



prifysgol cymru trinity saint devid
University of Wales Trinity St David

Student name: Anandu Unnikrishanan Nair

Student ID number : 2411630

Programme : MSc – Automotive Engineering

Module : Hybrid Powertrain and Control

Module code: ACEB7007

Assignment Title : Modelling Automotive Control Systems in MATLAB

Table of contents

TASK 1

1. Introduction.....	3
2. System Inputs and Outputs.....	3
2.1 input.....	3
2.2 output.....	3
3. Sensors and Actuators.....	4
3.1 Sensors.....	4
3.2 Actuators.....	4
4. Control Algorithm.....	4-5
5. Sampling Time Consideration.....	5
5.1 Suitable Sampling Time.....	5
5.2 The Effect of Postponements.....	5
6. Communication Protocols.....	6
7. Real-World Case Studies.....	6
7.1 National Highway Traffic Safety Administration (NHTSA) Study.....	6
7.2 Mercedes-Benz and BMW Implementation.....	6
8. Development and Analysis Tools.....	8
9. Possible Enhancements.....	7
9.1 Additional Sensors.....	7
9.2. Sensor and Actuator Upgrades.....	7
9.3 Integration with Advanced Driver Assistance Systems (ADAS).....	7
10. SystemArchitecture.....	7
11. Emerging Trends	7

TASK 2

1. Introduction	8
2. PID Controller Design	8
3. System Implementation	8
4. Simulation Results	9
4.1 System Response	9
4.2 Error Signal	9
4.3 Control Effort	9
5. Discussion	10
6. Conclusion	10

TASK 1

1. Introduction

Safety and vehicle dynamics control are essential components of contemporary automotive technologies that enhance driver satisfaction and lower accident rates. The Electronic Stability Control (ESC) system is among the most important technological developments in this field. Through the detection and mitigation of loss of traction (skidding), ESC is a computerized technique that improves vehicle stability. It helps the driver maintain control, especially in slick road conditions or during abrupt maneuvers, by automatically lowering engine torque and providing selective brakes to individual wheels.

The fact that ESC is a required system in many nations emphasizes its importance. ESC can reduce fatal single-vehicle crashes by up to 49% for automobiles and 58% for SUVs, according to the National Highway Traffic Safety Administration (NHTSA, 2020). The system components, control algorithms, communication protocols, development tools, and possible improvements of ESC are all thoroughly examined in this research.

2. System Inputs and Outputs

2.1 input

To keep an eye on driver inputs and vehicle dynamics, the Electronic Stability Control (ESC) system gathers data in real time from a variety of onboard sensors. Among the crucial input factors are:

- **Steering wheel angle:** The driver's intended direction is indicated by the steering angle, which is recorded by the steering angle sensor.
- **Wheel Speeds:** Used to evaluate vehicle speed and identify possible skidding, wheel speed sensors are mounted on each wheel.
- **Lateral Acceleration :** Monitored using an accelerometer to determine side-to-side vehicle movement.
- **Yaw Rate:** The vehicle's rotational movement around its vertical axis is measured by the yaw rate sensor.
- **Brake Pressure :** Acquired from brake pressure sensors to detect braking force applied by the driver.
- **Throttle Position :** Obtained via the throttle position sensor to determine driver acceleration input.

2.2 output

Vehicle stability is maintained by the ESC system, which provides precise output commands based on real-time analysis of the input data:

- **Brake Actuators:** To prevent understeer or oversteer, brake force is applied selectively to individual wheels.
- **Engine Control Unit (ECU):** Reduce vehicle speed by modifying engine torque through throttle input adjustments or fuel supply cuts.
- **Driver Alerts:** To let the driver know when ESC intervention takes place, turn on visual or audio alerts.

3. Sensors and Actuators

3.1 Sensors

The ESC system uses a variety of high-precision sensors to continuously track driver input and vehicle behavior. The important sensors consist of:

- **Steering Angle Sensor:** The steering wheel's rotational angle and speed are measured by the steering angle sensor. It is usually mounted on the steering column and gives vital information about the driver's intended direction.
- **Wheel Speed Sensors:** These sensors are mounted on each wheel and measure the speed at which each wheel rotates. The data helps the ESC system detect wheel slip, understeer, or oversteer conditions by comparing the rotational speeds.
- **Yaw Rate Sensor:** Measures the speed at which the car rotates on its vertical axis. This sensor is normally situated around the vehicle's centre of gravity and helps identify if the vehicle is rotating more or less than anticipated.
- **Accelerometers:** Determine the longitudinal and lateral acceleration forces applied to the car. While the longitudinal sensor tracks forward and backward acceleration to help traction and stability calculations, the lateral acceleration sensor detects sideways movement (cornering force).
- **Brake Pressure Sensors:** Keep an eye on the braking circuit's hydraulic brake pressure. During ESC intervention, this data is utilized to modify individual wheel braking and shows the amount of brake force the driver is demanding.
- **Throttle Position Sensor:** Provides information on the driver's acceleration requirement by detecting the accelerator pedal's position. When stability control measures are needed, this information is used to modify engine torque.

3.2 Actuators

- **Hydraulic Brake Actuators:** Individual wheels are subjected to braking force via electronically controlled actuators. The system can help the driver maintain control by compensating for traction loss by varying brake pressure at particular wheels.
- **Electronic Throttle Actuator:** When required, an engine torque actuator lowers engine torque to avoid excessive wheel spin or unstable vehicles. This is performed using electronic throttle control, ignition timing adjustment, or fuel cut-off techniques coordinated by the Engine Control Unit (ECU).

4. Control Algorithm

By continuously comparing the driver's planned direction, as decided by steering input, with the actual movement of the vehicle, as detected by a variety of onboard sensors, the ESC control algorithm is meant to improve vehicle stability. The system steps in to preserve control when a discrepancy suggesting possible instability is found. The algorithm proceeds methodically:

- **Reference Yaw Rate Calculation:** This method establishes a baseline for steady cornering behavior by estimating the expected yaw rate based on variables like steering input, vehicle speed, and lateral acceleration.

- **Actual Yaw Rate Measurement:** The yaw rate sensor records rotational motion around the vertical axis to provide the vehicle's real-time yaw rate.
- **Error Calculation:** To determine if the vehicle is veering off course, the system calculates the difference between the reference and actual yaw rates.
- **Decision Logic :** The system uses decision logic to identify whether the vehicle is experiencing understeer, or front wheels losing grip, or oversteer, or rear wheels losing grip, if the error exceeds a predetermined threshold.
- **Actuation:** To combat instability, the system reduces engine torque when needed and provides braking force selectively to the inner or outer wheels, assisting the vehicle in regaining control.

Depending on the size of the fault, a Proportional-Integral-Derivative (PID) controller is frequently employed to calculate exact corrective steps. To maximize stability interventions while taking future vehicle states into account, more sophisticated methods like Model Predictive Control (MPC) may also be used (Rajamani, 2012). The ESC system improves vehicle safety and handling by dynamically modifying engine power and braking, especially under difficult driving circumstances.

5. Sampling Time Consideration

5.1 Suitable Sampling Time

For the ESC system to function effectively, timely and accurate data collection is necessary. A typical sampling duration falls between 10 ms and 20 ms (equivalent to a frequency of 50 Hz to 100 Hz) in order to guarantee real-time responsiveness (Guzzella & Sciarretta, 2013). The system can identify and respond quickly to abrupt changes in vehicle dynamics, such sliding or loss of grip, because to this high-frequency sampling. Reduced sampling time improves stability control accuracy and guarantees seamless corrective action without discernible lag.

5.2 The Effect of Postponements

The efficiency of the ESC system can be severely impacted by any delays in data collection, processing, or actuation. Among the possible outcomes are:

- **Decreased System Responsiveness:** The ESC system's capacity to sustain vehicle control may be diminished if a delayed response to instability leads to a slower corrective action.
- **Increased Instability Risk:** Minor instabilities can worsen and make recovery more challenging if corrective actions are not taken promptly.
- **Possible Loss of Control:** Excessive delays might jeopardize vehicle safety and result in accidents in critical situations such abrupt evasive maneuvers or slick roads.

Real-time processing with low latency is essential to reducing these hazards. To guarantee quick ESC intervention execution, sophisticated embedded controllers, specialized software algorithms, and effective communication protocols (such CAN bus) are used

6. Communication Protocols

For sensors, controllers, and actuators to exchange real-time data, the ESC system depends on strong in-vehicle communication networks. With speeds up to 1 Mbps and excellent dependability and error detection, the most used protocol is the Controller Area Network (CAN), which is appropriate for the majority of automotive applications. FlexRay, which is frequently utilized in safety-critical ESC solutions in luxury cars, offers up to 10 Mbps speed, improved fault tolerance, and higher bandwidth for more demanding systems. In contrast, non-essential tasks like human-machine interfaces are handled via the Local Interconnect Network (LIN). System complexity and financial limitations determine which of CAN and FlexRay is best.

7. Real-World Case Studies

7.1 National Highway Traffic Safety Administration (NHTSA) Study

In 2020, research by the National Highway Traffic Safety Administration (NHTSA) shown how well Electronic Stability Control (ESC) works to lower the number of auto accidents. ESC has reduced single-vehicle collisions for passenger cars by 49% and SUVs by 20%, according to the study. These figures highlight the function of ESC in preventing loss of control, especially on slippery or snowy roads. ESC helps drivers maintain stability by regulating engine power and automatically applying brakes to individual wheels, lowering the risk of rollovers or skidding. Because of this, ESC is now required in all new cars in several nations, including the US and the EU, making it a crucial development in automobile safety.

7.2 Mercedes-Benz and BMW Implementation

Dynamic Stability Control (DSC) and torque vectoring are two more technologies that luxury automakers like Mercedes-Benz and BMW have added to ESC over time. By maximizing power distribution among wheels, torque vectoring enhances handling and traction. For example, BMW's DSC adjusts to changing driving circumstances in addition to correcting understeer and oversteer. In the meantime, Mercedes-Benz incorporates the Electronic Stability Program (ESP), which actively steps in to improve driving accuracy in real time. These cutting-edge applications demonstrate how ESC technology is progressing beyond simple stability control, improving driving performance and safety in luxury automobiles.

8. Development and Analysis Tools

Tool	Functionality
MATLAB/Simulink	System modeling, control design, simulation.
CarSim	High-fidelity vehicle dynamics simulation.
ETAS INCA	Data acquisition, calibration, real-time testing.
dSPACE	Hardware-in-the-loop (HIL) simulation.
CANoe/CANalyzer	Communication protocol analysis and testing.

9. Possible Enhancements

9.1 Additional Sensors

Adding more sensors to the ESC system can increase its precision and adaptability. In order to modify stability control tactics appropriately, road friction estimation sensors are able to identify surface conditions, such as ice or wet roads. The integration of GPS and Inertial Measurement Units (IMUs) improves overall system responsiveness by enabling more precise vehicle positioning and trajectory prediction.

9.2. Sensor and Actuator Upgrades

By improving data accuracy, upgrading to higher-resolution sensors enables more precise stability management. Electromechanical brake actuators improve system efficiency by reducing response time when used in place of conventional hydraulic brake actuators.

9.3 Integration with Advanced Driver Assistance Systems (ADAS)

For coordinated vehicle control that improves overall safety and driving stability, ESC can be used with Autonomous Emergency Braking (AEB), Adaptive Cruise Control (ACC), and Lane Keeping Assist (LKA).

10. System Architecture

A hierarchical control architecture is used by the Electronic Stability Control (ESC) system to guarantee effective data processing and prompt remedial action.

- **Sensor Layer** : it's made up of several sensors that track the dynamics of the vehicle continually, including accelerometers, brake pressure, throttle position, steering angle, wheel speed, and yaw rate.
- **Control Layer**: analyses sensor data and applies stability control methods (such as Model Predictive Control or PID) to identify the required remedial measures.
- **Actuation Layer**: This layer applies corrective actions by triggering brake actuators on each wheel and modifying engine torque through the ECU.
- **Communication Layer**: Enables smooth coordination between system components by facilitating real-time data flow over fast networks like CAN or FlexRay.

11. Emerging Trends

Developments in artificial intelligence and connectivity are influencing the direction of ESC systems. Predictive stability management is made possible by AI-based control algorithms that examine driving trends and external factors. Through data exchange with other vehicles and infrastructure, Vehicle-to-Everything (V2X) connectivity enables ESC to predict road dangers, such as slick surfaces or abrupt shifts in traffic. Furthermore, incorporating autonomous driving technology improves coordinated vehicle control, guaranteeing safer and more seamless maneuvers. These developments are intended to enhance driver assistance features, increase vehicle safety, and facilitate the shift to completely autonomous mobility.

TASK 2

1. Introduction

Network delays and signal resolution limitations are important factors that affect the stability and performance of contemporary control systems. Decreased response times and possible instability can result from communication delays, which are frequently brought on by data transfer over networks. Control precision is further impacted by quantization's reduced signal resolution. The goal of this exercise is to use MATLAB to design a PID controller while taking low-resolution signal encoding and network delays into account. We assess how these practical limitations affect the controller's efficacy and overall system performance by examining the system's response, error signal, and control effort.

2. PID Controller Design

The PID controller modifies the control signal according to proportional, integral, and derivative terms in order to govern system behavior. The chosen gains are:

- Proportional Gain (K_p): 2: Modifies the control effort in direct proportion to the error.
- Integral Gain (K_i): 0.5: By adding up previous errors, this value removes steady-state error.
- Derivative Gain (K_d): 0.1: Enhances system stability by forecasting future errors.

High-frequency data gathering is ensured with a sample time of 0.01s, enabling real-time responsiveness. A network delay of 0.05s is included to mimic actual communication restrictions. The control signal is shifted by this delay, which lowers responsiveness and may lead to instability. The system continuously corrects errors and modifies controls to make up for this delay.

3. System Implementation

In order to replicate real-world restrictions, the control system is constructed in MATLAB utilizing a discrete-time PID loop that incorporates network delays and signal normalization.

- Error Computation: After taking network latency into account, the error signal is computed as the difference between the delayed actual output and the intended setpoint.
- PID Control Calculation: To create the control signal, the proportional, integral, and derivative terms are calculated using the specified gains ($K_p = 2$, $K_i = 0.5$, $K_d = 0.1$).
- Signal Encoding and Decoding: To replicate low-resolution signal transmission and introduce quantization effects, the calculated control signal is run through an 8-bit encoding function.
- System Update: To ensure stability modifications over time, a first-order system model uses the control signal to update the actual output.

This implementation genuinely illustrates how communication limitations and low resolution affect system accuracy and performance by integrating network latency and quantization.

4. Simulation Results

4.1 System Response

The MATLAB output graph's first subplot shows the actual output (blue line) and the setpoint (red dashed line). The system response gradually approaches the setpoint, illustrating how the 8-bit signal encoding and network delay (0.05s) affect system accuracy. The output rises more slowly due to the delay, and the precision of the response is somewhat distorted by quantization.

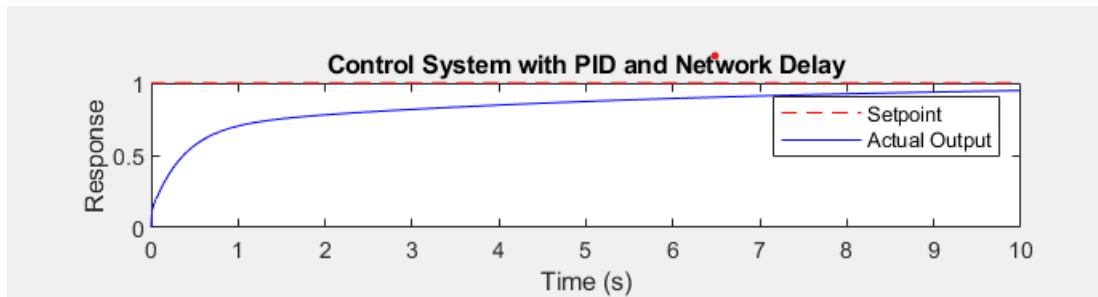


Figure1: System Response

4.2 Error Signal

The error signal, shown in the second subplot, is initially strong because of the discrepancy between the delayed system output and the intended setpoint. The error gradually decreases when the PID controller modifies the control effort. The system's capacity to rapidly achieve steady-state accuracy is hampered by the slightly slower error reduction caused by network delay.

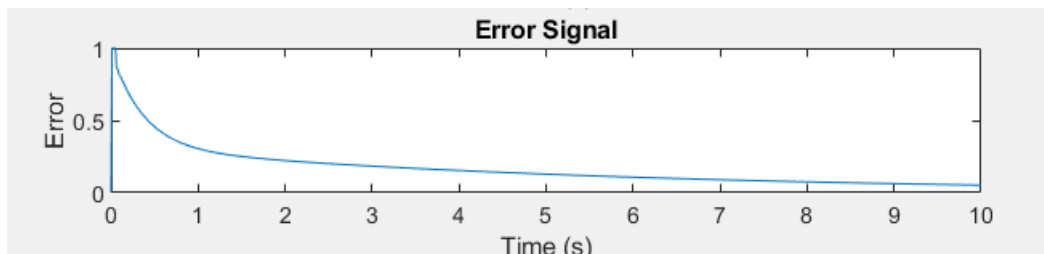


Figure 2: Error Signal

4.3 Control Effort

The third subplot displays the control effort, which stands for the PID controller's remedial measures. To offset the first error, the controller first applies a strong control signal. The control effort steadies over time, maintaining system stability with little oscillations. The smoothness of the control effort may be limited by small variations introduced by the quantization effect.

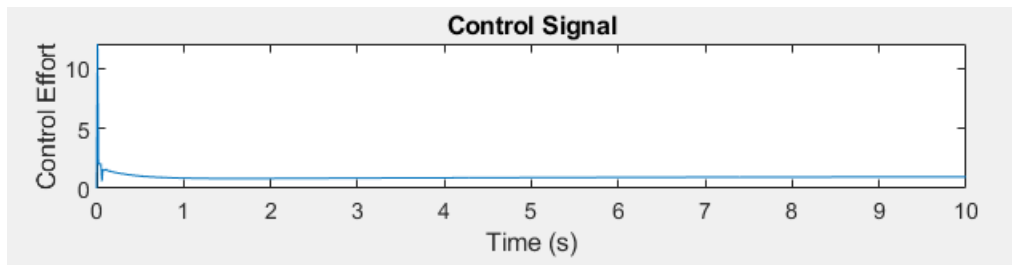


Figure 3: Control Effort

5. Discussion

Important issues in real-time control systems are brought to light by the PID controller's implementation when network latency and low-resolution encoding are present. For applications like autonomous driving or robotic systems that need quick adjustments, network latency (0.05s) results in a perceptible lag in the system reaction, which reduces its effectiveness. The controller is forced to respond to out-of-date information due to the delayed feedback, which raises the possibility of excess or slow reaction.

In addition, translation errors are introduced by the 8-bit signal encoding, which lowers the accuracy of control signals. Performance in high-precision applications may be impacted by this restriction, which could cause slight variations in the system output and control effort. The PID controller effectively stabilizes the system despite these difficulties, proving its adaptability to disruptions. It is confirmed that the controller keeps the system stable under limited circumstances when the error signal steadily drops, and the control effort stabilizes.

Several methods can be investigated to further maximize performance. The impact of delays would be lessened by providing more frequent updates through an increase in sample frequency. PID gain tuning may reduce steady-state error and improve response time. More sophisticated methods, like Model Predictive Control (MPC), could be used to forecast future conditions and more efficiently make up for delays. In real-world applications, these enhancements might improve real-time responsiveness and control precision.

6. Conclusion

The system is successfully stabilized by the PID controller in spite of the difficulties caused by signal encoding restrictions and network latency. The findings show that consistent performance can be achieved by appropriately adjusting control parameters to lessen the effects of delay and quantization mistakes. Real-time responsiveness is impacted by network-induced latency, nevertheless, underscoring the necessity of reliable compensating strategies in real-world applications. In order to dynamically modify controller parameters in response to shifting network conditions, future research could investigate adaptive control techniques as gain scheduling or artificial intelligence-based tuning. Furthermore, applying predictive control techniques could improve system performance even more in settings where delays are a concern.

References

- Guzzella, L., & Sciarretta, A. (2013). *Vehicle Propulsion Systems: Introduction to Modeling and Optimization*. Springer.
- NHTSA. (2020). *Evaluation of Electronic Stability Control on Road Safety*. Retrieved from www.nhtsa.gov
- Rajamani, R. (2012). *Vehicle Dynamics and Control*. Springer.
- Mercedes-Benz. (2021). *Electronic Stability Program (ESP) Overview*. Retrieved from www.mercedes-benz.com
- BMW Group. (2022). *Dynamic Stability Control (DSC) System*. Retrieved from www.bmw.com