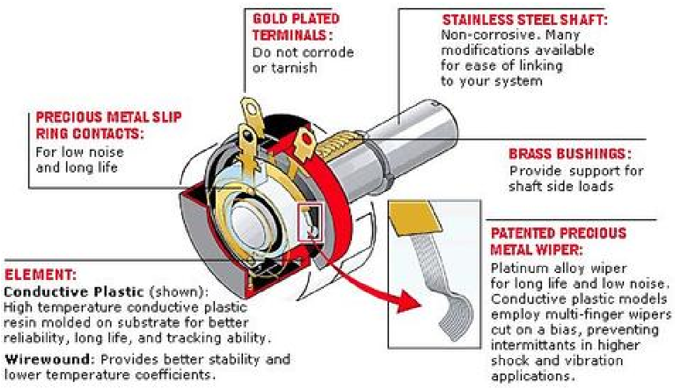


FIGURE 44 Potentiometer components

Battery

There are types of batteries that are used in electrical vehicles:

1. Lithium-ion (Li-ion):

Lithium metal has high electrochemical reduction potential (3.045 V) and the lowest atomic mass (6.94), which shows promise for a battery of 3 V cell potential when combined with a suitable positive electrode. The interest in secondary lithium cells soared soon after the advent of lithium primary cells in the 1970s, but the major difficulty was the highly reactive nature of the lithium metal with moisture, restricting the use of liquid electrolytes. Discovery in the late 1970s by researchers at Oxford University that lithium can be intercalated (absorbed) into the crystal lattice of cobalt or nickel to form LiCoO2 or LiNiO2 paved the way toward the development of Li-ion batteries.3 The use of metallic-lithium is bypassed in Li-ion batteries by using lithium intercalated (absorbed) carbons (LixC) in the form of graphite or coke as the negative electrode, along with the lithium metallic oxides as the positive electrode. The graphite is capable of hosting lithium up to a composition of LiC6. The majority of the Li-ion batteries uses positive electrodes of cobalt oxide, which is expensive but proven to be the most satisfactory. The alternative positive electrode is based on nickel oxide LiNiO2, which is structurally more complex but costs less. Performance is similar to that of cobalt oxide electrodes. Manganeseoxide-based positive electrodes (LiMn2O4 or LiMnO2) are also under research, because manganese is cheaper, widely available, and less toxic.

The cell discharge operation in a lithium ion cell using LiCoO2.During cell discharge, lithium ions (Li+) are released from the negative electrode that travels through an organic electrolyte toward the positive electrode. In the positive electrode, the lithium ions are quickly incorporated into the lithium compound material. The process is completely reversible. The chemical reactions at the electrodes are as follows:

At the negative electrode, The cathode (marked +) half-reaction is:

$$\mathrm{Li}_{1-x}\mathrm{CoO}_2 + x\mathrm{Li}^+ + x\mathrm{e}^- \rightleftarrows \mathrm{LiCoO}_2$$

The anode (marked −) half-reaction is:

$$x\,\mathrm{LiC}_6 \rightleftarrows xL_1^+ + x\mathrm{e}^- + x\mathrm{C}_6$$

During cell charge operation, lithium ions move in the opposite direction from the positive electrode to the negative electrode. The nominal cell voltage for a

Li-ion battery is 3.6 V, which is equivalent to three NiMH or NiCd battery cells. Lithium-ion batteries have high specific energy, high specific power, high energy efficiency, good high-temperature performance, and low self-discharge. The components of Li-ion batteries are also recyclable. These characteristics make Li-ion batteries highly suitable for EV and HEV and other applications of rechargeable batteries.

2. LI-POLYMER BATTERY:

Lithium-polymer evolved out of the development of solid state electrolytes, i.e., solids capable of conducting ions but that are electron insulators. The solid state electrolytes resulted from research in the 1970s on ionic conduction in polymers. These batteries are considered solid state batteries, because their electrolytes are solids. The most common polymer electrolyte is polyethylene oxide compounded with an appropriate electrolyte salt.

The most promising positive electrode material for Li-poly batteries is vanadium oxide V6O13.1 This oxide interlaces up to eight lithium atoms per oxide molecule with the following positive electrode reaction:

$$Li_x + V_6O_{13} + xe^- \rightleftarrows Li_xV_6O_{13}$$

Li-poly batteries have the potential for the highest specific energy and power. The solid polymers, replacing the more flammable liquid electrolytes in other type of batteries, can conduct ions at temperatures above 60°C. The use of solid polymers also has a great safety advantage in case of EV and HEV accidents. Because the lithium is intercalated into carbon electrodes, the lithium is in ionic form and is less reactive than pure lithium metal. The thin Li-poly cell gives the added advantage of forming a battery of any size or shape to suit the available space within the EV or HEV chassis. The main disadvantage of the Li-poly battery is the need to operate the battery cell in the temperature range of 80 to 120°C. Li-poly batteries with high specific energy, initially developed for EV applications, also have the potential to provide high specific power for HEV applications. The other key characteristics of the Li-poly are good cycle and calendar life.

Lithium iron phosphate battery (LiFePO4) is type of lithium polymer batteries that is known for its high endurance to various environmental conditions, a longer cycle life, a very constant discharge voltage which allows the cell to deliver virtually full power until it is discharged ,and higher current or peak-power ratings.

Battery’s charging unit

During EV charging, the charger transforms electricity supplied by the local utility into energy compatible with the vehicle’s battery pack voltage requirements. According to the Society of Automotive Engineers (SAE), the complete EV charging system consists of the equipment required to both condition and transfer energy from a constant frequency, constant-voltage source or network to direct current. The direct current is required for the purpose of charging the battery and/or operating the EV electrical systems (e.g., EV interior preconditioning, traction battery thermal management, onboard vehicle computer). The charger communicates with the battery management system and/or monitor (BMON). The management system and/or BMON in turn calculates how much voltage and current is required to charge the battery system.

Charging is accomplished by passing an electrical current through the battery to reform its active materials into their high-energy charge state. The charging process is basically a reverse of the discharging process. Current is forced to flow back to the traction battery pack. This current initiates a chemical reaction in the opposite direction. The algorithm by which this is achieved differs depending upon the battery type and due to the variations in their chemical compositions.

The EV is connected to the EV supply equipment (EVSE), which, in turn, is connected to the local utility. The National Electrical Code (NEC) defines this equipment as the ungrounded conductors, grounded conductors, equipment grounding conductors, EV couplings and connectors, attachment plugs, and all other fittings, devices, power outlets, or accessories installed specifically for the purpose of delivering energy from the utility wiring to the EV.

For residential or private and most public charging locations, there are two power levels: Level I and Level II. Level I or convenience charging, allows for charging the traction battery pack while the vehicle is connected to a 120V, 15A branch circuit. A complete charging cycle takes anywhere from 10 to 15 hours to be completed. This type of charging system uses the common grounded electrical outlets and is used when Level II charging is unavailable. Level II charging takes place while the vehicle is connected to a 240V, 40 A circuit, dedicated solely for EV traction battery charging purposes only. At the Level II voltage and current levels, a full charge takes from 3 to 8 hours, depending on battery type. In order to sustain the Level II power requirements, EVSE must be hardwired to the premises wiring.

A third power level, Level III is any EVSE with a power rating greater than Level II. Most Level III charging systems are located off the vehicle platforms. Level III charging is defined as the EV equivalent of a commercial gasoline service station. In this case, a Level III charging station can successfully charge an EV in a matter of minutes. To accomplish Level III charging, the equipment must be rated at power levels from 75 to 150kW. The Level III requires supply circuit to the equipment be rated at 480V, 3 f and between 90 to 250A. However, the supply circuit for the Level III charge may be even larger in capacity. The equipment is to be handled by specially trained personnel.

All EV infrastructural equipment, at all power levels, are required to be manufactured and installed in accordance with published standards documents such as: NFPA (NEC Article 625), SAE (J1772, J1773, J2293, others), UL (2202, 2231, 2251, others), IEEE/IEC, FCC (Title 47–Part 15), and several others.

The EV system will be connected to the vehicle by the general public in all weather conditions. There are currently two primary methods of transferring power to EVs:

1. Conductive coupling:

In the conductive coupling method, connectors use a physical metallic contact to pass electrical energy when they are joined together. Specific EV coupling systems—connectors paired with inlets—have been designed that provide a non-energized interface to the charger operator. Thus, not only is voltage prevented from being present before the connection is completed, the metallic contacts are completely covered and inaccessible to the operator.

2. Inductive coupling:

In the inductive coupling method, the coupling system acts as a transformer. AC power is transferred magnetically, or induced, between a primary winding, on the supply side, to a secondary winding, on the vehicle side. This method uses EV infrastructure that converts standard power-line frequency (60 Hz) to high frequency (80,000 to 300,000 Hz), reducing the size of the transformer equipment. The inductive connection is developed primarily for EV applications, though it has been applied to other small appliances. In both conductive and inductive coupling, the connection process is safe and convenient for all users.

There are three primary methods of charging EV batteries: (1) constant voltage; (2) constant current; and (3) a combination of the two.

Most EV charging systems use a constant voltage for the initial portion of the charging process, followed by a constant current for the finish. Most of the battery capacity is restored during the constant voltage portion of the charging cycle. The constant-current portion of the charge cycle, commonly referred to as a trickle charge, serves to slowly top off the battery at a rate sufficiently slow to prevent the off-gassing of either hydrogen or oxygen from the electrolyte.

3.3 Control design

Introduction

The control design section will cover the possible methods that the system could be controlled in order to be usable by end user, there are two approaches:

1. Open loop approach
2. Closed loop approach

Open loop approach includes system that could be controlled by end user by sending direct commands to the system but without forming any kind of feedback to ensure that command is actually executed as intended. Most of the non-off-road vehicles tend to use that approach since the system is too simple to require such control or adding feedback control will cost more that the system should cost.

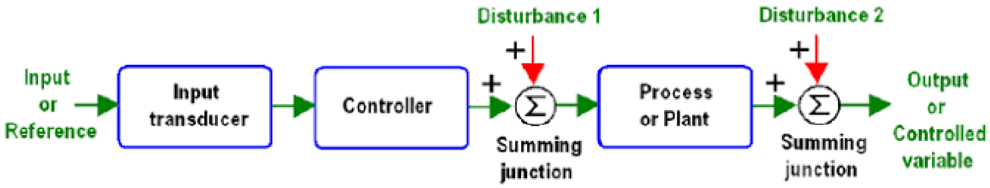


FIGURE 45 Open loop system

On the other hand, closed loop approach will give the system a feedback loop that revise every order sent before execution and apply a corrective action if the order doesn't match end user's command. All of modern off-road vehicles use this approach to ensure safety of the passengers; however, it could be a major disadvantage when used on a simple system since it may slow real time response of that system.

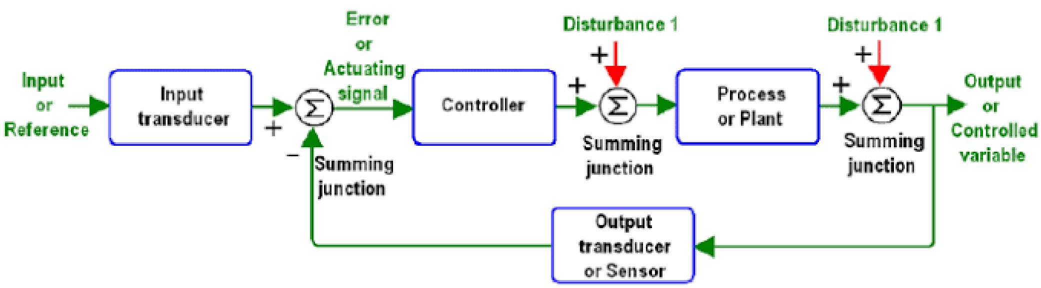


FIGURE 46 Closed loop system

Open loop approach

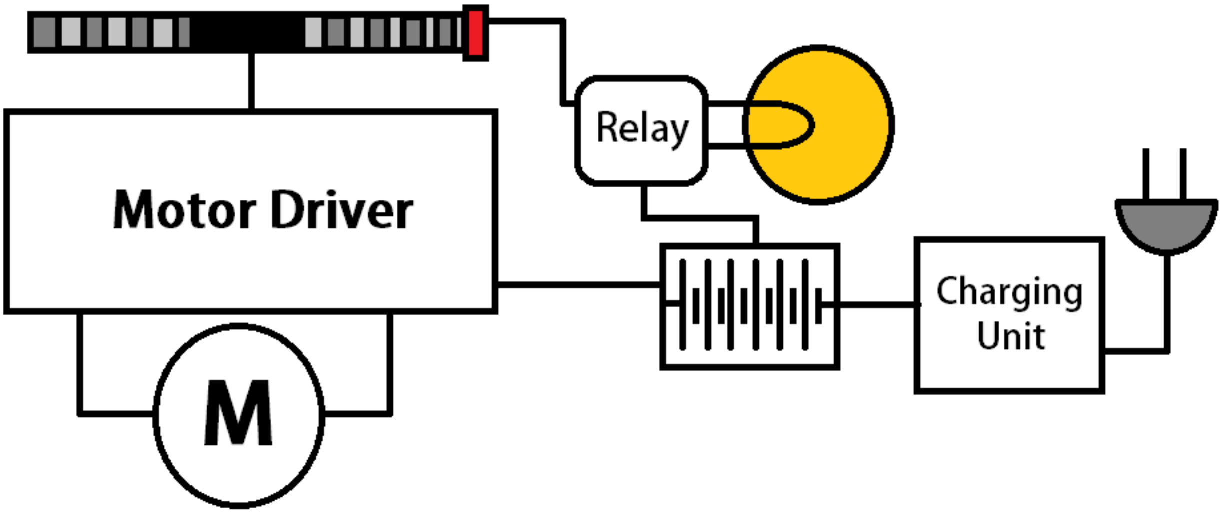


FIGURE 47 Open loop system diagram

As shown in the diagram, the system will use throttle handlebar with motor driver to control the speed of the driving motor thus controlling the speed of the vehicle.

As for the headlamp, it will be controlled using a basic power circuit that consists of a switch which control a relay that turn power on and off the headlamp.

The battery will be connected to the entire system and will be charged using a charging unit that manages the charging process along with an indicator that helps the user to know whether the battery finished charging or not.

Closed loop approach

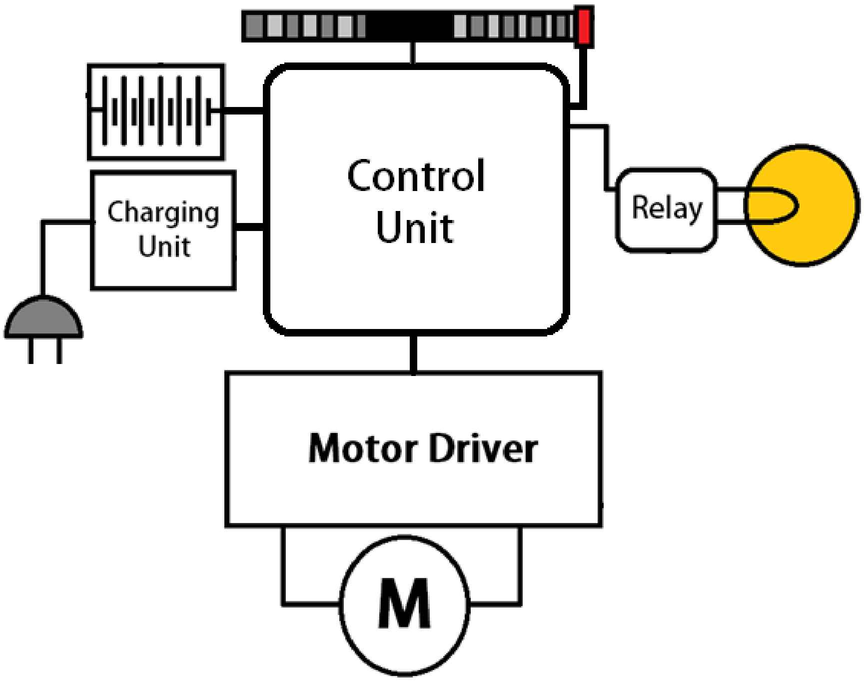


FIGURE 48 Closed loop system diagram

The system will use a control unit in order to:

1. Supervise every action that takes place
2. Provide the system with feedback to ensure that user commands are executed as required.
3. Manage the power used to prolong the vehicle's working time for example, lowering the vehicle's speed automatically in case of low battery
4. Assist system in braking process by decelerating vehicle's speed gradually to provide safety and comfort to the end user
5. Manage the charging process of the battery by provide constant current and voltage to the battery
6. Provide the end user with information about which component of the vehicle should go to maintenance

System used

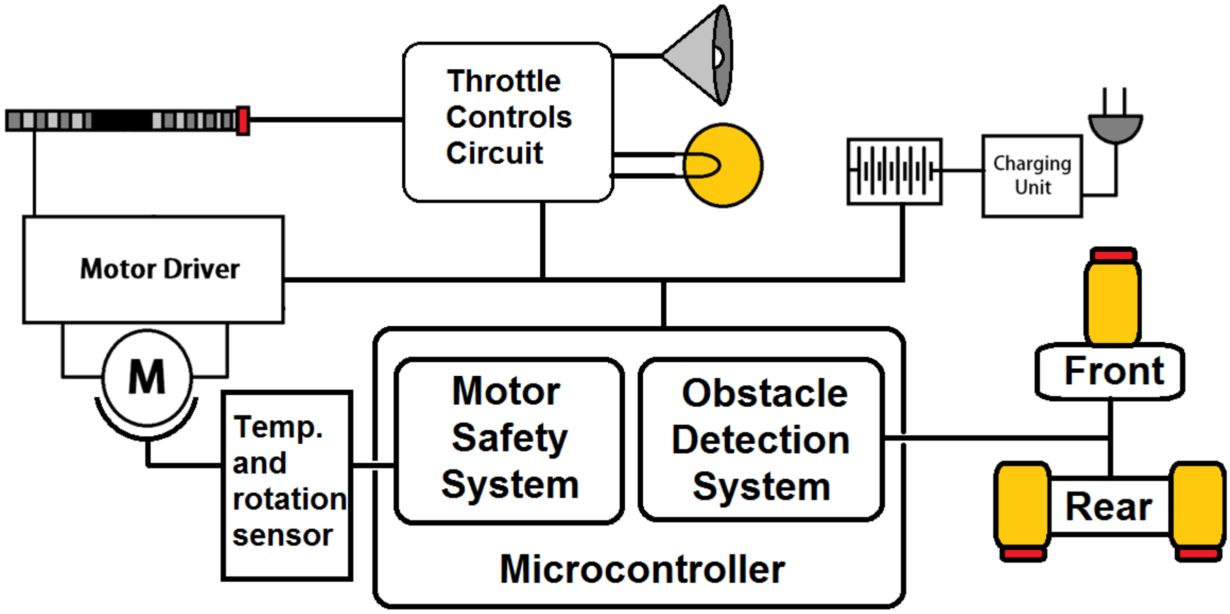


FIGURE 49 CONTROL SYSTEM LAYOUT

In order to provide better performance for the system and to avoid many hazards that may result due to slow response time or malfunctioning, the system was divided into split subsystems:

1. Throttle controls circuit: circuit that connects horn, headlight and taillight to throttle handlebar user buttons and interacts to brake lever
2. Motor driver: includes system main driving unit(DC motor, throttle handlebar speed control twist handle, motor driver, and brake lever's switch)
3. Obstacle detection system: consists of infrared distance sensors (two at the rear and one at the front fork) to measure distance between vehicle and its surroundings and alerting user if vehicle is too close to an obstacle
4. Motor safety system: measures and tests motor to stop motor if it's overloaded (exceeds required temperature) or overheated (exceeds recommended operation temperature)
5. Battery unit and battery charging unit

This isn't the optimum option but this configuration will provide quicker response time and safer ride for user.

CHAPTER FOUR

MODELING, SIMULATION AND CALCULATIONS

Chapter Four: Modeling, simulation and calculations

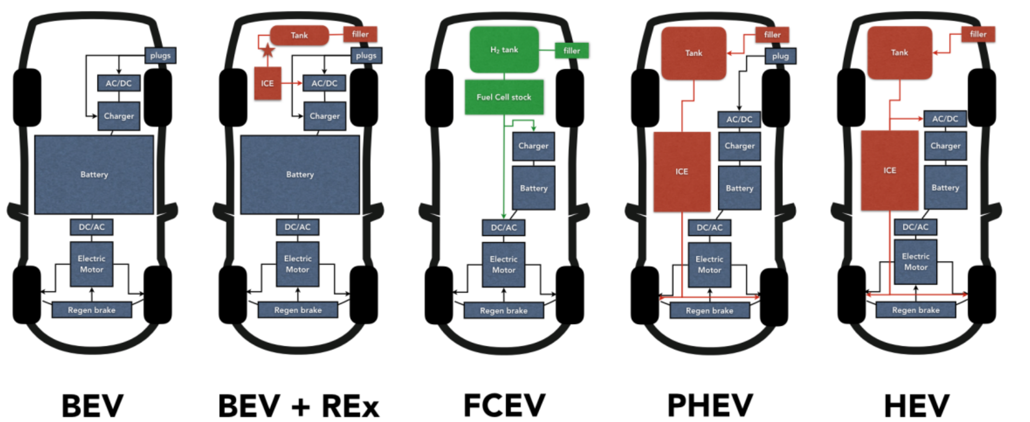
Introduction

In order to represent a system without having it in the real world, an unrealistic mathematical model is established with design parameters (length, mass, etc.) and every changeable state (position, velocity, etc.) then model is tested by a simulation that shows how your system will respond to the change that you want by seeing each state response with respect to time (time domain) or with respect to frequency (frequency domain or S-domain) and based on it you see whether the response is satisfying and fits the design requirement or the system needs modifications. In this chapter will discuss:

1. System modeling
2. Simulation of system model

System modeling

Any vehicle (regardless of its type) consists of many subsystems including suspension, steering, drive, transmission, electrical system and much more depending on vehicle type as shown in figure 41.



Example: Tesla Model S	BMW i3	Toyota Mirai	Mini Countryman Plug-In	Toyota Prius
Energy efficiency: 73%	73% ↔ 20%	22% (???)	60% ↔ 17%	54% ↔ 15%
Transmission: NO	NO	NO	YES	YES / HSD
Gearshift: NO	NO	NO	YES	YES
Engine: AC induction/synchro	AC synchronous	AC synchronous	AC synchronous	AC synchronous
Emissions: -66% CO_2	-66% ↔ -8% CO_2	-50% (???) CO_2	-58% ↔ +2% CO_2	-57% ↔ +11% CO_2

FIGURE 50 Subsystems inside different types of vehicles

There are two ways to model any vehicle:

1. Merging all subsystems into one system however that requires understanding every subsystem along with its relation with other subsystems and accurate data to give accurate response which any vehicle manufacturer can easily provide due to the fact that the manufacturer usually fabricate (almost) every part of the vehicle
2. Dealing with every subsystem separately so you can observe every subsystem's response as if they are not connected with each other which will be not accurate as the above solution but can be helpful if the subsystems of the vehicle are separated from each other or have weak relation between each other which is the used approach
    - The models that will be discussed are:
        a. Half car suspension model
        b. Kinematic steering model
        c. Drive system model
        d. Half car model for moving vehicle on a road

Half car suspension model

As discussed in chapter three, the vehicle suspension system follows half car model assumptions and mathematical model which MATLAB has built-in Simulink model for the system which was used (figure 51 and 52) providing these initial conditions:

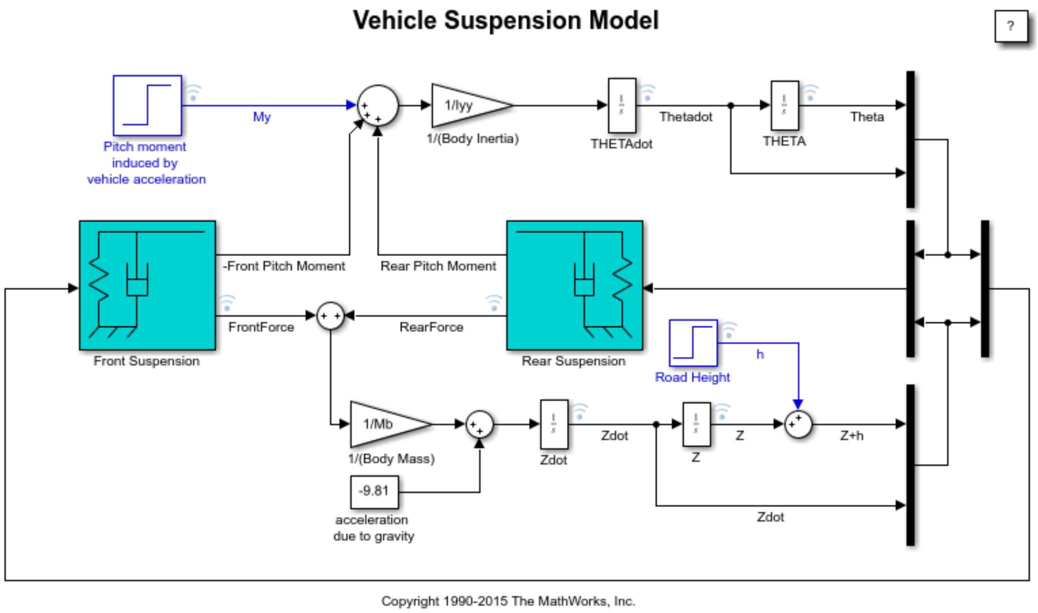


FIGURE 51 Top-level diagram of the suspension model

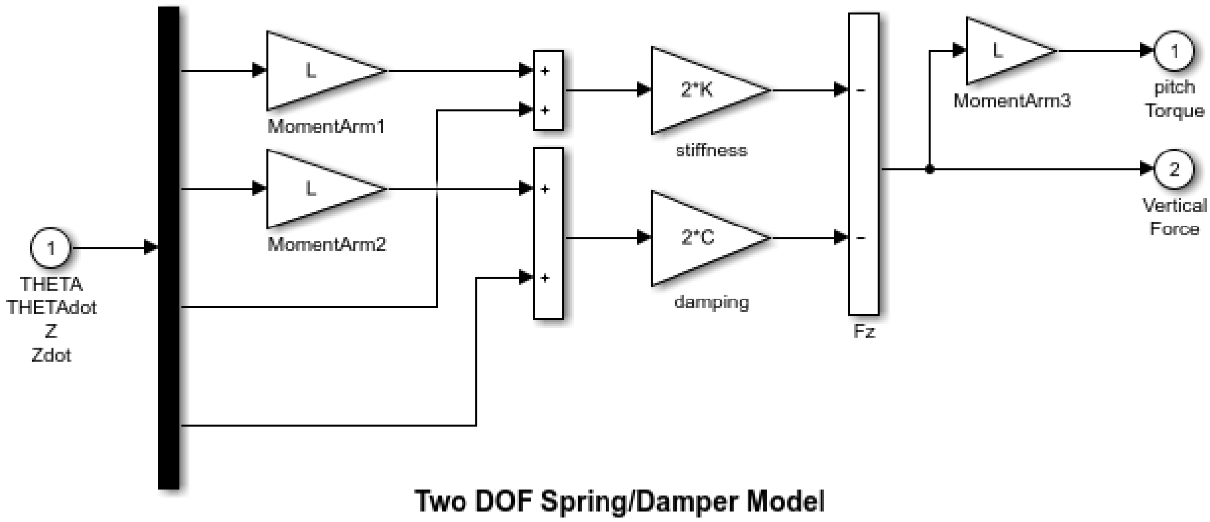


FIGURE 52 The spring/damper model used in front suspension and rear suspension subsystems

Kinematic steering model

Since the steering system has direct relation with driver input, the simulation is used to show vehicle trajectory in an assumed facility lane (figure 53) applying following assumptions:

1. Vehicle is moving at constant speed and didn't start from rest
2. Vehicle is taking low speed turn (no slipping)
3. Vehicle didn't start from rest

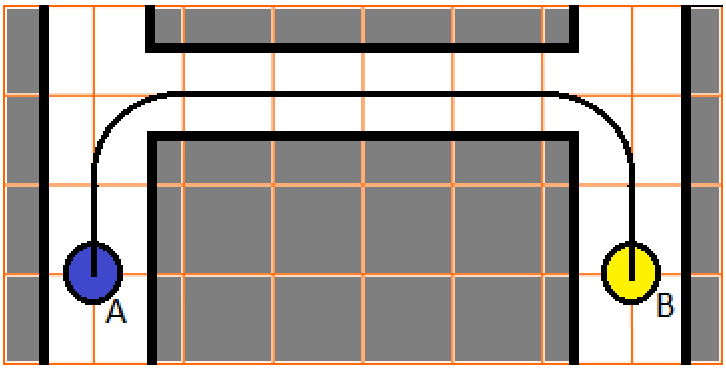


FIGURE 53 Facility lane with planned trajectory

For academic and scientific honesty, the model with created by Marc Compere, Associate professor of mechanical engineering at Embry-Riddle Aeronautical University using the model that he uploaded at MATLAB file exchange by the name (Simple 2D kinematic vehicle steering model and animation) and was used in context of this project.

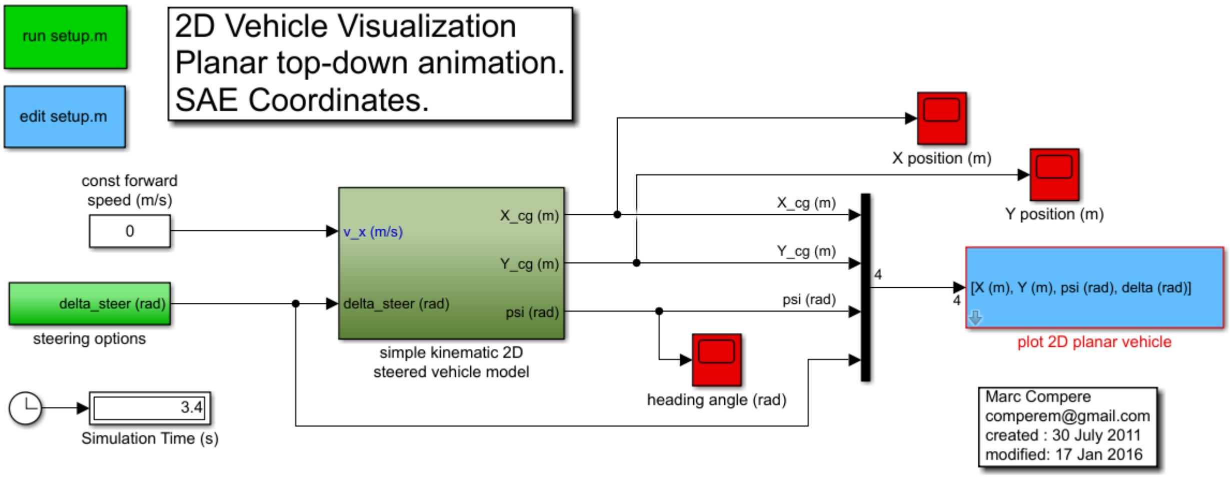


FIGURE 54 Top-level diagram of the steering model

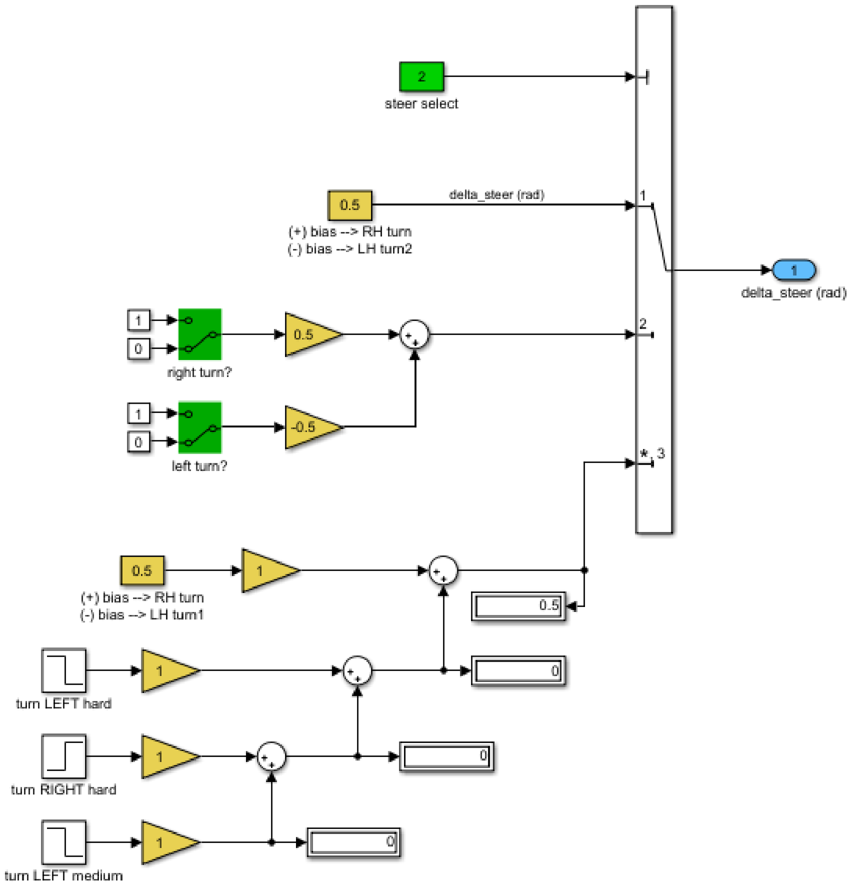


FIGURE 55 Steering options subsystem

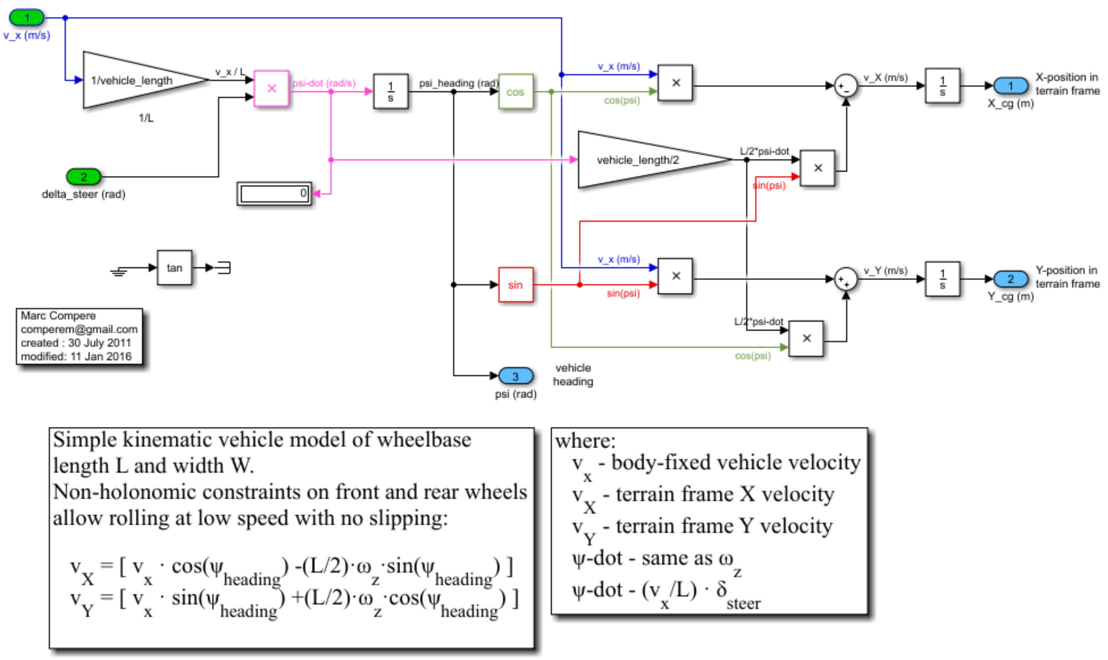


FIGURE 56 Steering model subsystem

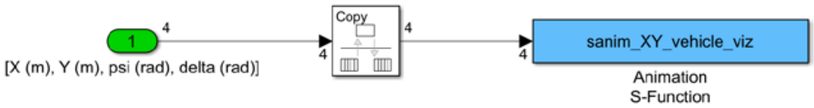


FIGURE 57 Plot 2d planar vehicle subsystem

As shown in figure 55, there are many steering options including option 2 which emulates manual control of vehicle direction which can be used along with step simulation to simulate steering as close as real world. The model plots vehicle CG (center of gravity) trajectory using SAE (Society of Automotive Engineers) coordinates by the following equations:

The Ackermann relationship:

$$\delta_0 \cong \frac{L}{(R+t/2)}$$

$$\delta_i \cong \frac{L}{(R-t/2)}$$

$$\delta = \mathrm{L/R}$$

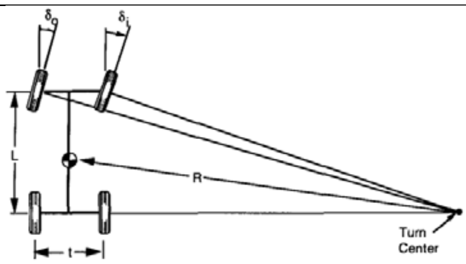


FIGURE 58 Steering system parameters

The velocity at point ‘o’:

$$v_o^{xy} = \begin{bmatrix} v_x & \hat{\imath} \\ 0 & \hat{\jmath} \end{bmatrix}$$

To get the velocity at point ‘g’:

$$v_g^{xy} = v_o^{xy} + \vec{\omega} \times \vec{r}_{og}$$

Using the coordinate transformation matrix to transform the velocity of point ‘g’ in the body-fixed xy frame to the inertial, or terrain-fixed XY

The trace connected frame with:

$$v_g^{XY} = \begin{bmatrix} \cos(\psi) & -\sin(\psi) \\ \sin(\psi) & \cos(\psi) \end{bmatrix} \cdot v_g^{xy}$$

Then integrate the terrain-frame velocities to achieve position in XY as a function of body-fixed steering input:

$$\begin{bmatrix} X_g \\ Y_g \end{bmatrix} = \int v_g^{XY} dt$$

$$\psi = \int \dot{\psi} dt$$

$$\dot{\psi} = \left(\frac{v_x}{L}\right) \delta_{\text{steer}}$$

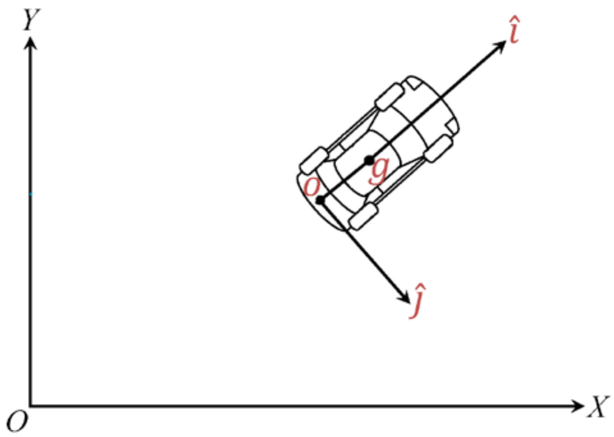


FIGURE 59 Vehicle movement parameters in 2d planar space

Drive system model

The drive system model as shown in figure 51 consists of simply a dc motor connected to main axle via transmission system (sprocket-chain system) which transfers speed and torque from motor to main axle

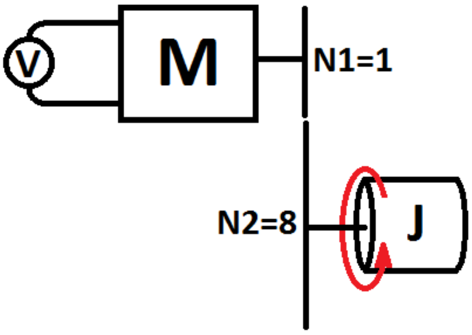


FIGURE 60 DRIVE SYSTEM DIAGRAM

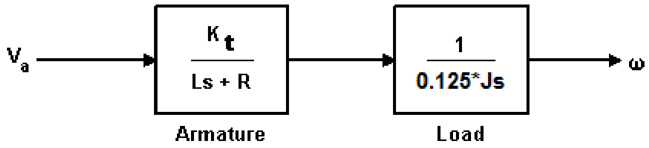


FIGURE 61 Drive system block diagram

The system was modeled and simulated in Wolfram SystemModeler

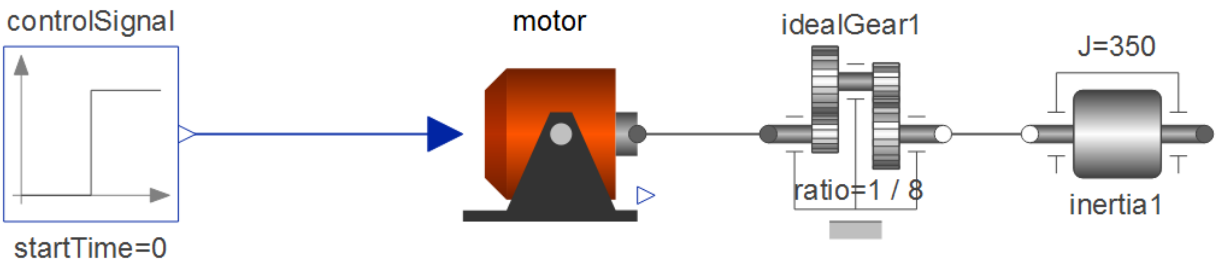


FIGURE 62 Wolfram SystemModeler drive system model

The system transfer function is:

$$G(s) = \frac{Kt}{0.125Js(Ls+R)} = \frac{\left(\frac{Kt}{Ra * Jm}\right)}{0.125Js\left\{\left(s + \left(\frac{Dm}{Jm}\right)\right) + \left(\frac{Kt * Kb}{Ra * Jm}\right)\right\}}$$

Half car model for moving vehicle on a road

This is a simulation for studying vehicle dynamics moving on a predefined road as 4-DOF (degree of freedom) half car model vehicle response and motion visualized in real time assuming:

1. Ignoring aerodynamic effect
2. Constant acceleration and deceleration
3. Uniform gravitational field (center of gravity same as center of mass)
4. Load is focused on center of gravity

For academic and scientific honesty, the simulation with created by Najam R. Syed, computer vision R&D engineer at Kitware using python scripts that was uploaded on GitHub under the name (half-car suspension model) and was used in context of this project.

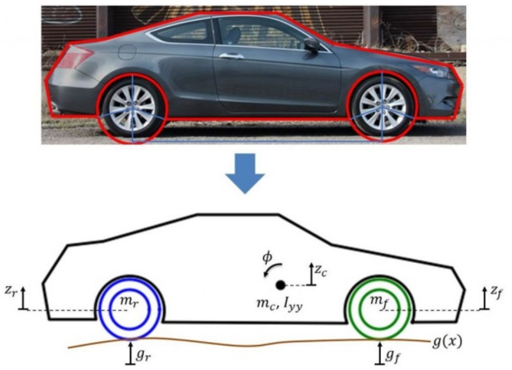


FIGURE 63 2010 Honda accord coupe from real world to frame

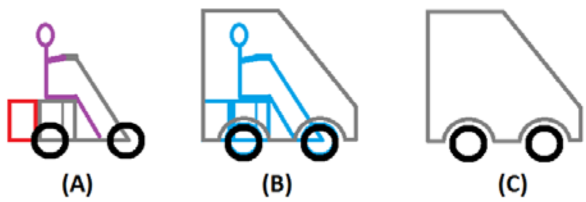


FIGURE 64 Illustration shows process of converting vehicle to frame

Although the aerodynamic effect on the vehicle is neglected, it’s highly recommended to draw vehicle frame to provide better visual understanding to system’s response as shown in figure 54 and 55.

The simulation main point is to demonstrate the effect of road on vehicle’s suspension system in real time considering wheel’s stiffness and damping as a factor instead of just plotting step response that doesn’t provide user with much information about system. The vertical road profile used is this simulation is generated as sine wave and then manipulated depending on your desired road profile which in our case is a bump road

FIGURE 65 Bump road profile

And that is the analysis used for this simulation:

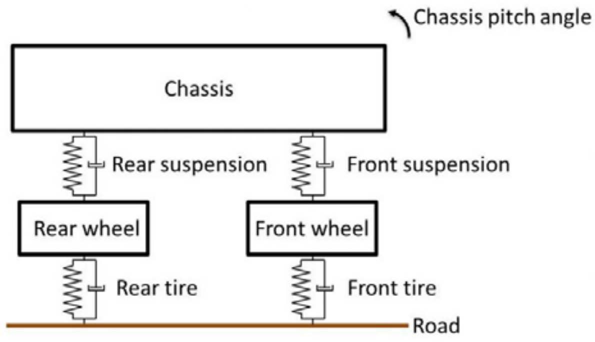
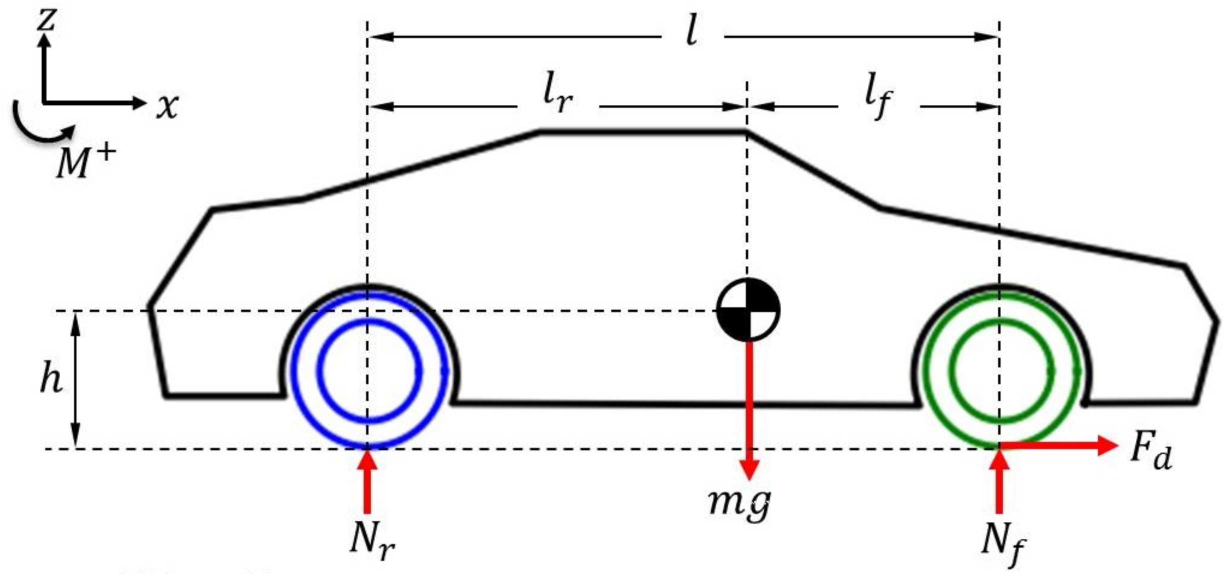
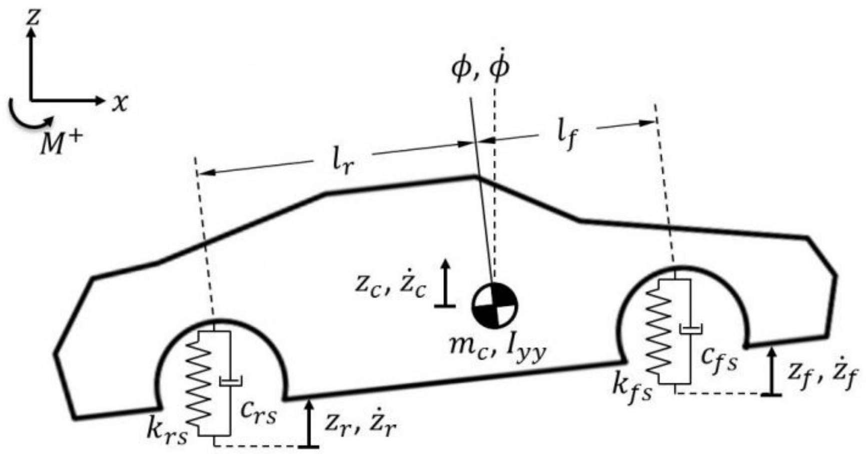


FIGURE 66 4 DOF Half car model

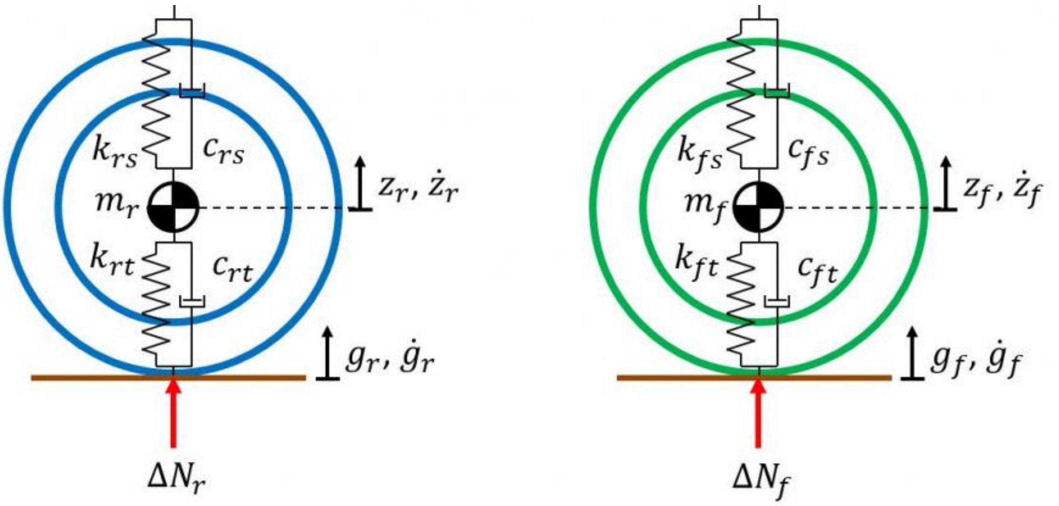


$$\Sigma F_x = F_d = ma$$
$$\Sigma F_z = N_f + N_r - mg = 0$$
$$\Sigma M_{/c} = l_f N_f - l_r N_r + hF_d = 0$$
$$(l_f + l_r)N_f - l_r mg + hma = 0$$
$$\therefore N_f = \frac{l_r}{l} mg - \frac{h}{l} ma$$
$$-(l_f + l_r)N_r + l_f mg + hma = 0$$
$$\therefore N_r = \frac{l_f}{l} mg + \frac{h}{l} ma$$



$$m_c\ddot{z}_c = -(l_f\phi + z_c - z_f)k_{fs} + (l_r\phi - z_c + z_r)k_{rs} - (l_f\dot{\phi} + \dot{z}_c - \dot{z}_f)c_{fs} + (l_r\dot{\phi} - \dot{z}_c + \dot{z}_r)c_{rs}$$

$$I_{yy}\ddot{\phi} = -l_f(l_f\phi + z_c - z_f)k_{fs} - l_r(l_r\phi - z_c + z_f)k_{rs} - l_f(l_f\dot{\phi} + \dot{z}_c - \dot{z}_r)c_{fs} - l_r(l_r\dot{\phi} - \dot{z}_c + \dot{z}_r)c_{rs}$$



$$m_f\ddot{z}_f = (l_f\phi + z_c - z_f)k_{fs} + (l_f\dot{\phi} + \dot{z}_c - \dot{z}_f)c_{fs} - (z_f - g_f)k_{ft} - (\dot{z}_f - \dot{g}_f)c_{ft} + \Delta N_f$$

$$m_r\ddot{z}_r = -(l_r\phi - z_c + z_r)k_{rs} - (l_r\dot{\phi} - \dot{z}_c + \dot{z}_r)c_{rs} - (z_r - g_r)k_{rt} - (\dot{z}_r - \dot{g}_r)c_{rt} + \Delta N_r$$

$$\ddot{z}_c = \frac{1}{m_c}\left[-(l_f\phi + z_c - z_f)k_{fs} + (l_r\phi - z_c + z_r)k_{rs} - (l_f\dot{\phi} + \dot{z}_c - \dot{z}_f)c_{fs} + (l_r\dot{\phi} - \dot{z}_c + \dot{z}_r)c_{rs}\right]$$

$$\ddot{\phi} = \frac{1}{I_{yy}}\left[-l_f(l_f\phi + z_c - z_f)k_{fs} - l_r(l_r\phi - z_c + z_f)k_{rs} - l_f(l_f\dot{\phi} + \dot{z}_c - \dot{z}_r)c_{fs} - l_r(l_r\dot{\phi} - \dot{z}_c + \dot{z}_r)c_{rs}\right]$$

$$\ddot{z}_f = \frac{1}{m_f}\left[(l_f\phi + z_c - z_f)k_{fs} + (l_f\dot{\phi} + \dot{z}_c - \dot{z}_f)c_{fs} - (z_f - g_f)k_{ft} - (\dot{z}_f - \dot{g}_f)c_{ft} + \Delta N_f\right]$$

$$\ddot{z}_r = \frac{1}{m_r}\left[-(l_r\phi - z_c + z_r)k_{rs} - (l_r\dot{\phi} - \dot{z}_c + \dot{z}_r)c_{rs} - (z_r - g_r)k_{rt} - (\dot{z}_r - \dot{g}_r)c_{rt} + \Delta N_r\right]$$

$$\ddot{\boldsymbol{q}} = [K]\boldsymbol{q} + [C]\dot{\boldsymbol{q}} + [K_g]\boldsymbol{g} + [C_g]\dot{\boldsymbol{g}} + \boldsymbol{n}$$

$$\begin{Bmatrix} \ddot{z}_c \\ \ddot{\phi} \\ \ddot{z}_f \\ \ddot{z}_r \end{Bmatrix} = \begin{bmatrix} \frac{-(k_{fs}+k_{rs})}{m_c} & \frac{l_r k_{rs} - l_f k_{fs}}{m_c} & \frac{k_{fs}}{m_c} & \frac{k_r}{m_c} \\ \frac{l_r k_{rs} - l_f k_{fs}}{I_{yy}} & \frac{-(l_f^2 k_{fs} + l_r^2 k_{rs})}{I_{yy}} & \frac{-l_f k_{fs}}{I_{yy}} & \frac{-l_r k_{rs}}{I_{yy}} \\ \frac{k_{fs}}{m_f} & \frac{l_f k_{fs}}{m_f} & \frac{-(k_{fs}+k_{ft})}{m_f} & 0 \\ \frac{k_{rs}}{m_r} & \frac{-l_r k_{rs}}{m_r} & 0 & \frac{-(k_{rs}+k_{rt})}{m_r} \end{bmatrix} \begin{Bmatrix} z_c \\ \phi \\ z_f \\ z_r \end{Bmatrix}$$

$$+ \begin{bmatrix} \frac{-(c_{fs}+c_{rs})}{m_c} & \frac{l_r c_{rs} - l_f c_{fs}}{m_c} & \frac{c_{fs}}{m_c} & \frac{c_r}{m_c} \\ \frac{l_r c_{rs} - l_f c_{fs}}{I_{yy}} & \frac{-(l_f^2 c_{fs} + l_r^2 c_{rs})}{I_{yy}} & \frac{-l_f c_{fs}}{I_{yy}} & \frac{-l_r c_{rs}}{I_{yy}} \\ \frac{c_{fs}}{m_f} & \frac{l_f c_{fs}}{m_f} & \frac{-(c_{fs}+c_{ft})}{m_f} & 0 \\ \frac{c_{rs}}{m_r} & \frac{-l_r c_{rs}}{m_r} & 0 & \frac{-(c_{rs}+c_{rt})}{m_r} \end{bmatrix} \begin{Bmatrix} \dot{z}_c \\ \dot{\phi} \\ \dot{z}_f \\ \dot{z}_r \end{Bmatrix}$$

$$+ \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \frac{k_{ft}}{m_f} & 0 \\ 0 & \frac{k_{rt}}{m_r} \end{bmatrix} \begin{Bmatrix} g_f \\ g_r \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \frac{c_{ft}}{m_f} & 0 \\ 0 & \frac{c_{rt}}{m_r} \end{bmatrix} \begin{Bmatrix} \dot{g}_f \\ \dot{g}_r \end{Bmatrix} + \begin{Bmatrix} 0 \\ 0 \\ \frac{\Delta N_f}{m_f} \\ \frac{\Delta N_r}{m_r} \end{Bmatrix}$$

Solving using Euler method, the initial position will be set:

$$\boldsymbol{q}_0 = \boldsymbol{q}(0)$$

Also the initial velocity will be set:

$$\dot{\boldsymbol{q}}_0 = \dot{\boldsymbol{q}}(0)$$

And to calculate the positions at the next iteration based on the current positions and velocities:

$$\boldsymbol{q}_{i+1} = \boldsymbol{q}_i + \dot{\boldsymbol{q}}_i \Delta t$$

Finally, calculating the velocities at the next iteration based on the current velocities and accelerations:

$$\dot{\boldsymbol{q}}_{i+1} = \dot{\boldsymbol{q}}_i + \ddot{\boldsymbol{q}}_i \Delta t$$

Simulation of system model

After discussing each subsystem model along with theoretical background, this section will cover the simulation results and values of parameters used for each simulation and it's divided into:

1. Half car suspension model
2. Kinematic steering model
3. Drive system model
4. Half car model for moving vehicle on a road

Half car suspension model

Simulation platform: Mathworks Simulink

System parameters:

TABLE 5 Half car suspension model parameters

Symbol	Value	Description	Units
Lf	0.67	front hub displacement from body gravity center	Meter
Lr	0.19	rear hub displacement from body gravity center	Meter
Mb	250	body mass	Kilogram
Iyy	144	body moment of inertia about y-axis	kg.m^2
kf	11772	front suspension stiffness	N/m
kr	18393	rear suspension stiffness	N/m
cf	1337	front suspension damping	N.sec/m
cr	2102	rear suspension damping	N.sec/m

System Response:

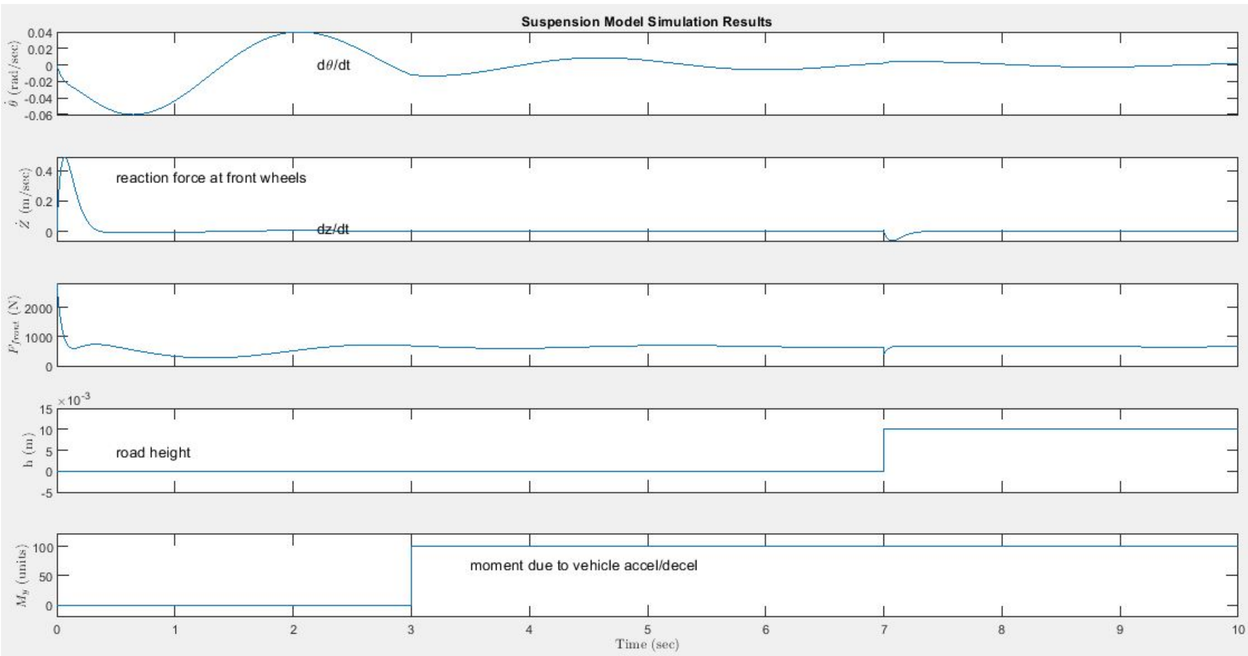


FIGURE 67 System plot response

Kinematic steering model

Simulation platform: Mathworks Simulink

System parameters:

TABLE 6 Kinematic steering model parameters

Symbol	Value	Description	Units
delta_steer	0.3	Steering angle	radian
vehicle_width	0.7	Vehicle's track	Meters
vehicle_length	0.86	Vehicle's wheelbase	Meters
v_x	3	Vehicle's velocity	Meter/second

System Response:

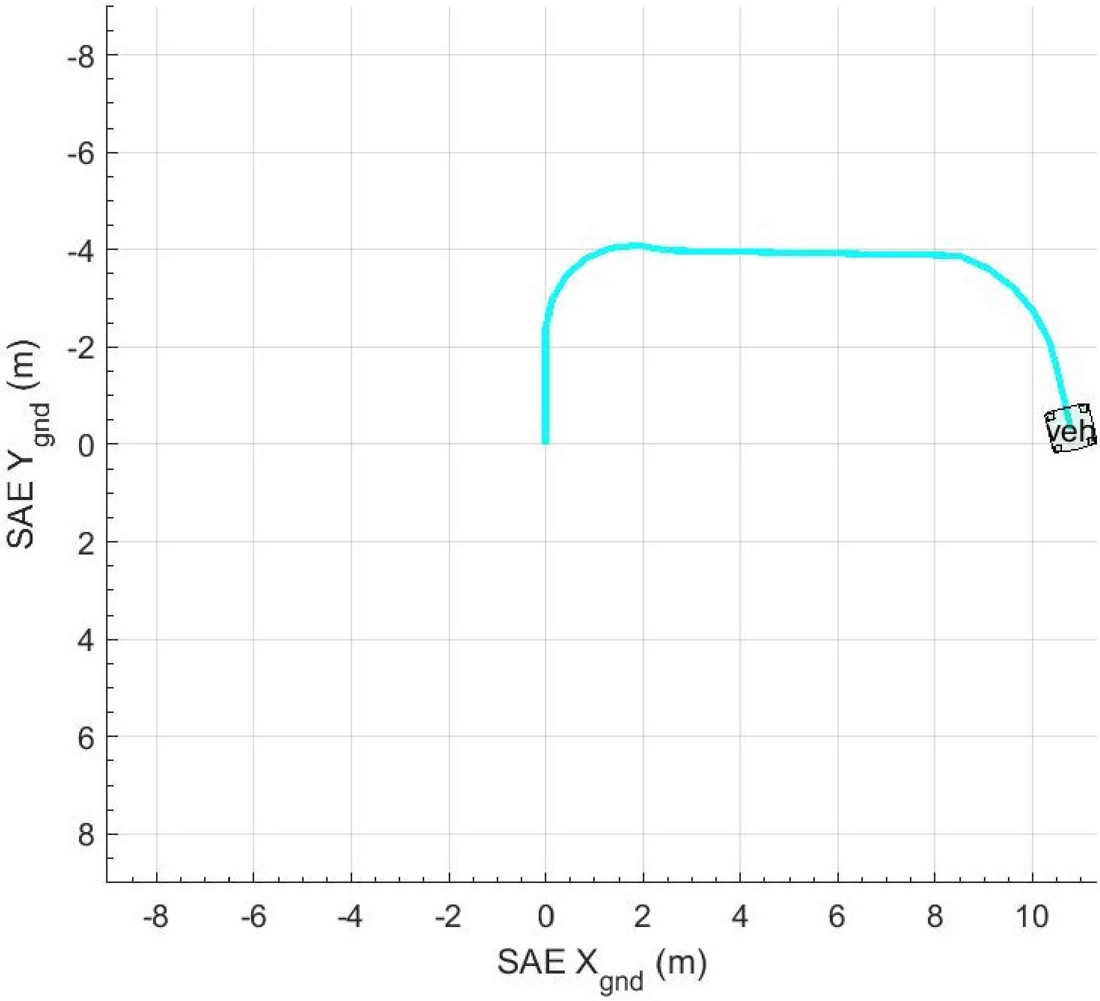


FIGURE 68 Vehicle trajectory with manual control

Simulation platform: Wolfram SystemModeler

System parameters:

TABLE 7 Drive system model parameters

Symbol	Value	Description	Units
R	0.089	Motor resistance	Ohm
L	0.017	Motor inductance	Radian
J_motor	2.67619	Motor’s rotor mass moment of inertia	Meter
EMFk	240	Motor voltage constant	RPM/Volt
ratio	0.125	Transmission ratio	dimetionless
J	350	Driving shaft mass moment of inertia	

System Response:

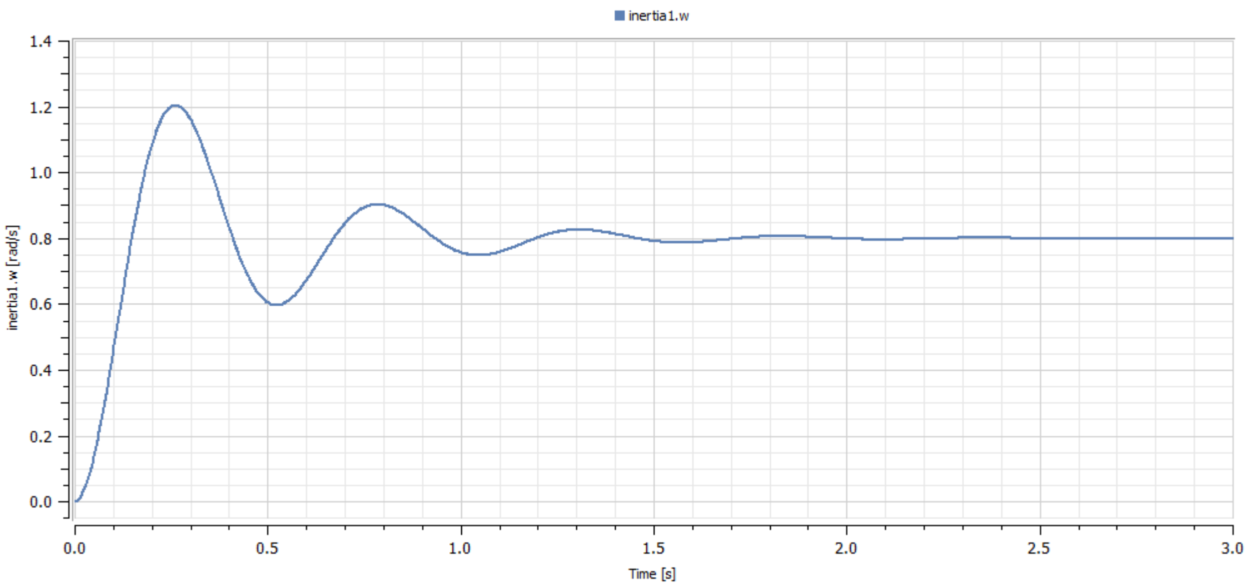


FIGURE 69 Drive system step response at driving axle

Half car model for moving vehicle on a road

Simulation platform: Python (run via windows command prompt)
System parameters:

TABLE 8 Half car model for moving vehicle on a road parameters

Symbol	Value	Description	Units
Lf	0.67	front hub displacement from body gravity center	Meter
Lr	0.19	rear hub displacement from body gravity center	Meter
Mb	250	body mass	Kilogram
Iyy	144	body moment of inertia about y-axis	kg.m^2
kf	11772	front suspension stiffness	N/m
kr	18393	rear suspension stiffness	N/m
cf	1337	front suspension damping	N.sec/m
cr	2102	rear suspension damping	N.sec/m
kt	15696	tire stiffness	N/m
ct	1447	tire damping	N.sec/m
mt	5	Tire mass	Kilogram

System Response:

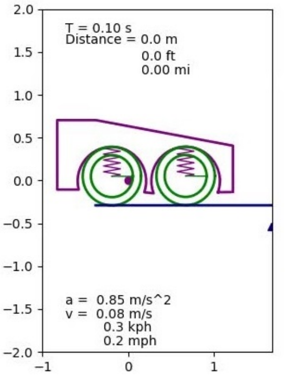


FIGURE 70 Vehicle startup

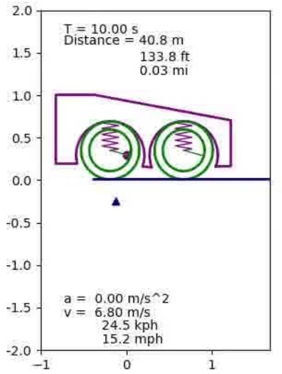


FIGURE 71 Vehicle at constant speed

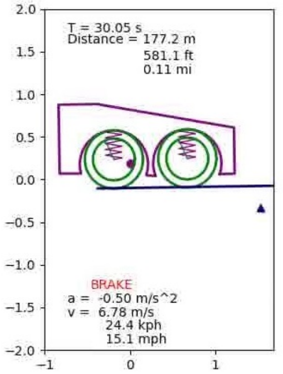


FIGURE 72 Vehicle braking

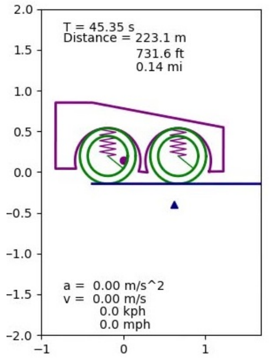


FIGURE 73 Vehicle stopped

Note: the response of the system is presented in form of a video

CHAPTER FIVE

HARDWARE IMPLEMENTATION

Chapter Five: Hardware Implementation

Introduction

After verifying system's design by establishing mathematical model for and testing its response by simulation, the system is implemented to the real world.

This chapter is divided into:

1. Frame and Body
2. Drive system
3. Braking system
4. Suspension system
5. Battery and Battery's charging unit
6. Control System

Note: In the time of writing this document, the project was incomplete; however, the implementation methods of the project were verified to be true.

1. Frame and body

The frame (as mentioned in the design chapter) consists of two steel plates each of them cut on laser cutting machine then 40*40*2 mm box section galvanized steel bars are cut to construct reinforcing structure between two plates (one at the top and other at bottom) then boxes are joined to plates by electrical arc welding

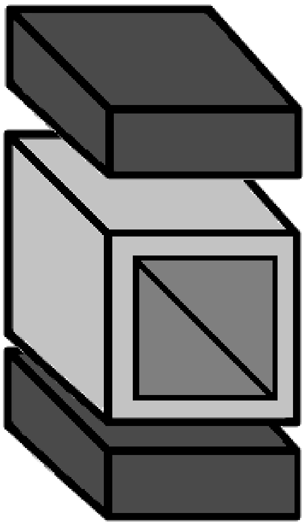


Figure 74 Sandwich-structured composite concept implementation

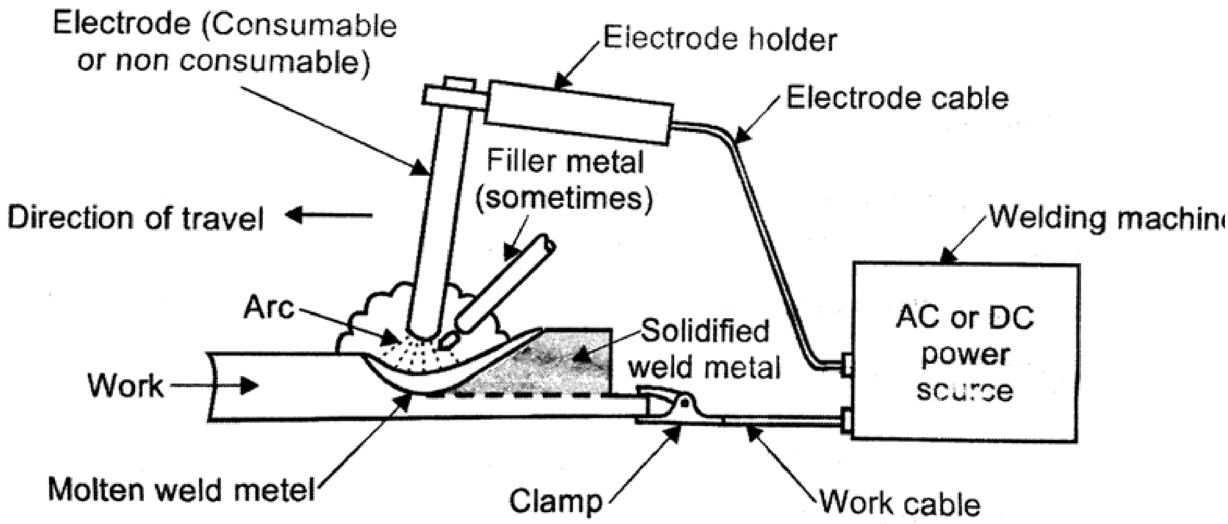


FIGURE 75 Electrical arc welding

FIGURE 76 Vehicle's frame

2. Drive system

Main drive elements (mechanical):

TABLE 9 Sprocket and chain selected

Sprocket	Type	Number of teeth	Material	
Motor sprocket	#420	10	High-carbon steel with hardened teeth and a black oxide finish	 FIGURE 77 Motor sprocket
Axle sprocket	#420	80	Aircraft-grade tempered (hardened) aluminum alloy.	 FIGURE 78 Axle sprocket
Chain type: #420				

Driving axle (rear axle):

- The original design was to fabricate a custom rear axle

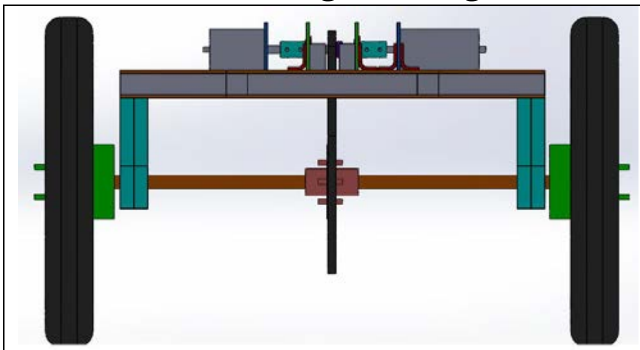


FIGURE 79 Drive system assembled (old)

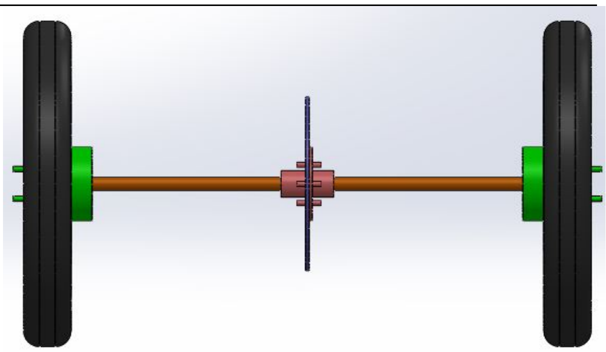


FIGURE 80 Rear axle (old)

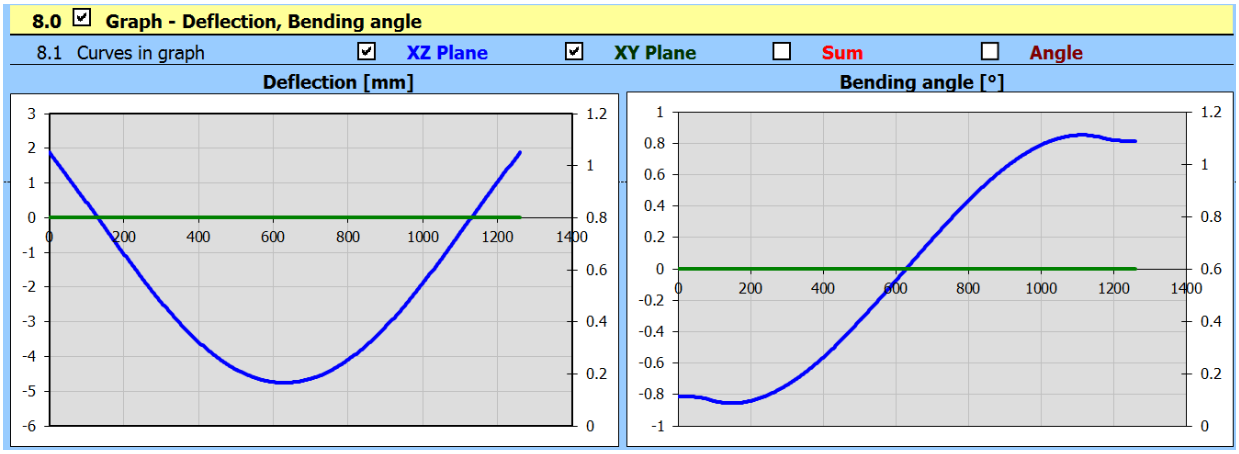


FIGURE 81 Shaft analysis (defelction and bending angle)

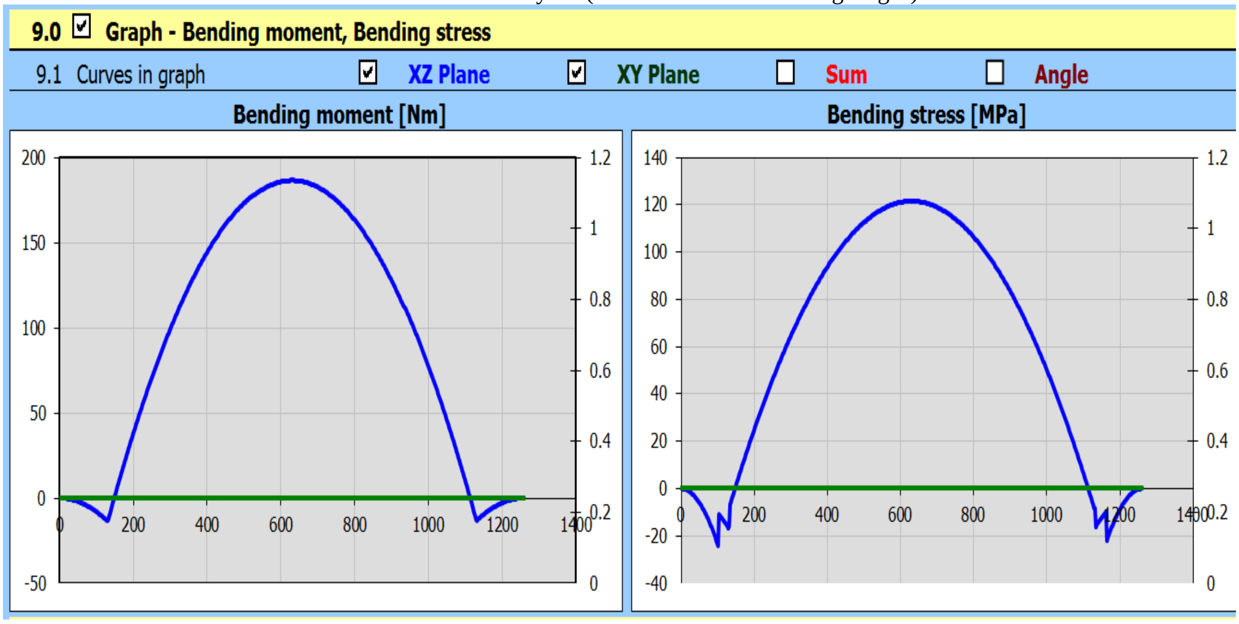


FIGURE 82 Shaft analysis (bending moment and bending stress)

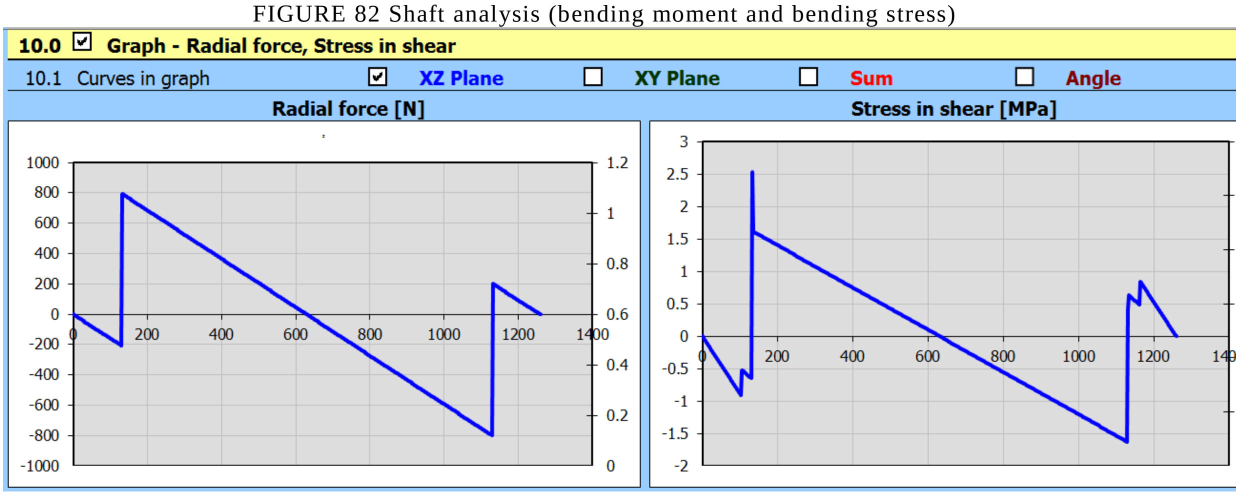


FIGURE 83 Shaft analysis (radial force and shear stress)

- Due to manufacturing limitation and shortage in time, tricycle’s rear axle with differential was used which can carry up to 1500 kilograms

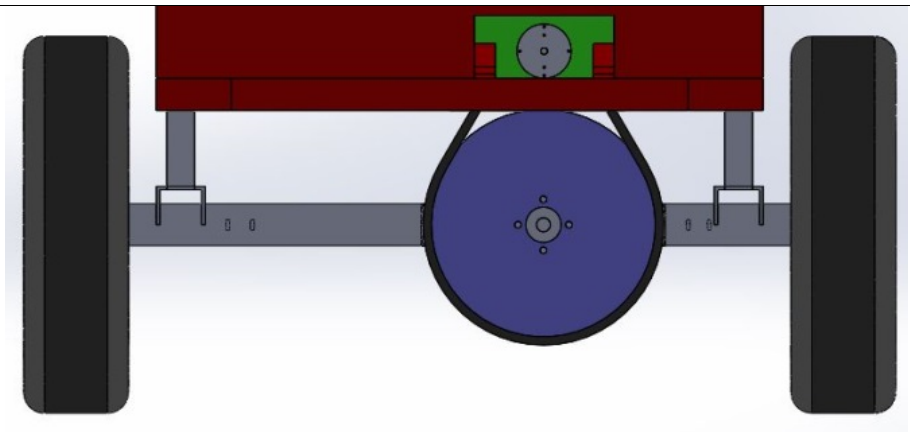


Figure 84 Drive system assembled

FIGURE 85 Tricycle’s rear axle with differential (uncovered)

FIGURE 86 Tricycle’s rear axle with differential (covered)

FIGURE 87Tricycle's rear axle with differential (limited-slip type)

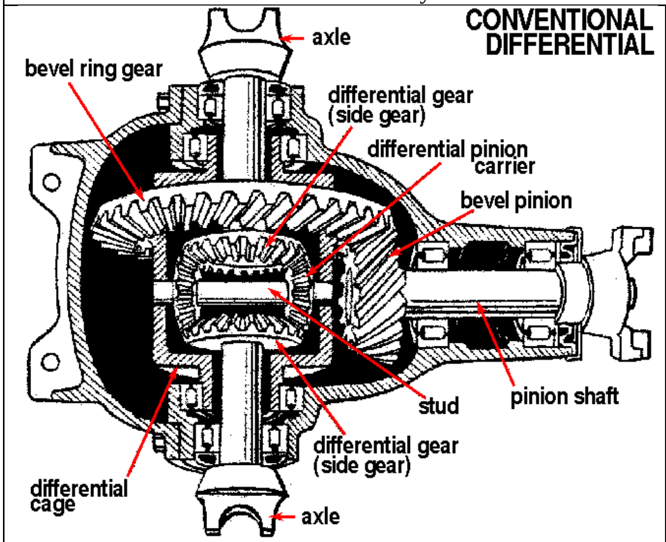


FIGURE 88 Conventional differential components

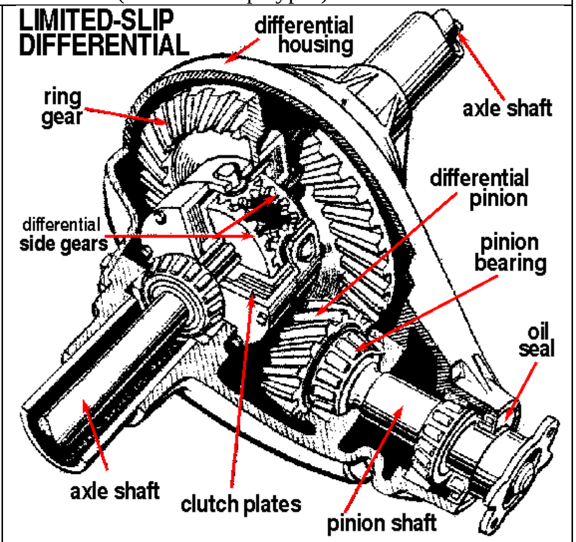
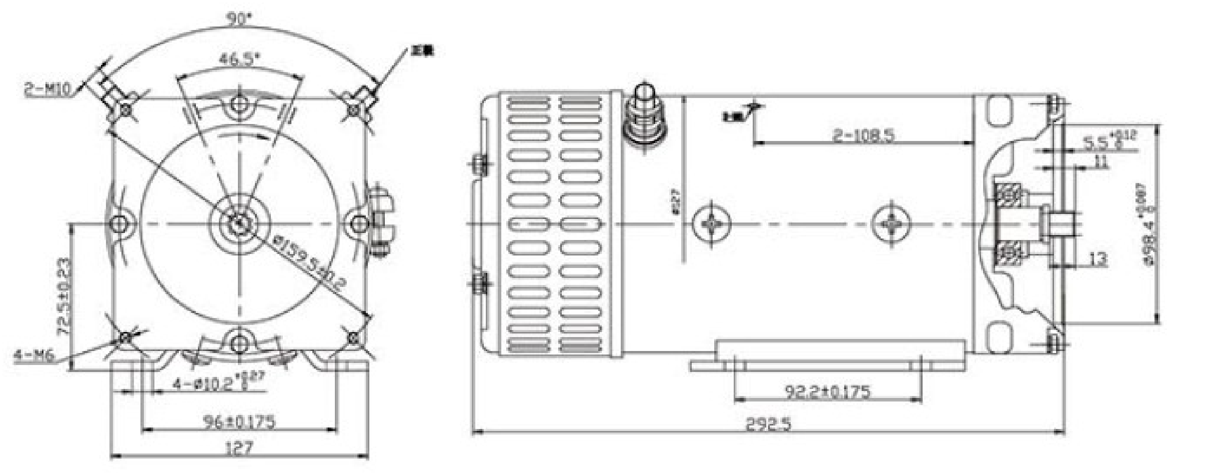


FIGURE 89 Limited-slip differential components

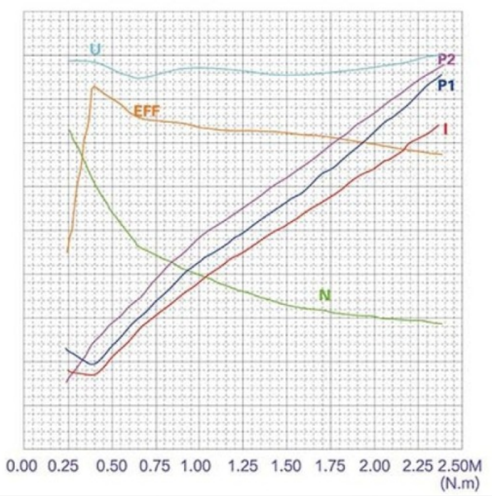
Dc motor:

- The original motor that was going to be used:



电压/Voltage	功率/Power	转速/Speed	转向/Rotation	外径/0.D
24V	4.0KW	3000RPM	CW/顺时针	127mm

U(V)	I(A)	n(rpm)	P1(W)	P2(W)	EFF(%)
27.00	280.0	8903	5992	4000	100.0
24.30	252.0	8012.7	5393	3600	90.0
21.60	224.0	7122.4	4794	3200	80.0
18.90	196.0	6232.1	4194	2800	70.0
16.20	168.0	5341.8	3595	2400	60.0
13.50	140.0	4451.5	2996	2000	50.0
10.80	112.0	3561.2	2397	1600	40.0
8.10	84.0	2670.9	1798	1200	30.0
5.40	56.0	1780.6	1198	800	20.0
2.70	28.0	890.3	599	400	10.0
0.00	0.0	0	0	0	0.0



最大效率点（Max_Efficiency）		最大输出功率点（Max_Pout）	
效率（Eff）	= 84.69（%）	效率（Eff）	= 68.20（%）
转速（n）	= 5524（rpm）	转速（n）	= 2620（rpm）
转矩（M）	= 1.750（N.m）	转矩（M）	= 13.020（N.m
电流（I）	= 49.230（A）	电流（I）	= 212.750（A）
输出功率（P2）	= 1009.90（W）	输出功率（P2）	= 3571.90（W

FIGURE 90 Motor data along with measurement data

- However, Due to issues with shipment and the customs the following motor was used:

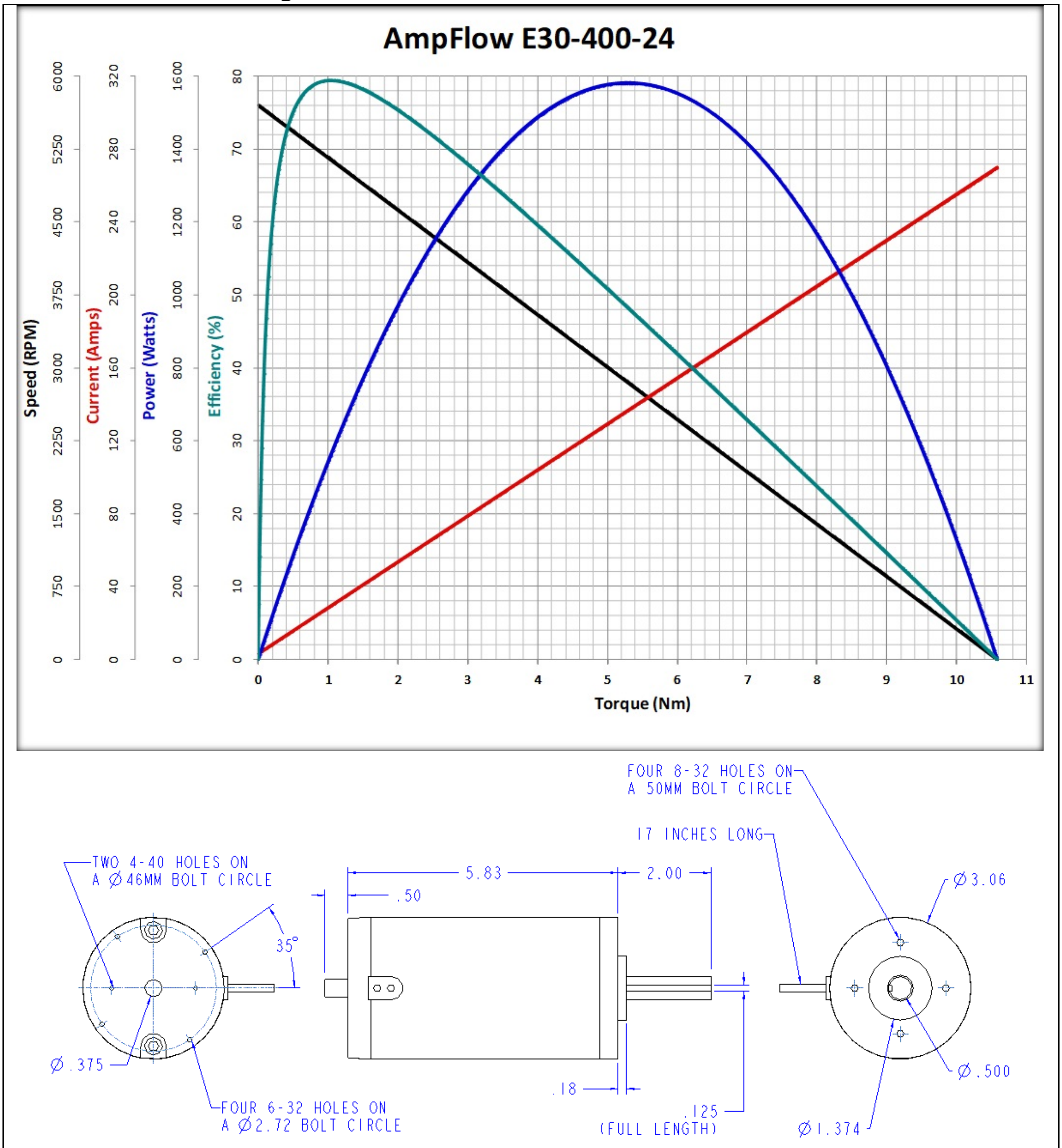


FIGURE 91 Motor data along with speed-torque curve

Motor driver:

- The following motor driver was used:

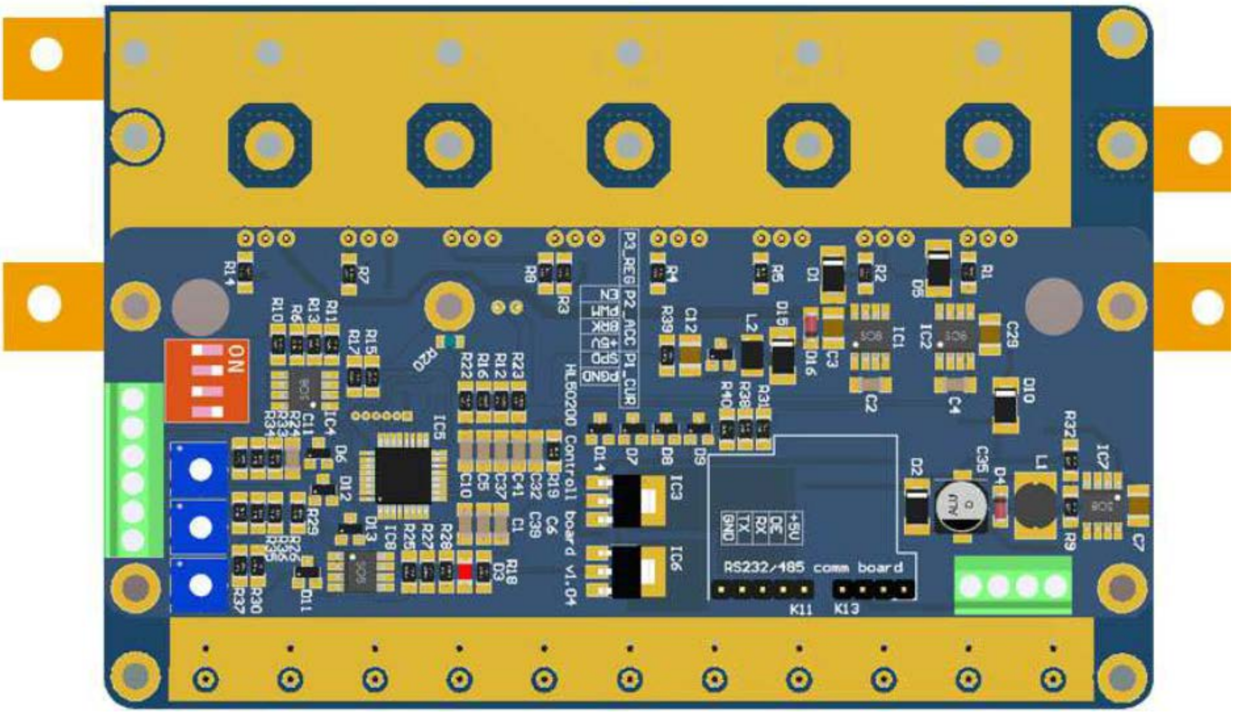


FIGURE 92 Motor driver

TECHNICAL SPECIFICATIONS:	
Supply voltage:	10-50V
Output current:	300A peak 200A continuous at 25°C
Minimal duty cycle:	0%
Maximal duty cycle:	min 96%
Protections:	Over current protection, Output short protection with minimal load inductance
Switching frequency:	20kHz
Power connection:	M6 on 10x3mm copper trails

3. Braking system

- The type of braking system is disk brake mounted to the front wheel:

FIGURE 93 Braking system

FIGURE 94 Disk brake’s rotor

FIGURE 95 Disk brake's caliper

FIGURE 96 Handle with brake lever

FIGURE 97 Brake fluid tank

FIGURE 98 Brake fluid

4. Suspension system

- The shock absorbers used are compatible with Honda cg125:

FIGURE 99 Vehicle's front fork assembled

FIGURE 100 Seat's suspension (in box)

FIGURE 101 Seat's suspension

5. Battery and Battery's charging unit

- Although the original design was to use 24 volts LiFePO4 battery, 24 volts lithium ion battery was used instead due to current consumption limitation on LiFePO4 batteries
- The batteries of drive system was separated from control system battery which is a 12 volts lithium polymer battery

 FIGURE 102 24 Volts 10 ah lithium ion battery	 FIGURE 103 24 Volts 10 ah lithium ion battery charger
FIGURE 104 12 Volts lithium polymer batteries	FIGURE 105 12 Volts lithium polymer batteries charger

6. Control System

- Throttle control circuit:
  - Circuit voltage 24 volts
  - This where throttle handlebar is connected along with other controls as lighting ,turn signal , horn and brake light along with speedometer to provide user with data about vehicle's speed , lights and battery

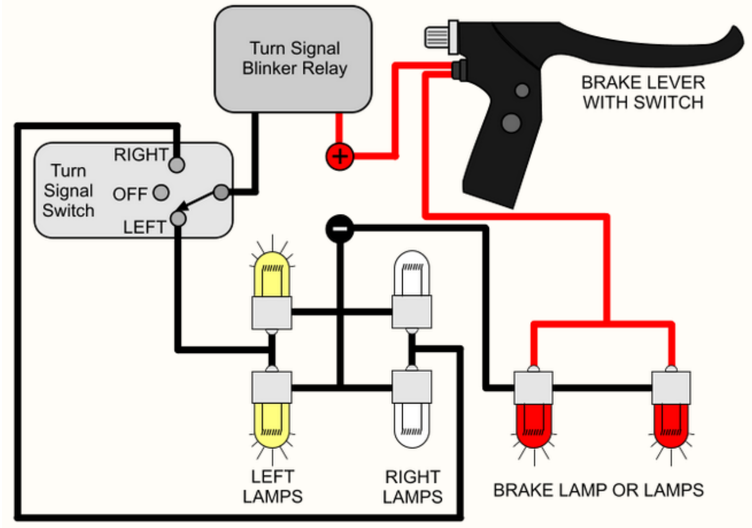


FIGURE 106 Brake lever circuit

FIGURE 107 Speedometer

FIGURE 108 Throttle handlebar

FIGURE 109 Headlamp

FIGURE 110 Turn signal flasher

FIGURE 111 Throttle controls handle

FIGURE 112 Brake signal lamp

FIGURE 113 Turn signal lamp

- Motor driver circuit:
    - Circuit voltage 24 volts
    - In order provide reverse (backward) motion , a 7.5kw changeover switch was used

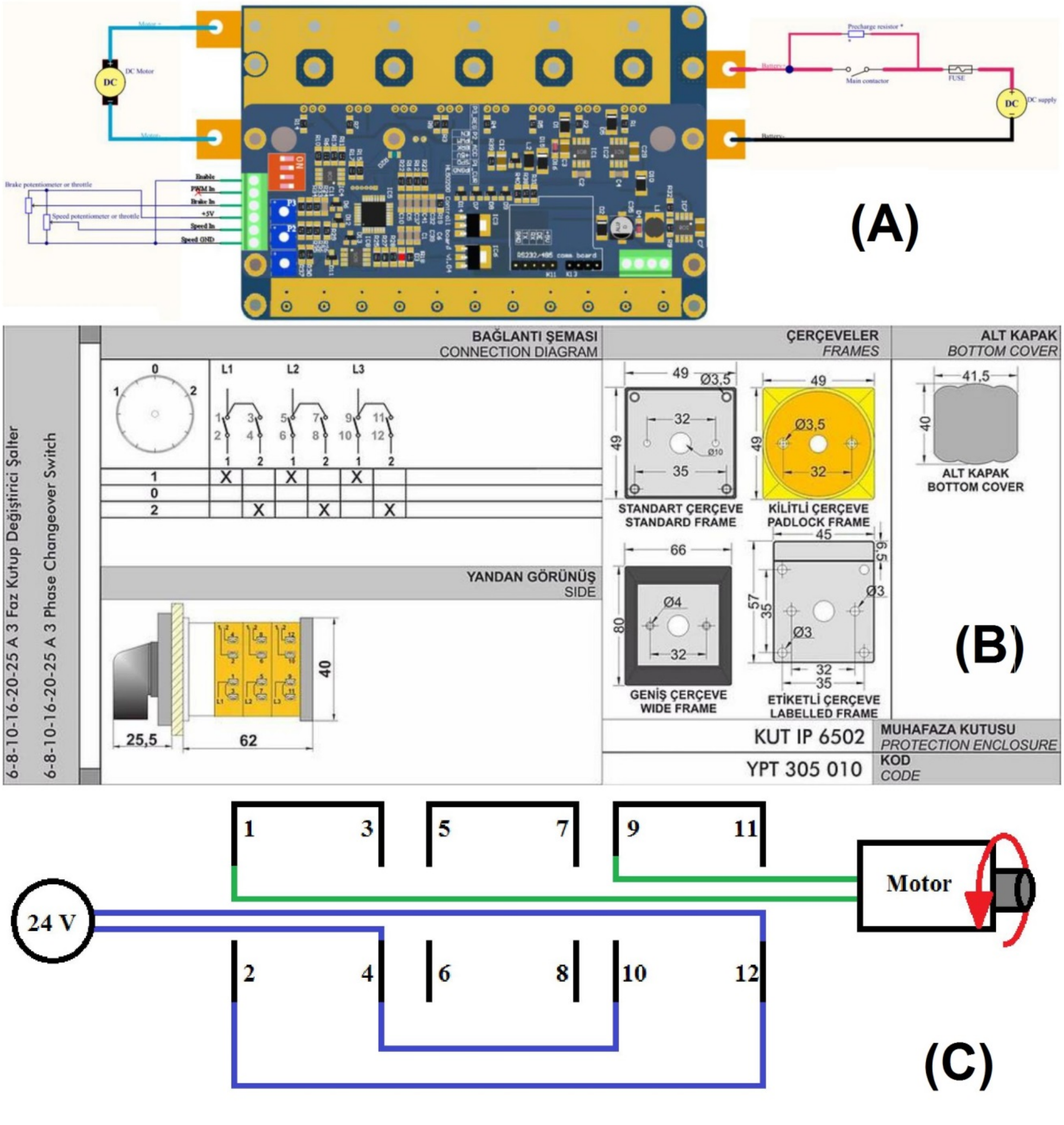
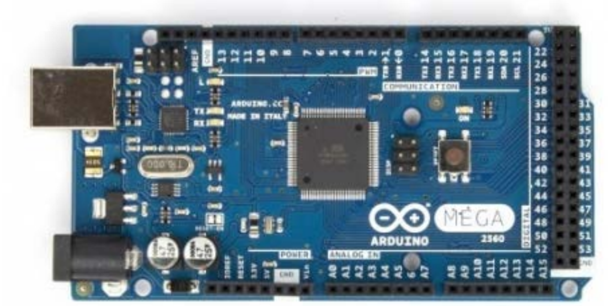
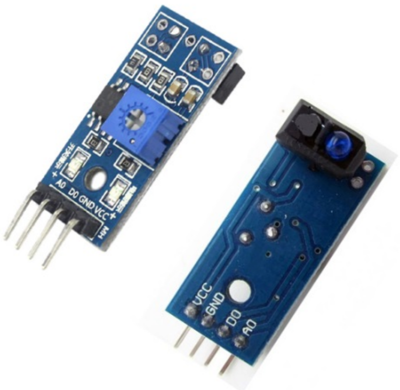
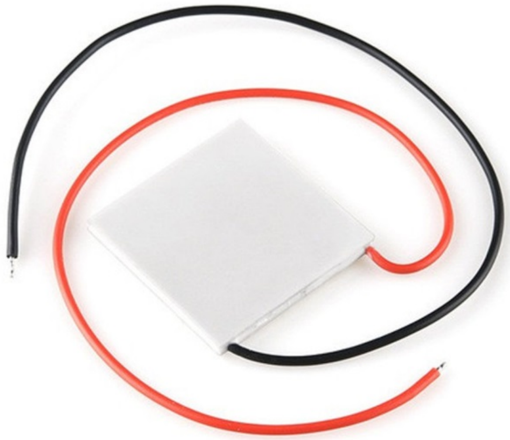


FIGURE 114 (A) Motor driver circuit (b) changeover switch that will be used to reverse motor's direction and switch between charging mode and operation mode and (c) the wiring of the changeover switch to reverse motor direction

- Motor safety and obstacle detection circuit:
  - Circuit voltage: 12 volts
  - The components used:

TABLE 10 Electrical compenents

picture	component	function
	DS18B20 "Waterproof Temperature Sensor" – 1m Length • 3.0-5.5V input voltage • Waterproof • -55°C to+125°C temperature range • ±0.5°C accuracy from -10°C to +85°C • 1 Wire interface	Measure motor temperature
	Arduino mega 2560	
	Line Follower Sensor – Digital • detecting the reflected distance: 1mm ~ 25mm applicable • with multi-turn precision potentiometer adjustable sensitivity adjustment • the working voltage of 3.3V-5V	Check chain motion

	Thermoelectric Cooler • Size: 40 x 40 x 3.6mm • lmax - 7A • Vmax - 15.4V • Qcmax - 62.2W • Tmax - 69C • Max Operating Temp: 180°C • Min Operating Temp: -50°C	Motor cooling
	Infrared Proximity Sensor -10 to 30 V • Supply Voltage: 6:30VDC • Supply Current: 25mA • Max Current: 100mA • Response time: < 2ms • Detection range from 5-30 cm adjustable • Type: NPN	Measure distance between vehicle and obstacle (obstacle detection)
	5mm LED with Metal Cover • Operating voltage: 3.3V-5V	Indicator for the user

	Buzzer 5V • Operating voltage: 5V	Indicator for the user
	Solid State Relay • Input voltage: 3~32Vdc • Output voltage: Output 5~200Vdc • Output current: 25A	Switching Thermoelectric Cooler ON and off
	BC337 "NPN" • Current Gain (hFE), 100 to 630 • Continuous Collector current (IC) is 800mA • Collector-Emitter voltage (VCEO) is 45 V • Collector-Base voltage (VCB0) is 50V • Emitter Base Voltage (VBE0) is 5V • Transition Frequency 100MHz • General Purpose NPN Amplifier Transistor	Switching buzzer ON and OFF

- Although a graphical display could be used to provide better visual interface to the user , it also will slow down system that’s why LEDs And buzzer were used instead

- The circuit diagram:

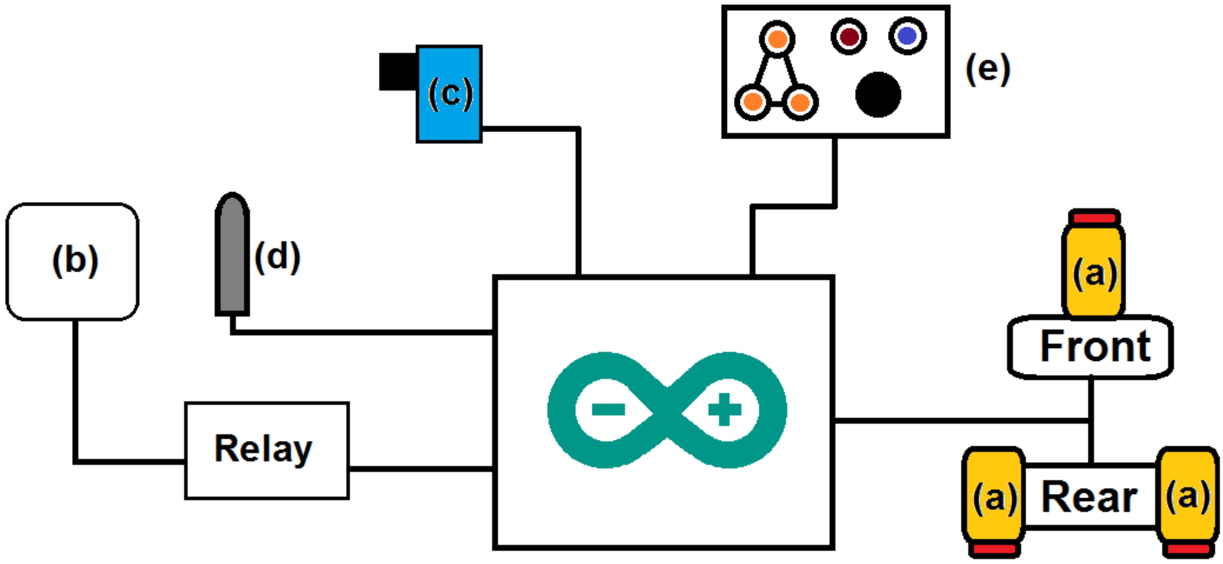


FIGURE 115 Motor safety and obstacle detection circuit diagram

For Arduino code and circuit schematic, check appendix B

CHAPTER SIX

CONCLUSION

Chapter Six: Conclusion

Introduction

Vehicles are complex type of machines that require serious considerations and tons of materials to manufacture; I know it's not academic to say so. From my experience, I learned the following:

1. Vehicle body design mainly depend on the weight it holds
2. Road is a critical factor in vehicle's stability
3. Vehicle industry constrained by standards
4. Simulation of sub systems individually is better than unifying all subsystems into one model
5. Electrical and electronic Subsystems decoupling makes for easier system assembly and maintenance

This chapter is divided into:

1. Project budget study
2. Future work

Project budget study

The following table will cover the vehicle cost:

TABLE 11 Project budget

Item	Cost (USD)	Cost (EGP)	Qty.
Lithium ion Battery 24 v 10Ah	99.95	1,597.26	1
Charger for 24v Lithium ion battery	27.95	446.66	1
24 v battery charger adaptor	8.95	143.03	1
Headlamp	19.95	318.81	1
Brake lamp	12.95	206.95	1
Turn signal lamp	10.01	160.00	2
Turn signal flasher relay	4.95	79.10	1
Axle sprocket	89.95	1,437.45	1
Motor sprocket	9.95	159.01	1
Chain 10 feet	39.95	638.42	1
Horn	5.95	95.08	1
Speedometer	19.95	318.81	1
Throttle handlebar	29.95	478.62	1
Throttle controls handlebar	17.95	286.85	1
Infrared Proximity sensor	23.47	375.00	3
Temperature sensor	4.07	65.00	1
Led 5mm and metal cover	0.50	8.00	4
BC 337	0.03	0.50	1
Buzzer	0.31	5.00	1
CAT 6 cable /Meters	3.13	50.00	10
High power cable/Meters	9.39	150.00	Var.
Arduino mega	16.27	260.00	1
DC Motor	109.00	1,741.89	1
Motor driver	170.01	2,716.70	1
Front fork	93.87	1,500.00	1
Seat suspension	15.64	250.00	4
Body and Frame	344.18	5,500.00	1
Rear axle	137.67	2,200.00	1
Lithium polymer battery 12 v	9.39	150.00	1
Charger for Lithium polymer battery 12 v	4.69	75.00	1
Vehicle decal	43.80	700.00	1
Electronics extras (resistors ,block terminals, boards, etc)	18.77	300.00	Var.
Total Cost	1,402.57	22,413.14	

Future work

After the manufacturing of the vehicle, a lot of features and improvements that can be added to the vehicle in future and some of them were achieved including:

1. Adding obstacle detection system which in practice was more effective since: the vehicle will have the ability to alarm the user from obstacles by using proximity sensor system that automatically turns on an alarm if the obstacle is in close range to the vehicle.

There is also other enhancements that will be considered in future design including:

1. Improve the vehicle's design: some improvements to the vehicle may be implemented including:
    a. Turn vehicle from three-wheeled vehicle to four-wheeled vehicle
    b. Turn vehicle's drive from two wheel to four wheel
    c. Turn vehicle's steering system from single wheel to two wheel steering
    d. Add extra batteries to extend vehicle's operating time
2. Self-Charging system: the vehicle will have the ability to charge its battery while moving by adding generators on each wheel
3. Self-driving system: the vehicle will have the ability to drive itself without a human driver to desired destination assigned by the user.
4. Ability to pull machinery

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Appendix A: Sprocket and chain charts

TABLE 12 Roller chain selection chart

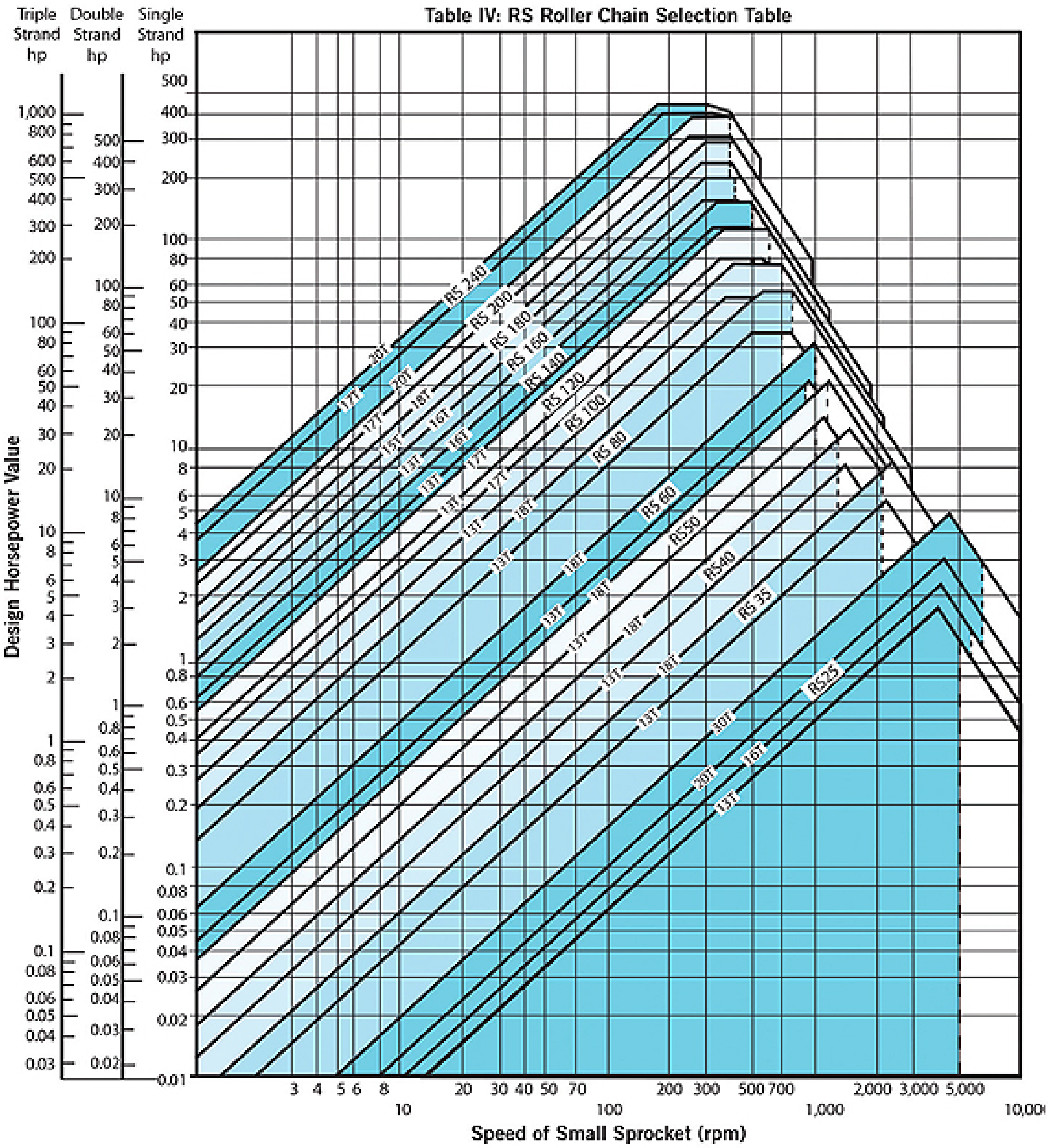


TABLE 13 Reduction ratio selection chart

Speed Ratios For Sprocket Combinations
Driver Sprocket Teeth

DRIVEN SPROCKET TEETH

	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
9	1.00																	
10	1.11	1.00																
11	1.22	1.10	1.00															
12	1.33	1.20	1.09	1.00														
13	1.44	1.30	1.18	1.08	1.00													
14	1.56	1.40	1.27	1.17	1.08	1.00												
15	1.67	1.50	1.36	1.25	1.15	1.07	1.00											
16	1.78	1.60	1.45	1.33	1.23	1.14	1.07	1.00										
17	1.89	1.70	1.55	1.42	1.31	1.21	1.13	1.06	1.00									
18	2.00	1.80	1.64	1.50	1.38	1.29	1.20	1.13	1.06	1.00								
19	2.11	1.90	1.73	1.58	1.46	1.36	1.27	1.19	1.12	1.06	1.00							
20	2.22	2.00	1.82	1.67	1.54	1.43	1.33	1.25	1.18	1.11	1.05	1.00						
21	2.33	2.10	1.91	1.75	1.61	1.50	1.40	1.31	1.23	1.17	1.10	1.05	1.00					
22	2.44	2.20	2.00	1.83	1.69	1.57	1.47	1.38	1.29	1.22	1.16	1.10	1.05	1.00				
23	2.56	2.30	2.09	1.92	1.77	1.64	1.53	1.44	1.35	1.28	1.21	1.15	1.09	1.04	1.00			
24	2.67	2.40	2.18	2.00	1.85	1.71	1.60	1.50	1.41	1.33	1.26	1.20	1.14	1.09	1.04	1.00		
25	2.78	2.50	2.27	2.08	1.92	1.79	1.67	1.56	1.47	1.39	1.32	1.25	1.19	1.14	1.09	1.04	1.00	
26	2.89	2.60	2.36	2.17	2.00	1.86	1.73	1.63	1.53	1.45	1.37	1.30	1.24	1.18	1.13	1.08	1.04	1.00
27	3.00	2.70	2.45	2.25	2.08	1.93	1.80	1.69	1.59	1.50	1.42	1.35	1.29	1.23	1.17	1.12	1.08	1.04
28	3.11	2.80	2.54	2.33	2.15	2.00	1.87	1.75	1.65	1.56	1.47	1.40	1.33	1.27	1.22	1.17	1.12	1.08
29	3.22	2.90	2.64	2.42	2.23	2.07	1.93	1.81	1.71	1.61	1.53	1.45	1.38	1.32	1.26	1.21	1.16	1.12
30	3.33	3.00	2.73	2.50	2.31	2.14	2.00	1.88	1.76	1.67	1.58	1.50	1.43	1.36	1.31	1.25	1.20	1.15
31	3.44	3.10	2.82	2.58	2.38	2.21	2.07	1.94	1.82	1.72	1.63	1.55	1.48	1.41	1.35	1.29	1.24	1.19
32	3.56	3.20	2.91	2.67	2.46	2.28	2.13	2.00	1.88	1.78	1.68	1.60	1.52	1.45	1.39	1.33	1.28	1.23
33	3.67	3.30	3.00	2.75	2.54	2.36	2.20	2.06	1.94	1.83	1.74	1.65	1.57	1.50	1.43	1.38	1.32	1.27
34	3.78	3.40	3.09	2.83	2.62	2.43	2.27	2.13	2.00	1.89	1.79	1.70	1.62	1.55	1.48	1.42	1.36	1.31
35	3.89	3.50	3.18	2.92	2.69	2.50	2.33	2.19	2.06	1.95	1.84	1.75	1.67	1.59	1.52	1.46	1.40	1.34
36	4.00	3.60	3.27	3.00	2.77	2.57	2.40	2.25	2.12	2.00	1.89	1.80	1.71	1.63	1.57	1.50	1.44	1.38
37	4.11	3.70	3.36	3.08	2.85	2.64	2.47	2.31	2.18	2.06	1.95	1.85	1.76	1.68	1.61	1.54	1.48	1.42
38	4.22	3.80	3.45	3.17	2.92	2.71	2.53	2.38	2.24	2.11	2.00	1.90	1.81	1.73	1.65	1.58	1.52	1.46
39	4.33	3.90	3.55	3.25	3.00	2.79	2.60	2.44	2.29	2.17	2.05	1.95	1.86	1.77	1.70	1.63	1.56	1.50
40	4.44	4.00	3.64	3.33	3.08	2.86	2.67	2.50	2.35	2.22	2.10	2.00	1.90	1.82	1.74	1.67	1.60	1.54
41	4.56	4.10	3.73	3.42	3.15	2.93	2.73	2.56	2.41	2.28	2.16	2.05	1.95	1.86	1.78	1.71	1.64	1.58
42	4.67	4.20	3.82	3.50	3.23	3.00	2.80	2.63	2.47	2.34	2.21	2.10	2.00	1.91	1.83	1.75	1.68	1.61
43	4.78	4.30	3.91	3.58	3.31	3.07	2.87	2.69	2.53	2.39	2.26	2.15	2.05	1.95	1.87	1.79	1.72	1.65
44	4.89	4.40	4.00	3.67	3.39	3.14	2.93	2.75	2.59	2.44	2.32	2.20	2.10	2.00	1.91	1.83	1.76	1.69
45	5.00	4.50	4.09	3.75	3.46	3.21	3.00	2.81	2.65	2.50	2.37	2.25	2.14	2.04	1.96	1.88	1.80	1.73
46	5.11	4.60	4.18	3.83	3.54	3.29	3.07	2.88	2.71	2.56	2.42	2.30	2.19	2.09	2.00	1.92	1.84	1.77
47	5.22	4.70	4.27	3.92	3.62	3.36	3.13	2.94	2.76	2.61	2.47	2.35	2.24	2.14	2.04	1.96	1.88	1.81
48	5.33	4.80	4.36	4.00	3.69	3.43	3.20	3.00	2.82	2.67	2.52	2.40	2.28	2.18	2.09	2.00	1.92	1.84
49	5.44	4.90	4.45	4.08	3.77	3.50	3.27	3.06	2.88	2.72	2.58	2.45	2.33	2.23	2.13	2.04	1.96	1.88
50	5.56	5.00	4.55	4.17	3.85	3.57	3.33	3.13	2.94	2.78	2.63	2.50	2.38	2.27	2.17	2.08	2.00	1.92
51	5.67	5.10	4.64	4.25	3.92	3.64	3.40	3.19	3.00	2.83	2.68	2.55	2.43	2.32	2.22	2.13	2.04	1.96
52	5.78	5.20	4.73	4.33	4.00	3.71	3.47	3.25	3.06	2.89	2.74	2.60	2.48	2.36	2.26	2.17	2.08	2.00
53	5.89	5.30	4.82	4.42	4.08	3.79	3.53	3.31	3.12	2.94	2.79	2.65	2.52	2.41	2.30	2.21	2.12	2.04
54	6.00	5.40	4.91	4.50	4.15	3.86	3.60	3.38	3.18	3.00	2.84	2.70	2.57	2.45	2.35	2.25	2.16	2.07
55	6.11	5.50	5.00	4.58	4.23	3.93	3.67	3.44	3.24	3.06	2.90	2.75	2.62	2.50	2.39	2.29	2.20	2.12
56	6.22	5.60	5.09	4.67	4.31	4.00	3.73	3.50	3.29	3.11	2.95	2.80	2.67	2.55	2.43	2.33	2.24	2.15
57	6.33	5.70	5.18	4.75	4.38	4.07	3.80	3.56	3.35	3.17	3.00	2.85	2.71	2.59	2.48	2.38	2.28	2.19
58	6.44	5.80	5.27	4.83	4.46	4.14	3.87	3.63	3.41	3.22	3.05	2.90	2.76	2.64	2.52	2.42	2.32	2.23
59	6.56	5.90	5.36	4.92	4.54	4.21	3.93	3.69	3.47	3.28	3.11	2.95	2.81	2.68	2.57	2.46	2.36	2.27
60	6.67	6.00	5.45	5.00	4.61	4.28	4.00	3.75	3.53	3.34	3.16	3.00	2.86	2.72	2.61	2.50	2.40	2.30
68	7.55	6.80	6.18	5.66	5.23	4.86	4.54	4.25	4.00	3.78	3.58	3.40	3.24	3.09	2.96	2.84	2.72	2.61
70	7.78	7.00	6.36	5.83	5.38	5.00	4.67	4.38	4.12	3.89	3.68	3.50	3.33	3.18	3.05	2.92	2.80	2.69
72	8.00	7.20	6.54	6.00	5.54	5.14	4.80	4.50	4.24	4.00	3.79	3.60	3.43	3.27	3.13	3.00	2.88	2.77
76			6.91	6.33	5.84	5.43	5.07	4.75	4.47	4.23	4.00	3.80	3.62	3.45	3.31	3.17	3.04	2.92
80			7.27	6.66	6.15	5.71	5.34	5.00	4.70	4.45	4.21	4.00	3.81	3.63	3.48	3.34	3.20	3.07
84				7.00	6.46	6.00	5.60	5.25	4.94	4.67	4.42	4.20	4.00	3.81	3.65	3.50	3.36	3.23
95					7.31	6.78	6.33	5.94	5.59	5.28	5.00	4.75	4.52	4.32	4.13	3.96	3.80	3.65
96					7.38	6.85	6.40	6.00	5.64	5.34	5.05	4.80	4.57	4.36	4.18	4.00	3.84	3.69
102						7.28	6.80	6.38	6.00	5.67	5.37	5.10	4.86	4.63	4.44	4.25	4.08	3.92
112								7.00	6.59	6.23	5.89	5.60	5.33	5.08	4.87	4.67	4.48	4.30

Appendix B: Motor safety and obstacle detection circuit

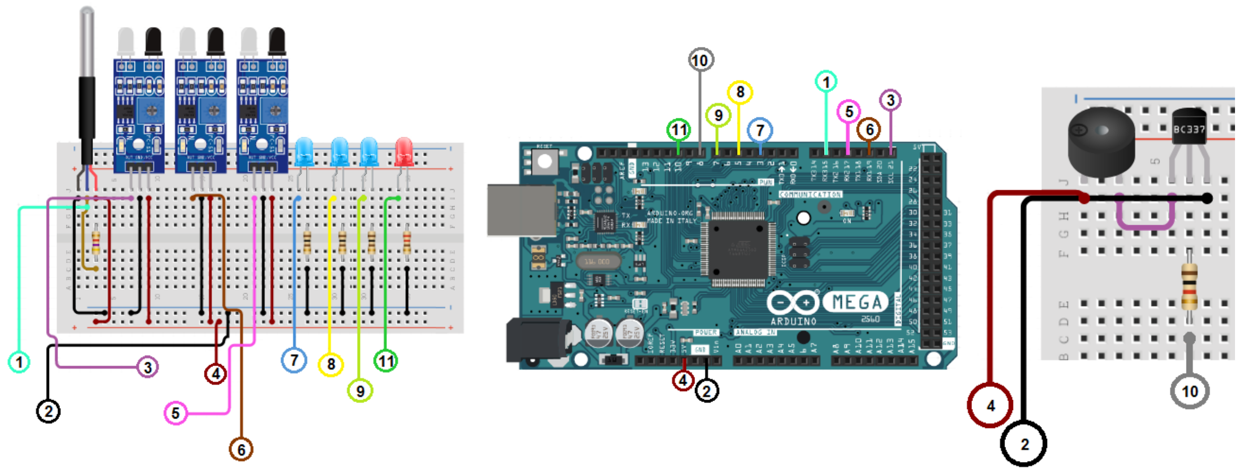


FIGURE 116 Circuit schematic

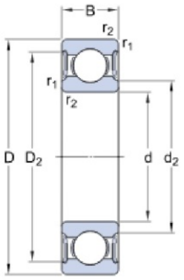
```
#include <OneWire.h>
#include <DallasTemperature.h>

#define REAR_SENSOR_L                21
#define REAR_SENSOR_R                19
#define FRONT_SENSOR                 17
#define TEMPERATURE_SENSOR           15
#define REAR_INDICATOR_L              3
#define REAR_INDICATOR_R              5
#define FRONT_INDICATOR               7
#define ALARM                         8
#define MOTOR_TEMPERATURE_INDICATOR  10

OneWire oneWire(TEMPERATURE_SENSOR);
DallasTemperature sensors(&oneWire);

void setup() {
  pinMode(REAR_SENSOR_L, INPUT_PULLUP);
  pinMode(REAR_SENSOR_R, INPUT_PULLUP);
  pinMode(FRONT_SENSOR,  INPUT_PULLUP);
  pinMode(REAR_INDICATOR_L, OUTPUT);
  pinMode(REAR_INDICATOR_R, OUTPUT);
  pinMode(FRONT_INDICATOR, OUTPUT);
  pinMode(ALARM, OUTPUT);
  sensors.begin();
}

void loop() {
```

```
  int REAR_SENSOR_L_READING = digitalRead(REAR_SENSOR_L);
  int REAR_SENSOR_R_READING = digitalRead(REAR_SENSOR_R);
  int FRONT_SENSOR_READING  = digitalRead(FRONT_SENSOR);
  sensors.requestTemperatures();
  float MOTOR_TEMPERATURE   = sensors.getTempCByIndex(0);
  int   MOTOR_TEMPERATURE_LEVEL = map(MOTOR_TEMPERATURE
, 0, 85, 0, 255);
   if(MOTOR_TEMPERATURE >= 40){

analogWrite(MOTOR_TEMPERATURE_INDICATOR,MOTOR_TEMPERA
TURE_LEVEL);
     }else if (MOTOR_TEMPERATURE >= 85){

analogWrite(MOTOR_TEMPERATURE_INDICATOR,MOTOR_TEMPERA
TURE_LEVEL);
   digitalWrite(ALARM,HIGH);
     }else{
       digitalWrite(ALARM,LOW);
       digitalWrite(MOTOR_TEMPERATURE_INDICATOR,LOW);
     }
     if(REAR_SENSOR_L_READING == 0){
    digitalWrite(REAR_INDICATOR_L,HIGH);
    digitalWrite(ALARM,HIGH);
     }else if(REAR_SENSOR_R_READING == 0){
    digitalWrite(REAR_INDICATOR_R,HIGH);
    digitalWrite(ALARM,HIGH);
     }else if(FRONT_SENSOR_READING == 0){
    digitalWrite(FRONT_INDICATOR,HIGH);
    digitalWrite(ALARM,HIGH);
     }else{
   digitalWrite(REAR_INDICATOR_L,LOW);
   digitalWrite(REAR_INDICATOR_R,LOW);
   digitalWrite(FRONT_INDICATOR,LOW);
   digitalWrite(ALARM,LOW);
     }
  delay(100);
}
```

Appendix C: Bearing datasheet

In order to provide smooth motion , bearing were added to both driving shaft and front fork. This section covers bearing used:

SKF **LS 7**



DIMENSIONS

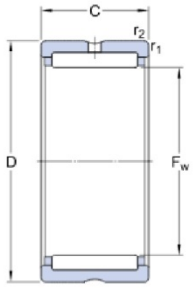
d	15.875 mm
D	39.688 mm
B	11.112 mm
d_2	≈ 21.5 mm
D_2	≈ 34.98 mm
$r_{1,2}$	min. 0.8 mm

CALCULATION DATA

Basic dynamic load rating	C	9.56 kN
Basic static load rating	C_0	4.75 kN
Fatigue load limit	P_u	0.2 kN
Reference speed		34000 r/min
Limiting speed		24000 r/min
Calculation factor	k_r	0.025
Calculation factor	f_0	13.1

FIGURE 117 LS 7 Deep groov ball bearing datasheet

SKF NK 26/20



DIMENSIONS

F_w	26 mm
D	34 mm
C	20 mm
$r_{1,2}$	min. 0.3 mm

CALCULATION DATA

Basic dynamic load rating	C	19.4 kN
Basic static load rating	C_0	34.5 kN
Fatigue load limit	P_u	4.25 kN
Reference speed		15000 r/min
Limiting speed		17000 r/min

FIGURE 118 NK 26/20 Needle roller bearings with machined rings datasheet