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1.Introduction

Modern automotive control systems have embedded digital controllers that are used in the control of vehicle dynamics. The cruise control requires constant checking of the vehicle speed and fast feedback to adjust actuator inputs to keep the car at the levels set by the driver. Whereas ideal conditions are modelled in the theory, real-life implementations are faced with discretisation, quantisation, sampling constraints, and communication delay. These limitations have a great impact on the stability and performance of a system.

According to ISO 15622 standard notes that the cruise control system should monitor the speed correctly, have transient behaviour, and handle disturbances in a robust way. Also, ISO 26262 focuses on reliability and safe operation in the case of faults like delays and sensor inaccuracy.

This report is a multi-scenario MATLAB simulation of a cruise control system, and assesses the performance of the controllers under various implementation constraints. The study also examines the impact of controller tuning, quantisation, sampling time, communication delay, and external disturbances systematically as opposed to concentrating on a single case. The findings are critically evaluated to come up with their conclusions on the implications of the findings in real-life automotive systems.

2. Task Description (Practical Description)

The system is a model of a digital cruise control system where the velocity of a vehicle is controlled under a PID controller. The signals are coded into binary and sent via a simulated communication channel after which they are sent to the actuator.

There were 7 scenarios examined:

Optimization of the system (baseline PID).

Poor controller (P-only)

Low bit resolution (4-bit)

Large sampling time (0.5 s)

Network delay (0.25 s)

External disturbance (hill)

Integrated system behaviour (reference tracking)

All scenarios produce velocity response and control effort curves, and this enables a direct comparison of performance of the system with different constraints.

3. Feedback Controller Performance and Analysis

The comparison of Scenario 2 (P-only) and Scenario 1 (PID) indicates the essential role of the design of controllers.

In Scenario 2, the system fails in completely. The speed decreases about 60 mph to 30 mph in 2-3 seconds. This is due to the fact that the proportional gain alone ($K_p=1$) is incapable of offsetting system resistance. The control effort is held constant at about 20 meaning that the controller is not flexible.

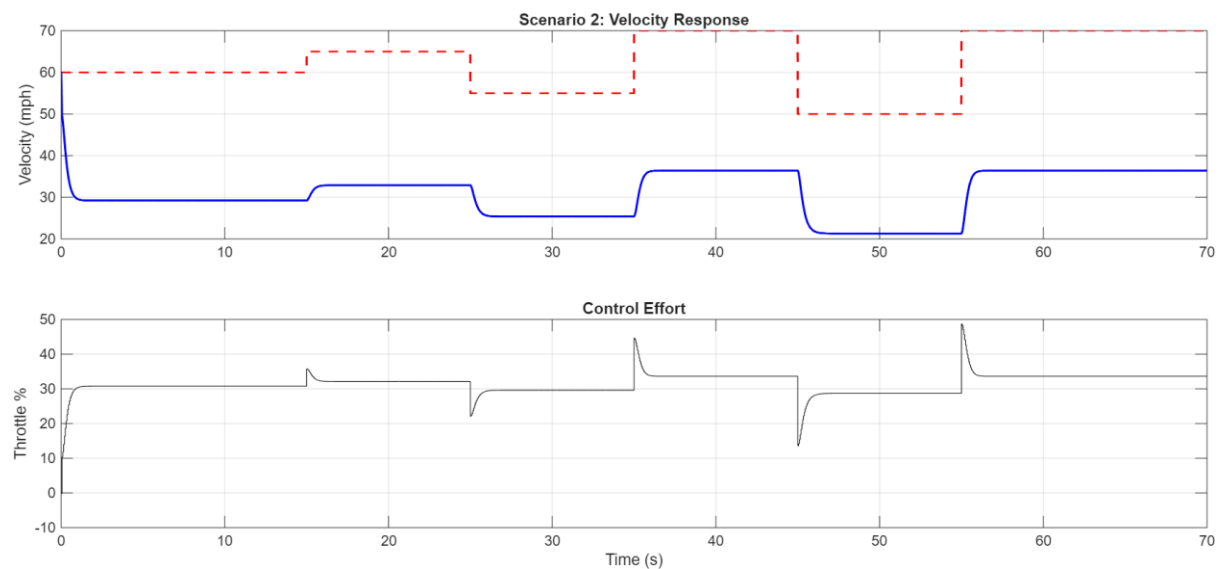
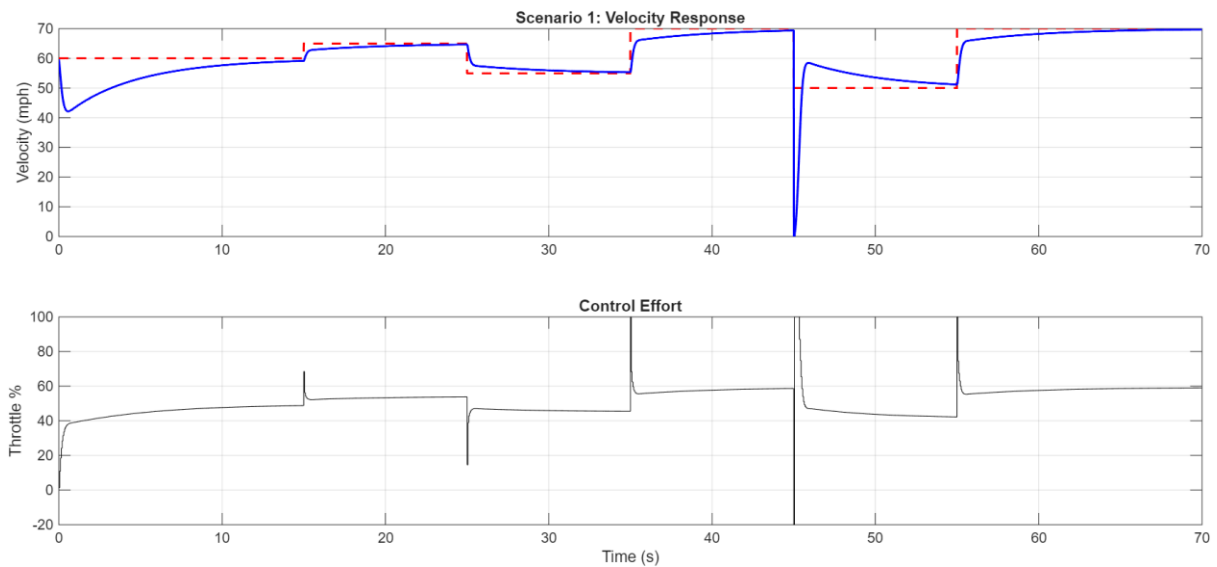


Figure 1-Scenario 2 (P-only)

According to ISO 15622, this behaviour is not acceptable as it is a total failure in tracking speed. Such behaviour would match loss of cruise control functionality in the real vehicles, which would be dangerous (Moghaddam et al., 2025).

Conversely, Scenario 1 (PID controller with $K_p=1.9$, $K_i=0.55$, $K_d=0.1$) is inaccurately tracked. The system attains 60 mph within a range of 8 seconds and error tolerance is within

the range of ± 1 -2 mph. This is superior to the case when using a single term as the integral term removes steady-state error, whereas the derivative term stabilises the response.



This performance however comes at a price. The effective control attempt reaches 80-100% which means that the actuator is used aggressively. In operation on actual cars, this would cause discomfort and higher fuel consumption. Therefore, there is a trade-off between quick reaction and comfort to the passengers.

The simulated response is slightly optimistic relative to that of (Yu, et al., 2022), since the real vehicles have other forms of nonlinearities including drag and gear dynamics. This indicates that although the controller achieves accurate tracking, the aggressive control effort may not be suitable for real automotive applications. Therefore, further tuning would be required to balance performance and comfort in line with ISO 15622 requirements.

4. Effect of Signal Encoding (Quantisation Analysis)

Scenario 3 looks into what will happen when signal resolution is lowered to 4 bits.

Acceleration response is in this case made visually stepped instead of smooth. This is due to the fact that the signal is drawn to a finite number of 16 discrete levels that creates a quantisation error of about 6%.

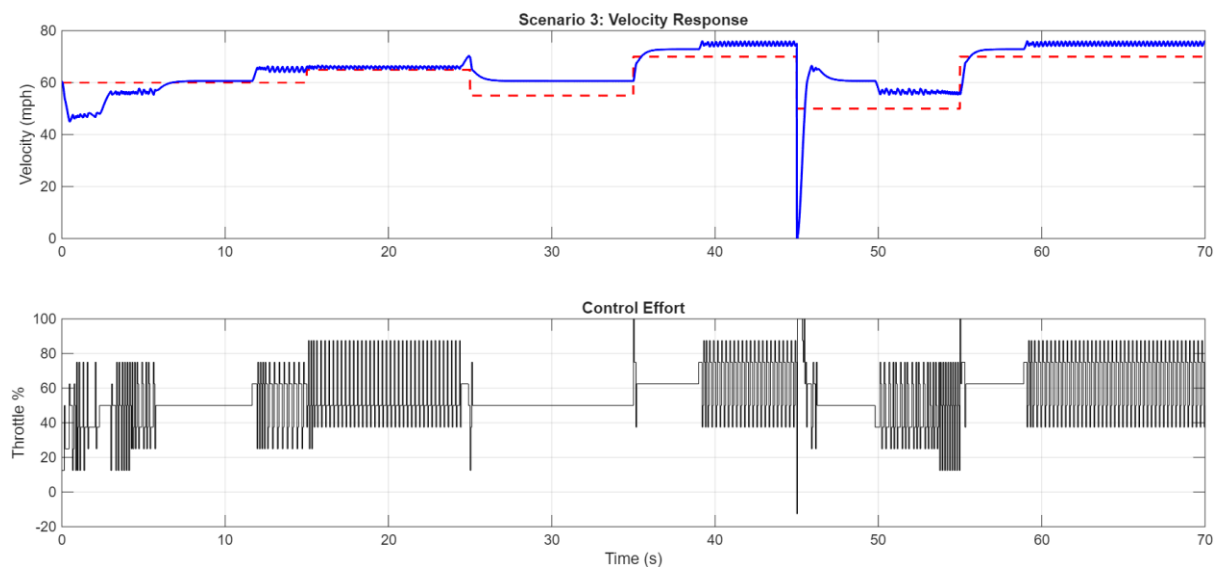


Figure 3-Quantisation

The controller responds to such artificial steps as actual changes in speed, which leads to rapid changes in control effort. Actuator chatter, as this phenomenon is termed, is something that should be avoided, contributing to mechanical wear, and making the ride unpleasant to the passengers.

By contrast, the 16-bit base system does not exhibit a sharp tracking with a significant error. This proves that the resolution increases as the accuracy of control increases with less quantisation noise.

The trade-off however is in terms of computational cost vs accuracy. An increase in the bit resolution combines the data and processing needs, which might surpass the ECU constraints in low-end cars. This suggests that insufficient resolution can negatively affect actuator behaviour and system reliability. In real vehicles, such effects would be undesirable as they may increase component wear and reduce performance quality.

The finding is consistent with the results reported by (Zhu et al., 2023), who observed that high-resolution sensing is more accurate in controlling but more complex systems.

5. Effect of Sampling Time

Scenario 4 doubles the sampling time of 0.05 s-0.5 s, which significantly decreases the rate of the controller update. The outcome is a slow and wavering reaction.

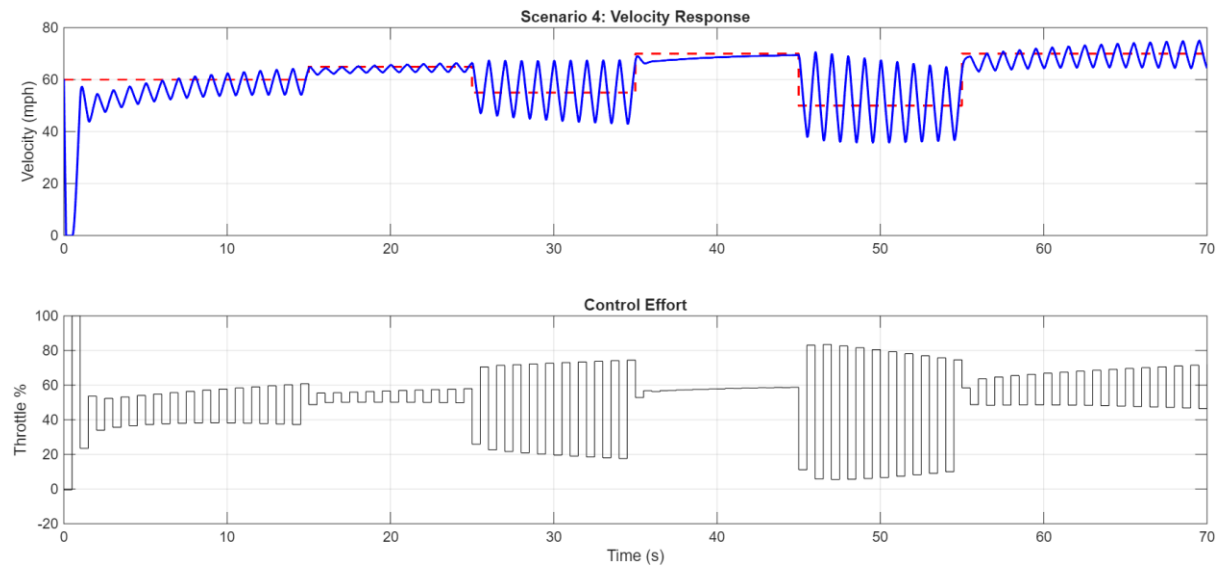


Figure 4

The reason behind this behaviour is that the controller obtains out-of-date information and thus, it takes a long time before the controller reacts to system changes. The effective delay lowers the stability margins of the system causing oscillations.

Control theory points of view include that more sampling time reduces the response time of a system to rapidly changing dynamics. This goes against ISO 15622 standards of smooth and stable regulation of speed.

In practice, the time span of the sampling in real-world systems is restricted by the capability of the ECU processors and the bandwidth. Although it is better to sample faster, it raises the computation load. Thus, there is a compromise between the sampling frequency and processor efficiency.

The 0.05 s (20 Hz) baseline is a sensible trade off value as it offers enough responsiveness without creating too much computing load (Salehpoor, 2025). However, increasing the

sampling time reduces system stability margins and may lead to oscillatory behaviour. In real automotive systems, such behaviour could compromise safety, highlighting the importance of selecting an appropriate sampling rate.

6. Effect of Communication Network Delay

The delay on the network is added in scenario 5-0.25 seconds, which is an approximation of the communication latency in the control loop. The system has reduced performance with slow responsiveness and even overshoot.

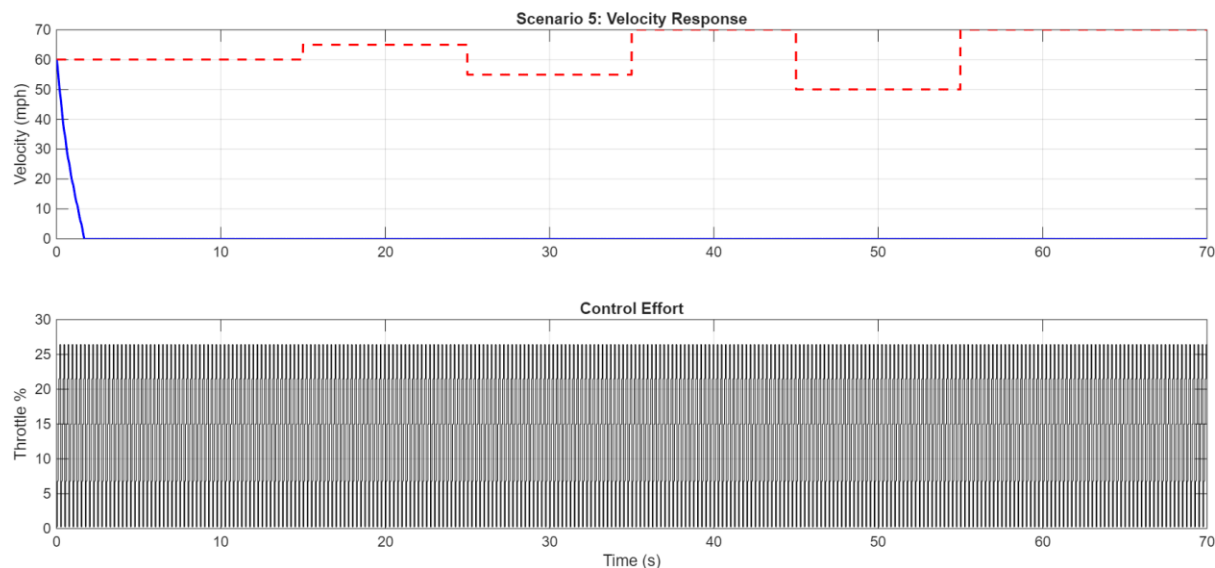


Figure 5

This is because the controller will use outdated feedback resulting in wrong control measures.

The delay basically causes the loss of phase margin that raises the chances of instability.

At the baseline system, the disturbance of a 40-50 seconds is corrected in about 3 seconds, which implies tolerable delay. Nonetheless, the delay of longer than 0.1 seconds greatly impairs performance.

As ISO 26262 suggests, these delays should be properly controlled in order to make the systems safe. Too much delay may cause unsafe behaviour especially in emergency acceleration or braking.

The trade-off in this case is between efficiency of the network and stability in control.

Although the longer delay has made communication load less, the delay also sacrifices the system performance and safety. This indicates that excessive delay can significantly degrade

system stability and lead to unsafe control actions. In practical automotive applications, minimising delay is essential to ensure reliable and safe operation in accordance with ISO 26262.

7. Effect of Real-World Disturbances (Hill Scenario)

In Scenario 6, an external disturbance is added that is in the form of a hill at the range of 40 to 55 seconds that decelerates by about 6 mph.

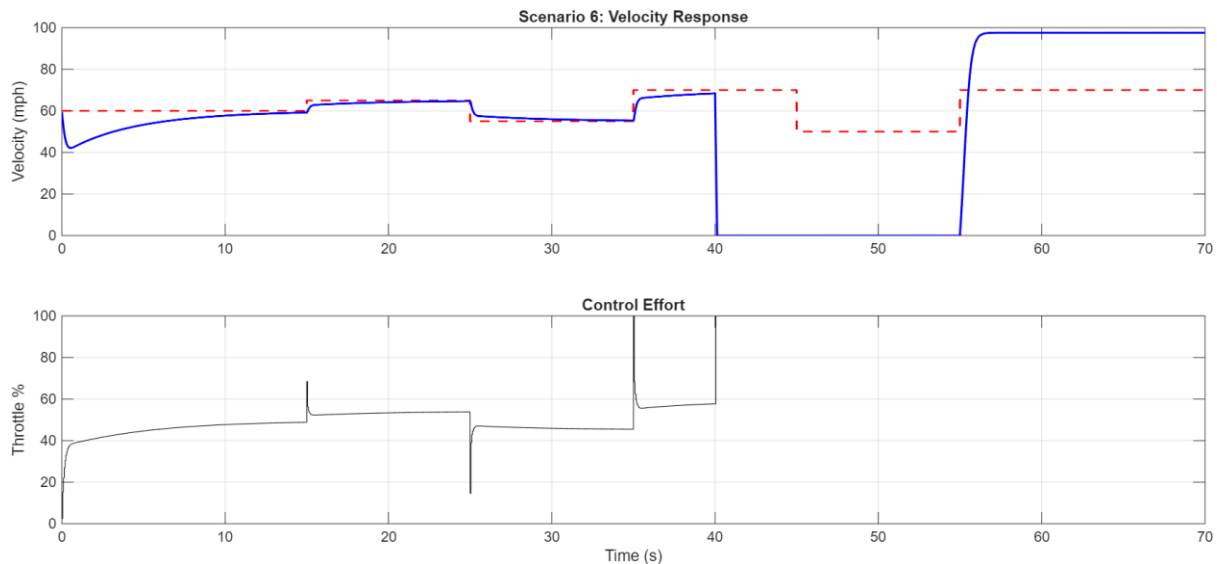


Figure 6

The controller reacts by putting more throttle effort in and counters the acceleration and gets back to the desired speed. This is considered a good disturbance rejection, which is one of the requirements in ISO 15622.

The reaction however is once again intended to be aggressive, with significant gains in control effort. In actual cars, other performance constraints like the maximum engine torque and fuel economy would restrict this behaviour (Ineza Havugimana et al., 2023).

This situation underlines the worthiness of sound controller design. In the absence of an inherent response, the system would not get back on track after the disruption as is the case in Scenario 2. This demonstrates that the controller has effective disturbance rejection capability. However, the high control effort required may not be ideal in real vehicles due to limitations in actuator capacity and fuel efficiency.

8. Additional Insights and Real-World Limitations

Although the simulation has good performance, it is necessary to note the limitations of the simulation. The MATLAB model is based on an ideal case and it is assumed that there is no noise, perfect sensors, as well as simplified vehicle dynamics.

As a matter of fact, a number of factors would deter performance:

Sensor's noise and uncertainty of measurement.

Gradients of the roads and aerodynamic drag.

Actuator saturation and delays.

ECU processing limitations

These would cause rise time to be higher, small steady-state errors, and system responsiveness to be lower. Thus, the outcomes are expected to be optimistic in relation to the actual systems.

9. Conclusion

This report provided an in-depth multi-scenario analysis of a digital cruise control system and the influence of implementation and design control constraints upon system performance.

The findings confirm that a poorly adjusted controller causes total system failure whereas a well thought-out PID controller will have precision tracking within a range of 1-2 mph. This performance is however associated with trade-offs such as excessive control effort and potential inconvenience of the passengers.

The paper also indicated that quantisation, sampling time, and communication delay play a major role in the system behaviour. Accuracy is enhanced through the use of high-resolution encoding and stability is guaranteed by the use of fast sampling and a low delay. Nonetheless, these enhancements make computations more demanding and make the system more complicated. These results highlight the importance of integrating control design with real-world constraints and safety standards to achieve reliable automotive system performance.

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