LIST OF CONTENTS

[I. INTRODUCTION 4](#_Toc135267332)

[1.1 INTRODUCTION TO ELECTRIC POWER STEERING (EPS) SYSTEM 4](#_Toc135267333)

[1.1.1 Steering system 4](#_Toc135267334)

[1.1.2 Electric power steering (EPS) system 5](#_Toc135267335)

[1.2 Introduction to Simulink and Simscape 6](#_Toc135267336)

[1.3 Project scope and Objectives 8](#_Toc135267337)

[1.4 Working conditions 8](#_Toc135267338)

[1.5 Technical requirements 8](#_Toc135267339)

[1.6 Limitation 8](#_Toc135267340)

[II. THEORETICAL BASIS 9](#_Toc135267341)

[2.1 Overall structure and Working principles of EPS system 9](#_Toc135267342)

[2.1.1 Overall structure 9](#_Toc135267343)

[2.1.2 Working principles 13](#_Toc135267344)

[2.2 Dynamic equilibrium equations of EPS system 13](#_Toc135267345)

[2.3 Overall diagram and control rules of EPS system 16](#_Toc135267346)

[2.4 PID controller 16](#_Toc135267347)

[II. SIMULATION PROCESS 18](#_Toc135267348)

[3.1 Creating a path for the vehicle 18](#_Toc135267349)

[3.3 Steering system 22](#_Toc135267350)

[3.3 Vehicle model 22](#_Toc135267351)

[3.4 Electric motor 24](#_Toc135267352)

LIST OF FIGURES

[Figure 1 Components of a steering system 4](#_Toc135267353)

[Figure 2 Components of a steering system with Electric Power Steering 5](#_Toc135267354)

[Figure 3 Sinulink 7](#_Toc135267355)

[Figure 4 Simscape 8](#_Toc135267356)

[Figure 5 EPS structure 9](#_Toc135267357)

[Figure 6 Torque sensor of EPS 9](#_Toc135267358)

[Figure 7 Steering angle sensor of EPS 10](#_Toc135267359)

[Figure 8 Control module of EPS 11](#_Toc135267360)

[Figure 9 Electric motor of EPS 12](#_Toc135267361)

[Figure 10 Reduction gear of EPS 13](#_Toc135267362)

[Figure 11 EPS structure 14](#_Toc135267363)

[Figure 12 EPS block diagram 16](#_Toc135267364)

[Figure 13 A PID controller structure 17](#_Toc135267365)

[Figure 14 A driving scenario - lane changing 18](#_Toc135267366)

[Figure 15 Heading angle of a vehicle 19](#_Toc135267367)

[Figure 16 Position of the Set Path block in the model 19](#_Toc135267368)

[Figure 17 Structure of Set Path block 20](#_Toc135267369)

[Figure 18 Position of driver block in the model 21](#_Toc135267370)

[Figure 19 Structure of Driver block 21](#_Toc135267371)

[Figure 20 Position of Steering system block in the model 22](#_Toc135267372)

[Figure 21 Position of Vehicle Body 3DOF block in the model 23](#_Toc135267373)

[Figure 22 Vehicle Body 3DOF Single Track block 23](#_Toc135267374)

[Figure 23 Vehicle Body 3DOF Dual Track block 24](#_Toc135267375)

[Figure 24 Overall structure of the model 25](#_Toc135267376)

# I. INTRODUCTION

## 1.1 INTRODUCTION TO ELECTRIC POWER STEERING (EPS) SYSTEM

### 1.1.1 Steering system

The steering system is one of the most important systems in any vehicle. It allows the driver to control the direction of movement and maneuver the vehicle as desired. A properly designed steering system provide drivers with precise control, feedback, and assistive power for safe and comfortable driving.

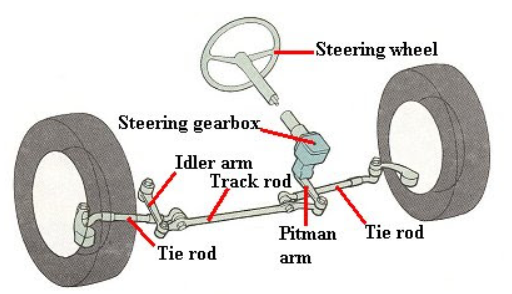


Figure 1 Components of a steering system

The basic components of a steering system are the steering wheel, steering column, steering gearbox, and linkages. The steering wheel allows the driver to input commands by turning left or right. The steering column transfers this rotational motion to the gearbox located under the vehicle. The steering gearbox then converts the rotation into linear motion that moves the steering linkages and turns the wheels. Various types of steering gearboxes are used, including rack and pinion, recirculating ball and worm and roller. The wheels are connected to the gearbox via tie rods, drag links and other linkages.

Early vehicles had direct mechanical steering with no power assistance. Drivers had to exert significant effort when turning the wheels at low speeds or parking. To reduce driver fatigue, power steering systems were introduced using hydraulic pressure or electric motors. Power steering valves control hydraulic pressure depending on how much the steering wheel is turned. Electric power steering systems use motors that sense steering torque and provide variable levels of assistance electronically.

Modern vehicles now integrate electronic controls into the steering system. Electronic control units process data from sensors monitoring torque, yaw rate, speed, and other variables. This enables features like speed-sensitive power assist, variable gear ratios, return-to-center function and active assist during evasive maneuvers. Advanced systems incorporate autonomous functions like lane centering and traffic jam assist.

### 1.1.2 Electric power steering (EPS) system

Electric power steering (EPS) systems use an electric motor to generate assistance torque instead of a hydraulic pump. This helps reduce fuel consumption by consuming electricity only when assistance torque is needed. EPS made its debut in the early 1990s and has since become the primary power steering technology for modern vehicles.

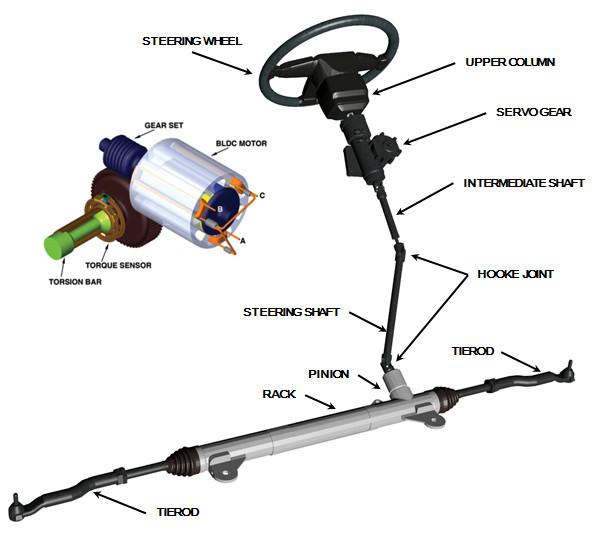


Figure 2 Components of a steering system with Electric Power Steering

Electric power steering systems provide numerous benefits over hydraulic systems, including improved fuel economy, flexibility for advanced functions and compact motor packages. Through precise control of an electric motor and sophisticated electronic controls, EPS aims to optimize steering assistance, dynamics and safety while reducing emissions from unnecessary hydraulic pump operation.

Electric power steering (EPS) systems have become a standard feature in modern vehicles to assist the driver and improve driving comfort. EPS uses an electric motor to generate the power that assists the driver's input torque on the steering wheel. Through precise control algorithms and rules, EPS enables features like variable assistance based on vehicle speed and self-centering when driving in a straight line. These systems aim to provide optimum balance between steering feel, maneuverability, and safety.

Simulation of EPS control rules plays an important role in the development and optimization of these systems. Computer simulations allow testing of different control strategies and parameters in a virtual environment before expensive physical prototypes are built. This greatly reduces development time and costs by eliminating trial-and-error experimentation using real hardware. Computer models of EPS systems can accurately emulate the dynamic behavior and interactions between the various system components.

This thesis report aims to build a simulation model of an EPS system to fully understand how the system works and behaves in different working conditions. The model will consist of mechanical components of steering system with electric motor, torque sensor, and EPS control unit.

There are several types of EPS widely used on production cars:

* Column EPS
* Single-Pinion EPS
* Dual-Pinion EPS
* Parallel Axis EPS

This project will simulate the control rules of Column EPS in Simulink and Simscape.

## 1.2 Introduction to Simulink and Simscape

Simulink is a block diagram environment for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling we to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

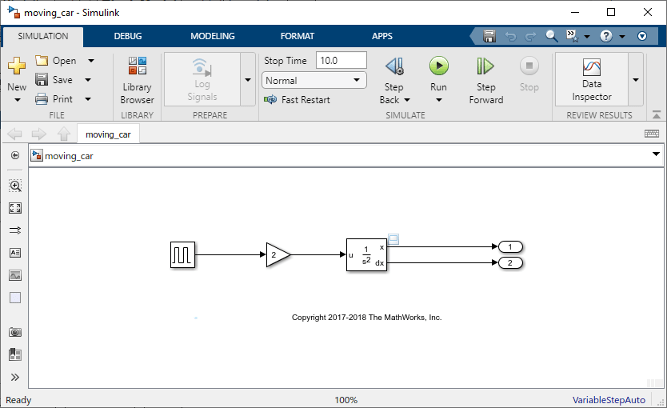


Figure 3 Sinulink

Simscape enables we to rapidly create models of physical systems within the Simulink environment. With Simscape we build physical component models based on physical connections that directly integrate with block diagrams and other modeling paradigms. We model systems such as electric motors, bridge rectifiers, hydraulic actuators, and refrigeration systems by assembling fundamental components into a schematic. Simscape add-on products provide more complex components and analysis capabilities. Simscape helps we develop control systems and test system-level performance. We can create custom component models using the MATLAB based Simscape language, which enables text-based authoring of physical modeling components, domains, and libraries. We can parameterize our models using MATLAB variables and expressions, and design control systems for our physical system in Simulink. To deploy our models to other simulation environments, including hardware-in-the-loop (HIL) systems, Simscape supports C-code generation.

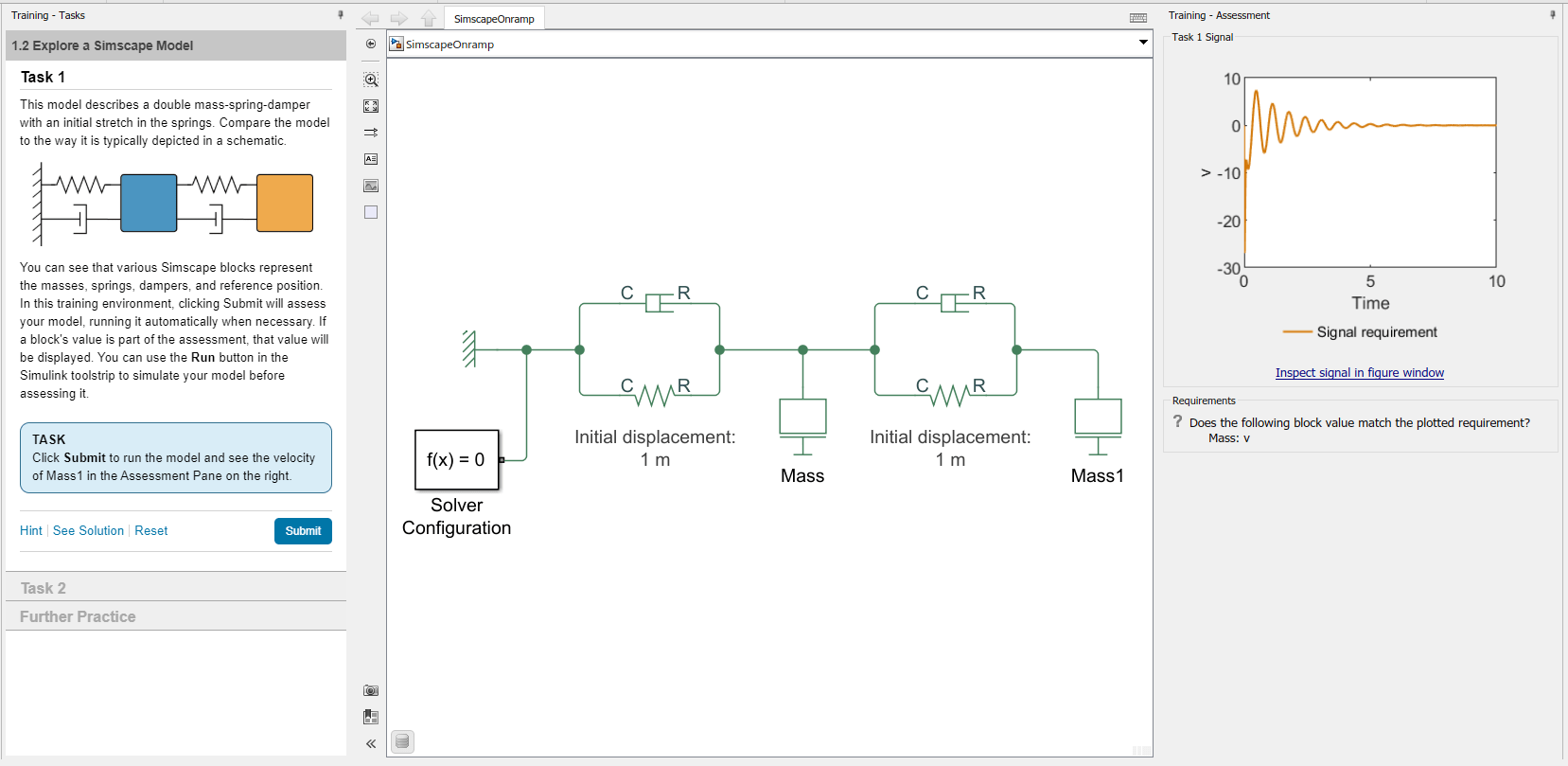


Figure 4 Simscape

## 1.3 Project scope and Objectives

The scope of the project is to solve the simulation model of the control rules of Electric Power Steering system using MATLAB/Simulink/Simscape and integration with steering system and vehicle body dynamics model.

The objectives of this project are to:

* Simulate the model of electric motor
* Control of electric motor
* Simulate the model of EPS system in Simulink and Simscape
* Simulate the control rules of EPS system
* Evaluate the results of assisting torque in different operating conditions of the vehicle (speed, steering wheel angle)

## 1.4 Working conditions

## 1.5 Technical requirements

* Simulation model works properly
* Accurate control rules of EPS system
* Vehicle can follow a desired path

## 1.6 Limitation

This project mainly focuses on the control rules of EPS system and ignores the electrical connections among electric components.

# II. THEORETICAL BASIS

## 2.1 Overall structure and Working principles of EPS system

### 2.1.1 Overall structure

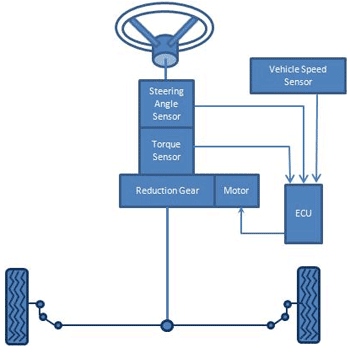


Figure 5 EPS structure

An electric power steering system is basically a steering system with additional components (mostly electric):

* Torque sensor:

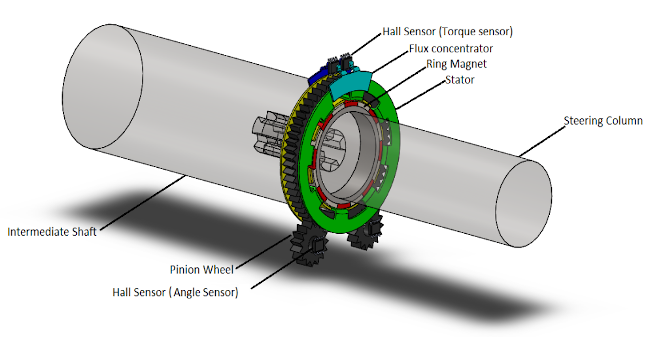


Figure 6 Torque sensor of EPS

It is a device used in electric power steering systems to measure the torque applied by the driver to the steering wheel. By calculating this data, the electronic control unit determines how much steering assistance to apply to the electric motor.

The torque sensor consists of input and output shafts connected by a torsion bar. The input shaft has splines, while the output shaft has slots. By moving the input and output shafts, torque is created in the torsion bar, which is magnetized and then converted into voltage.

* Steering angle sensor:

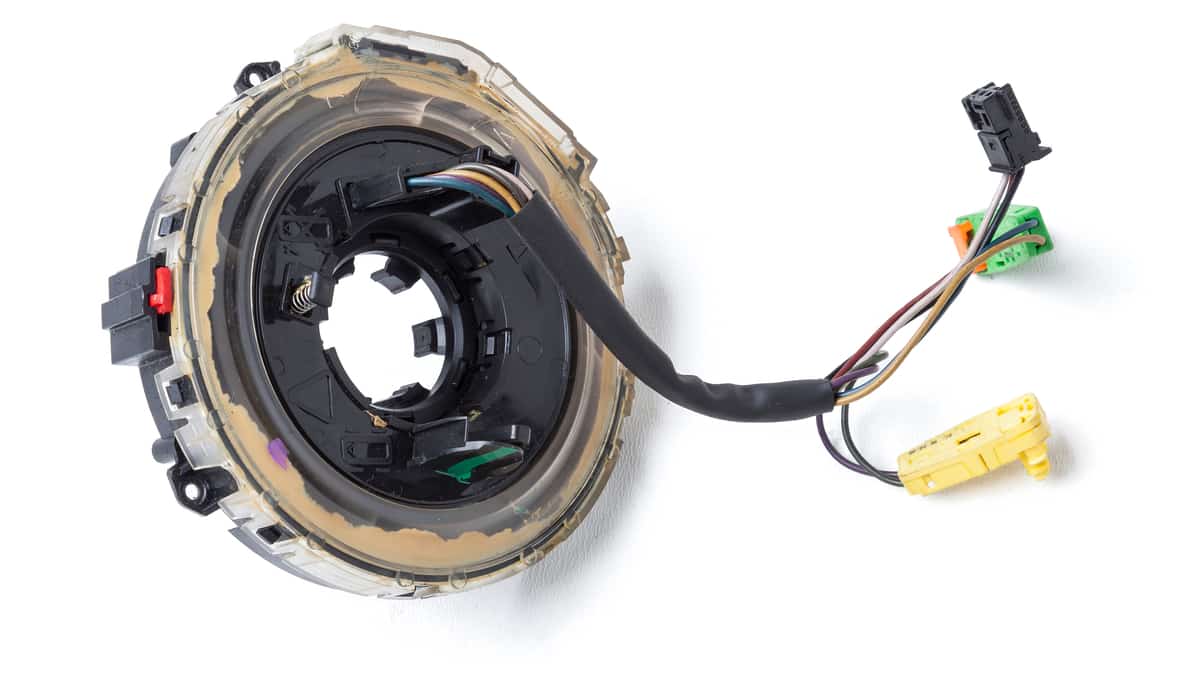


Figure 7 Steering angle sensor of EPS

It measures the position angle and rate of turn of the steering wheel. It matches the steering wheel with the vehicle’s wheels to determine where the driver wants to steer. Steering angle sensors are mounted in the steering column of a vehicle. In an EPS system, more than one angle sensor is used to provide redundancy and data verification. Nowadays, the torque sensor can also give information about the steering wheel angle so this sensor might not be necessary.

* EPS control unit (ECU):



Figure 8 Control module of EPS

The control module is responsible for managing the operation of the electric motor. It receives input signals from various sensors and the vehicle's electronic control unit (ECU) and sends output signals to the motor.

The control module uses complex algorithms to determine the amount of steering assistance required based on the driver's input, vehicle speed, and other factors. It adjusts the electric motor's power output accordingly to provide the right amount of steering assistance.

* Electric motor (assist motor)

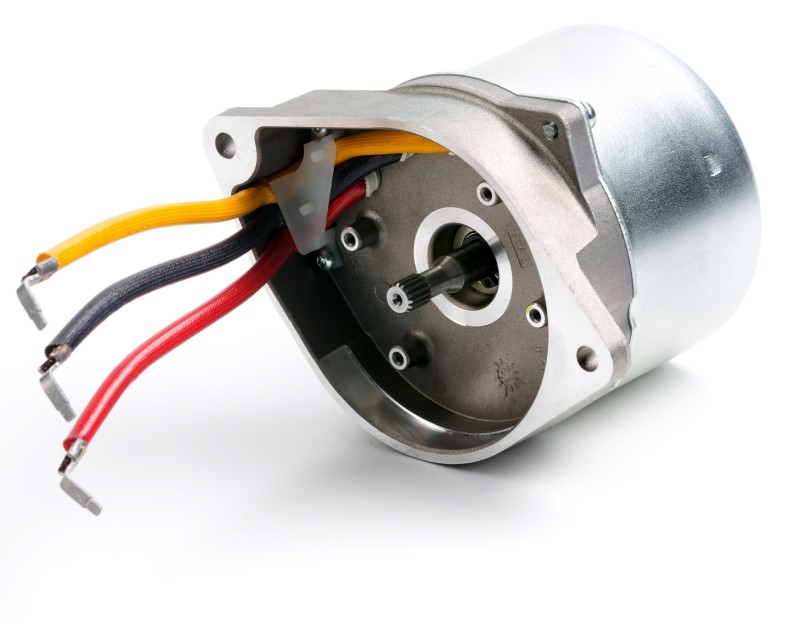


Figure 9 Electric motor of EPS

The electric motor is the heart of an EPS system. It generates the power needed to assist the driver in steering the vehicle. The motor is usually located on the steering column or the steering rack, and it is controlled by the system's control module.

Most electric power steering systems use a three-phase electric motor powered by a pulse width modulated DC voltage. The motor is brushless and has an operating voltage range of 9 to 16 volts. Three-phase motors allow for faster and more precise application of torque at low RPMs.

* Reduction gear

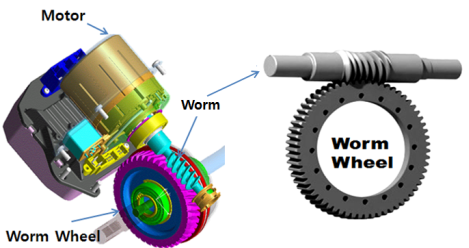


Figure 10 Reduction gear of EPS

When the steering wheel is returned from large steering efforts, such as when turning in an intersection, this reduction gear provides smooth steering corrections as well as improved comfort when the steering wheel is returned from large steering efforts, like when turning in straight lines.

### 2.1.2 Working principles

The working principle of an Electric Power Steering (EPS) system is based on the use of an electric motor to provide steering assistance to the driver. The EPS system operates by continuously monitoring the driver's steering input and vehicle speed and applying an appropriate amount of steering assistance to help the driver turn the wheels.

When the driver turns the steering wheel, the control module uses the torque sensor data to calculate the amount of assistance required from the electric motor. The control module then sends a signal to the electric motor, which applies the appropriate amount of assistance to the steering system. The electric motor can be located on the steering column or rack, and it can provide direct assistance to the steering system or operate a belt-driven system that helps from a remote location.

## 2.2 Dynamic equilibrium equations of EPS system

The dynamic equilibrium equations of a system are a set of mathematical equations that describe the motion and behavior of the system over time. These equations are used to determine how the system will respond to external forces and inputs, and they are essential for understanding the stability and performance of the system.

The function of the dynamic equilibrium equations is to establish a relationship between the forces acting on the system and the resulting motion and behavior of the system. These equations consider the mass, velocity, acceleration, and other physical properties of the system, as well as the external forces and inputs that are acting on it.

By using the dynamic equilibrium equations, engineers and scientists can simulate the behavior of a system under different conditions and inputs and can optimize the system's performance and stability. These equations are also essential for designing and testing new systems, and for troubleshooting problems in existing systems. Overall, the dynamic equilibrium equations are a fundamental tool for understanding and controlling the behavior of complex systems in a wide range of applications.

A picture containing text, diagram, plan, screenshot

Description automatically generated

Figure 11 EPS structure

To formulate the equilibrium equation of the electric power steering system, we divide the system into mechanical and electrical components, respectively:

Consider the equilibrium of the steering input shaft (from steering wheel to torsion bar input):

With

**🡺**

Consider the equilibrium at the rotor of the electric motor:

* Electrical equation
* Mechanical equation

With

**🡺**

Consider the equilibrium at the output steering shaft (from the torsion bar output to the steering mechanism gear)

With

**🡺**

With

– Steering wheel torque (Nm)

– Torsion bar

– Steering column angle

– Steering wheel angle

– Steering wheel

– Steering wheel inertia

**N** – reduction gear ratio

– Motor torque (Nm)

– Steering column

– Resistant torque on pinion (Nm)

– Steering column inertia

## 2.3 Overall diagram and control rules of EPS system

A picture containing text, diagram, screenshot, font

Description automatically generated

Figure 12 EPS block diagram

In order to simulate the control rules of EPS, a driving situation is created. A PID controller will play the role of the driver. It will receive the error signal between the set path and the actual path to adjust the torque acting on the steering wheel of the steering system. From there, the steering system block will give out the signals of left and right wheels angles to vehicle block. The vehicle block will move and feedback the actual moving direction.

The torque the driver exerted on the steering wheel will be compared with the steering limits which will be calculated based on the steering wheel angle and speed of the vehicle. If it exceeds the limit, the motor’s PID controller will receive the error signal between the torques and gives out voltage signal to control the motor to create the assisting torque

## 2.4 PID controller

PID (Proportional Integral Derivative) controller is a combination of three controllers:  
proportional, integral, and differential, capable of adjusting to the lowest possible error, increasing response speed, reducing overshoot, and limiting oscillation. The PID controller is a process control technique that engages in “proportional, integral, and differential” processing actions. That is, the resulting error signals will be minimized by the effect of the proportional effect, the effect of the integral effect and clarified by a rate obtained with the fractional effect before.

* P: It is a proportional adjustment method, which helps to generate an adjustment signal proportional to the input error according to the sampling time.
* I: Is the integral of the error over the sampling time. Integral control is a tuning method to generate tuning signals so that the error is reduced to 0. This tells us the total instantaneous error over time or the accumulated error in the past. The smaller the time, the stronger the integral adjustment effect, corresponding to the smaller deviation.
* D: Is the differential of the error. The differential control generates an adjustment signal that is proportional to the rate of change of the input bias. The larger the time, the stronger the differential tuning range, which corresponds to the faster the regulator responds to input changes.

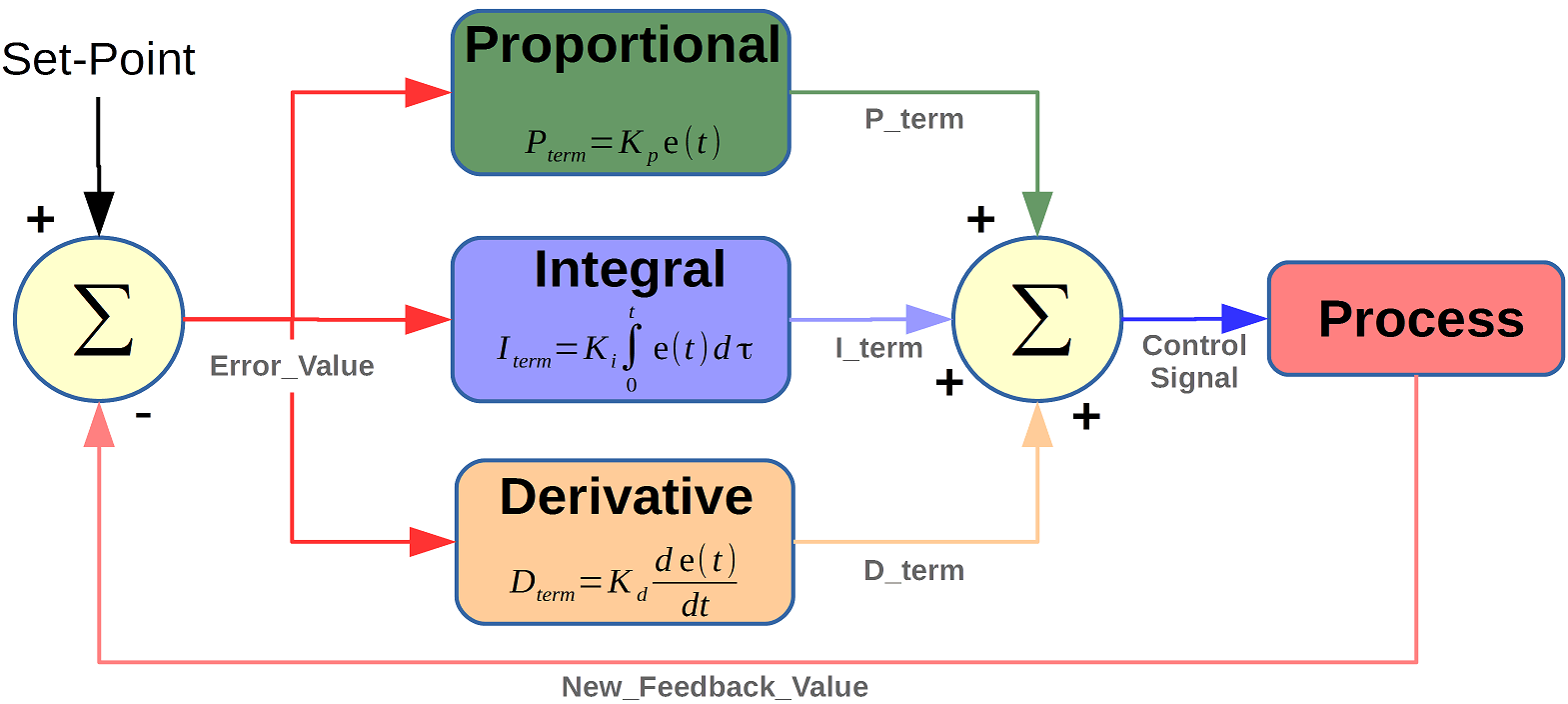


Figure 13 A PID controller structure

While being widely used in various industrial process with many advantages, there are some limitations

Advantages:

* PID controllers are simple and versatile, making them suitable for a wide range of systems.
* They can be easily implemented and applied to various control tasks with relatively little effort.
* PID controllers can be tuned to achieve stable and accurate control, making them effective in systems with slowly changing dynamics.
* Their continuous output enables them to respond quickly to changes in the system.
* PID controllers can be modified to meet specific requirements by adjusting the gain parameters, offering flexibility in system design.

Disadvantages

* PID controllers are sensitive to noise and disturbances, which can lead to instability and degraded performance.
* Tuning PID controllers can be challenging, particularly for complex systems with nonlinear or time-varying dynamics.
* They are not suitable for controlling systems with fast dynamics or high-frequency noise.
* Due to the lack of a system model, diagnosing problems and making improvements can be difficult.

In this project, PID controller will be used as a driver and a controller for electric motor.

# II. SIMULATION PROCESS

## 3.1 Creating a path for the vehicle

As previously stated, to accurately model the control rules of an electric power steering system, it is imperative to create a realistic driving scenario that involves the driver turning the steering wheel to the left or right. Therefore, the driving scenario will be lane changing.

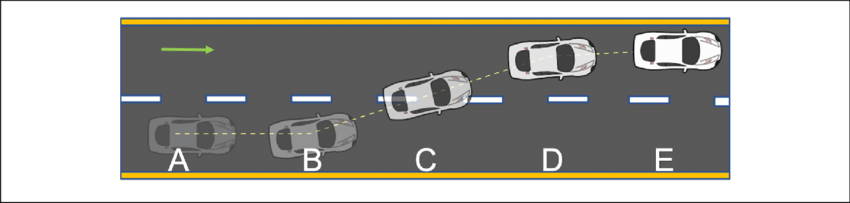


Figure 14 A driving scenario - lane changing

To create this driving scenario, the vehicle motion needs to be tracked so that the driver can adjust the steering wheel so that the vehicle will move in a preset path. This motion can be controlled by considering the displacement of the vehicle along x and y axis of the earth-fixed coordinate. However, as a PID controller will be used as a driver, it cannot control both variables (x and y displacement), so we need a variable that can present the displacement of the vehicle according to both x and y. As a result, heading angle of the vehicle will be the variable to be controlled.

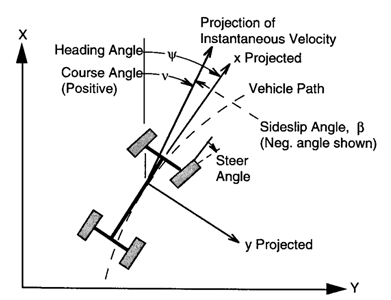


Figure 15 Heading angle of a vehicle

Heading angle of a vehicle is the angle between the moving direction and a fixed reference point, which in this driving scenario will be the x axis. In other words, it is the direction in which the vehicle is traveling relative to x axis. This heading angle will be calculated by as yaw (rad) a MATLAB block - Vehicle Body 3DOF, which will be described later.

A picture containing text, screenshot, diagram, design

Description automatically generated

Figure 16 Position of the Set Path block in the model

A picture containing diagram, text, plan, line

Description automatically generated

Figure 17 Structure of Set Path block

Heading angle will be calculated as:

With

– heading angle of vehicle (rad or degree)

– speed of vehicle along x-axis of earth coordinate (m/s)

– speed of vehicle along y-axis of earth coordinate (m/s)

From the above formula, we first create a table consisting of x and y coordinates of the car over time. Then, divide derivative of y by derivative of x to obtain the heading angle. From there, we have a lookup table of heading angles corresponding to each x coordinate of the vehicle.

From the original position where the car travels the dx distance, we will get a new x coordinate, now through the above lookup table, the heading angle is obtained. Use the new heading angle to calculate the new dx distance and repeat, similar to y. As a result, for each dx and dy, we will find the set heading angle for the car.

According to the coordinate system of the Vehicle Body 3DOF block in MATLAB, the vehicle will start moving in the direction x so x will be the path and y will be the distance between the 2 lanes. At different speeds, the distance x will increase or decrease to match reality. Y will have a maximum value of 3.5 because this is a standard width of a lane.

## 3.2 Driver block

To simulate the driver, simply use a PID controller.

A picture containing text, screenshot, diagram, design

Description automatically generated

Figure 18 Position of driver block in the model

It will receive the actual heading angle of the vehicle and output the steering torque to the steering system block. The P, I, D coefficients of this controller should be chosen correctly so that it can behave closest to a human.

A picture containing diagram, design

Description automatically generated

Figure 19 Structure of Driver block

## 3.3 Steering system

A picture containing text, screenshot, diagram, design

Description automatically generated

Figure 20 Position of Steering system block in the model

## 3.4 Vehicle model

To simulate the vehicle motion, we will use the Vehicle Body 3DOF block. The Vehicle Body 3DOF block implements a rigid two-axle vehicle body model to calculate longitudinal, lateral, and yaw motion. The block accounts for body mass and aerodynamic drag between the axles due to acceleration and steering.

A picture containing text, screenshot, diagram, design

Description automatically generated

Figure 21 Position of Vehicle Body 3DOF block in the model

In the Vehicle Dynamics Blockset™ library, there are two types of Vehicle Body 3DOF blocks that model longitudinal, lateral, and yaw motion.

* Vehicle Body 3DOF Single Track

A picture containing text, screenshot, sketch

Description automatically generated

Figure 22 Vehicle Body 3DOF Single Track block

* + Forces act along the center line at the front and rear axles.
  + No lateral load transfers.
* Vehicle Body 3DOF Dual Track

A diagram of a vehicle body

Description automatically generated with medium confidence

Figure 23 Vehicle Body 3DOF Dual Track block

* + Forces act at the four vehicle corners or hard points

To simulate precise vehicle model, we will the later type - Vehicle Body 3DOF Dual Track.

The function of this block in our system are to calculate these variables:

* X and Y displacement of the vehicle along earth fixed coordinate: these variables are needed to plot the actual path of the vehicle.
* Yaw angle: this is the heading angle of the vehicle that will be feedback to the driver to adjust the steering torque.

## 3.5 Electric motor

3.5.1 Simulation of electric motor

3.5.2 Control of electric motor

IV. SIMULATION RESULTS AND EVALUATION

A picture containing text, diagram, sketch, design

Description automatically generated

Figure 24 Overall structure of the model

V. CONCLUSION

VI. FUTURE WORK AND ENHANCEMENTS

VII. REFERENCE

1. R. -O. Nemes, M. Ruba and C. Martis, "Integration of Real-Time Electric Power Steering System Matlab/Simulink Model into National Instruments VeriStand Environment," 2018 IEEE 18th International Power Electronics and Motion Control Conference (PEMC), Budapest, Hungary, 2018, pp. 700-703, doi: 10.1109/EPEPEMC.2018.8521888.
2. Hiremath, R. R., & Isha, T. B. (2019, October 1). Modelling and simulation of electric power steering system using permanent magnet synchronous motor. *IOP Conference Series: Materials Science and Engineering*, *561*(1), 012124. https://doi.org/10.1088/1757-899x/561/1/012124
3. Li, S., Sheng, R., Cui, G., Zheng, S., Yu, Z., & Lu, X. (2017). Design of Assistance Characteristics Curve for Electric Power Steering System. *Proceedings of the 2017 2nd International Conference on Automation, Mechanical and Electrical Engineering (AMEE 2017)*. https://doi.org/10.2991/amee-17.2017.27