Scilab Case Study Project

On

Implementation of Conventional vs Improved PID Controllers in Xcos

Submitted by

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Domain

Engine System and Simulation

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Abstract

This case study presents the design and simulation analysis of a marine diesel engine speed controller utilizing the Xcos toolbox of Scilab, focusing on the application of PID (Proportional-Integral-Derivative) control theory. The marine diesel engine speed is subject to external disturbances during operation, causing variability in engine revolutions that adversely affect ship propulsion performance. To address this, a mathematical model of the marine diesel engine speed control system was developed and implemented in Xcos, allowing for simulation of both conventional PID and an improved PID controller.

Keywords: Marine diesel engine, PID controller, Xcos toolbox, Scilab, speed control, simulation model, control system design, marine propulsion, system stability, control signal analysis.

1 Introduction

The regulation of marine diesel engine speed is a critical concern in marine engineering, as engine speed is frequently affected by external disturbances such as waves, wind, and load variations during ship operation. These disturbances induce fluctuations in engine revolutions, which can compromise propulsion efficiency, increase mechanical stress, and negatively impact overall vessel performance.

Recognizing the importance of stable engine speed, this research presents a comprehensive investigation into the modeling and control of marine diesel engine speed, with a particular focus on Proportional-Integral-Derivative (PID) controllers. While prior studies have explored various control strategies—including fuzzy logic, Hamiltonian energy-based methods, and optimization algorithms—there has been limited holistic analysis of the PID controller's role and performance in marine applications.

In this study, a detailed mathematical model of the marine diesel engine speed control system was developed and implemented in the Simulink/Matlab environment. The functional blocks represent the key components of the propulsion system, including the engine, actuator, and feedback mechanisms. Both conventional and improved PID controllers were designed and evaluated, with controller parameters (Kp, Ki, Kd) optimized for marine conditions.

Simulation results demonstrate that the improved PID controller achieves superior performance compared to the conventional PID approach. Specifically, the improved controller offers faster settling times, reduced maximum deviation, and enhanced stability in response to step changes and disturbances. For instance, the improved PID controller reduced the stable time from 10 seconds to 8.5 seconds and limited the regulation range more effectively, resulting in smoother engine operation.

The findings confirm that advanced PID-based control strategies can significantly enhance the stability and reliability of marine diesel engine speed regulation. These improvements are essential for maintaining efficient propulsion, reducing mechanical wear, and ensuring compliance with operational and environmental standards.

In conclusion, the comprehensive analysis and simulation of PID controllers conducted in this research provide a valuable foundation for further advancements in marine engine speed control. The results underscore the continued relevance and adaptability of PID-based methods for modern marine engineering applications.

2 Problem Statement

The project focuses on addressing the challenges towards improved PID parameter assignment. The challenges are as follows:

1. **Removing the Need of Actuator Transfer Function Approximations**: The transfer function of the actuator system of the marine diesel engine has been obtained in the earlier research work using algorithms like HIWOPSO [1]. This has to be completely replaced

by PID Control.

2. **Need for Improved Speed Control Models**: There is a necessity to develop and evaluate improved PID-based speed control models that can provide faster response, greater stability, and reduced regulation range compared to conventional PID controllers, thereby enhancing the reliability and efficiency of marine propulsion systems.

This work aims to address these challenges by developing a robust mathematical model validated through simulation results, enabling improved marine engine performance.

3 Basic Concepts Related to the Topic

PID Controller Fundamentals

The Proportional-Integral-Derivative (PID) controller is one of the most widely adopted strategies in industrial control, including marine diesel engine speed regulation. The PID controller combines three distinct actions to achieve robust and responsive control:

- **Proportional (P) Control:** The controller output is directly proportional to the error signal:
$$u(t) = K_p e(t) \tag{1}$$
In the Laplace domain, this becomes $U(s) = K_p E(s)$, where K_p is the proportional gain.

- **Integral (I) Control:** The controller output is based on the accumulation of past errors, effectively eliminating steady-state error:
$$u(t) = K_i \int_0^t e(\tau) d\tau \tag{2}$$
The transfer function is $U(s) = \frac{K_i}{s} E(s)$, where K_i is the integral gain.

- **Derivative (D) Control:** The controller output is proportional to the rate of change of the error, improving transient response:
$$u(t) = K_d \frac{de(t)}{dt} \tag{3}$$
With transfer function $U(s) = K_d s E(s)$, where K_d is the derivative gain.

These actions can be combined in various ways:

- **PI Controller:**
$$u(t) = K_p e(t) + K_p \frac{1}{T_i} \int_0^t e(\tau) d\tau \tag{4}$$

- **PD Controller:**
$$u(t) = K_p e(t) + K_p T_d \frac{de(t)}{dt} \tag{5}$$

- **PID Controller:**

$$u(t) = K_p e(t) + K_p \frac{1}{T_i} \int_0^t e(\tau) d\tau + K_p T_d \frac{de(t)}{dt} \tag{6}$$

The corresponding transfer function is:

$$U(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) E(s) \tag{7}$$

Here, K_p is the proportional gain, T_i is the integral time constant, and T_d is the derivative time constant.

PID controllers are favoured for their simplicity, versatility, and effectiveness in a wide range of engineering applications. Proper tuning of the K_p, K_i, and K_d parameters allows for optimal performance in terms of stability, response speed, and disturbance rejection—qualities essential for marine diesel engine speed control.

4 Flowchart

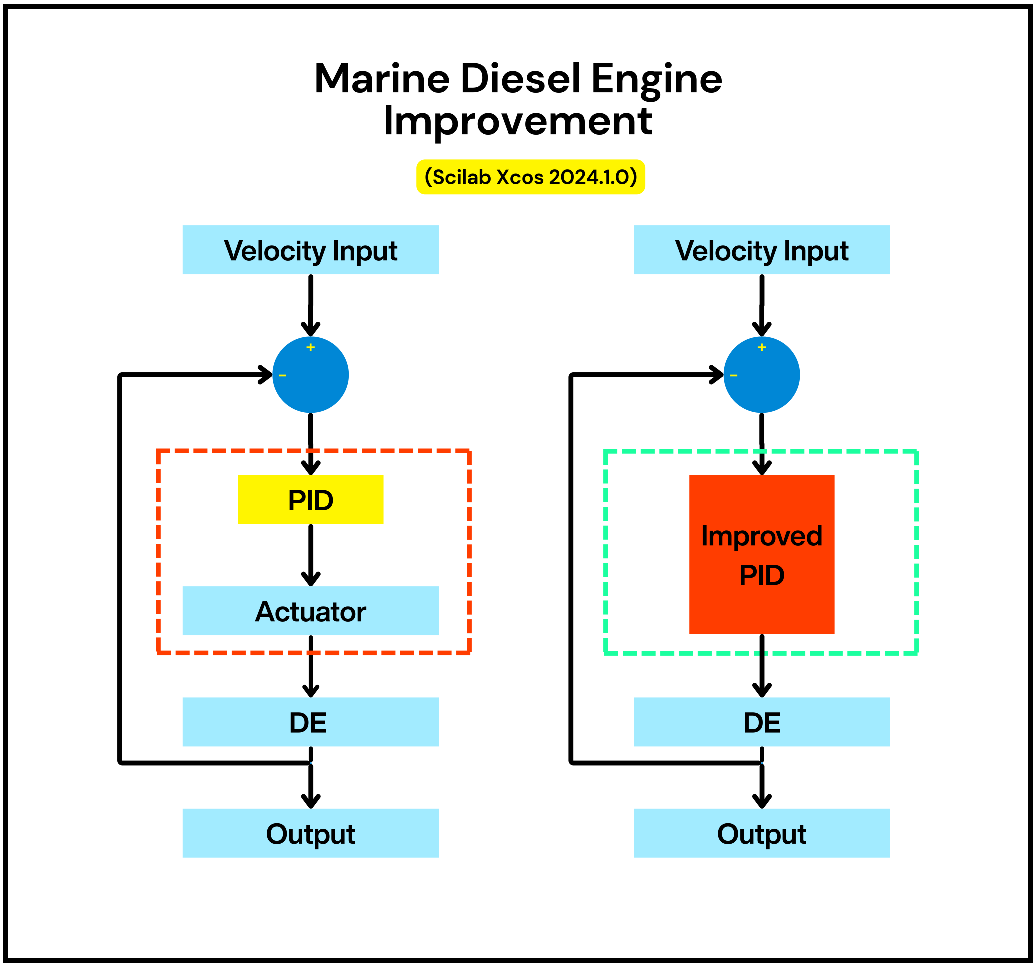

Figure 1: Diesel Engine Improvement Flowchart (Basic Outline)

5 Software/Hardware Used

The software that has been primarily used is the normal **Scilab 2024.1.0** scripting console. The device on which the program has been ran is a **Windows 11 OS** machine. The solver used for this simulation is **Implicif Runge-Kutta 45 or RK45**.

6 Procedure of Execution

The execution of the code can be done as follows:

1. Open Scilab on desktop. For the Xcos diagram creation, version 2024.1.0 have been used, other versions can also be applied.

2. Open **marinede.zcos** .

3. All the blocks have been arranged in a Scilab Xcos diagram, with the inputs fed in the PID control circuits.

4. Run the file using the play button above.

5. Observe the graphical outputs for the code, as set with various labelled scopes.

7 Results

The following graphs have been obtained as a result.

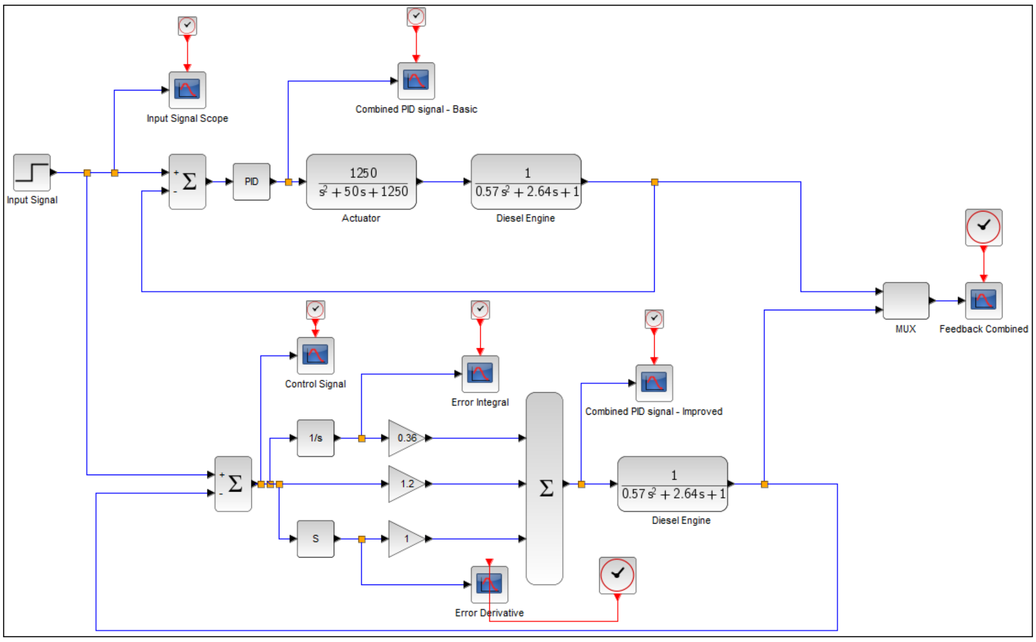

Figure 2: Xcos Model for the Comparative Systems

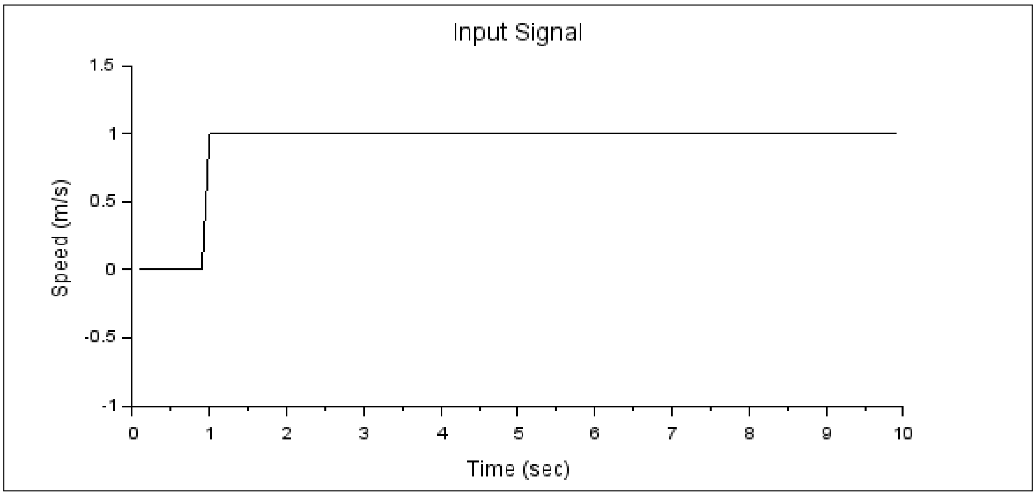

Figure 3: Input Velocity Signal (*Step Input*)

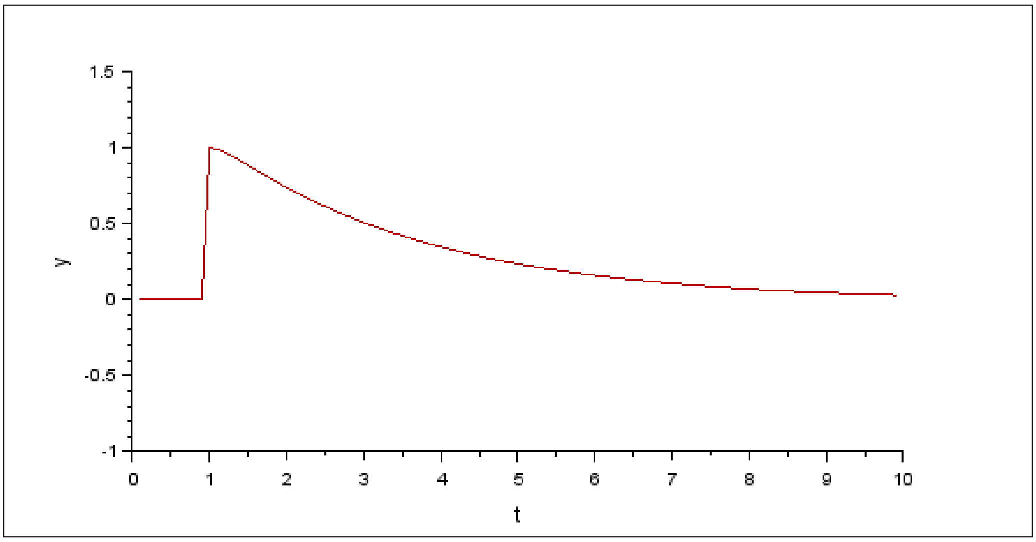

Figure 4: Control Signal

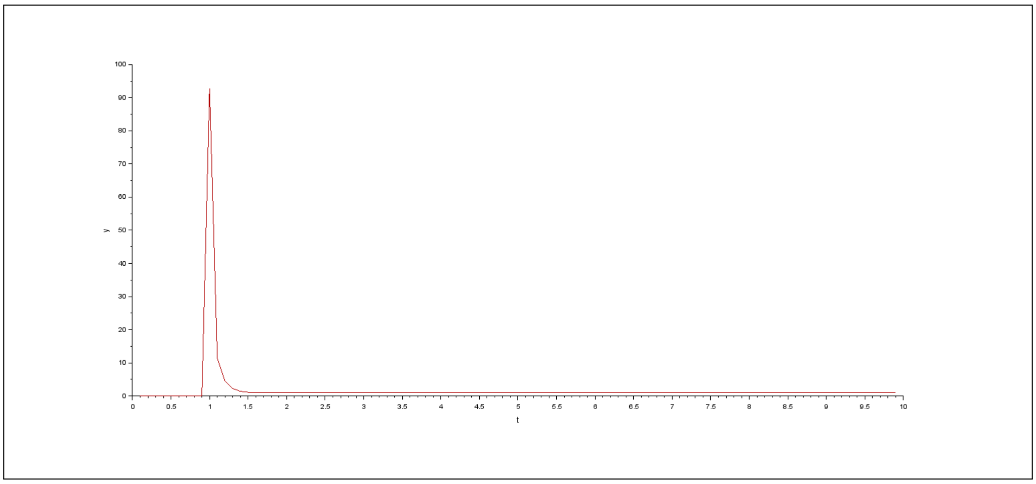

Figure 5: PID Signal for the Basic Model (*Step Input*)

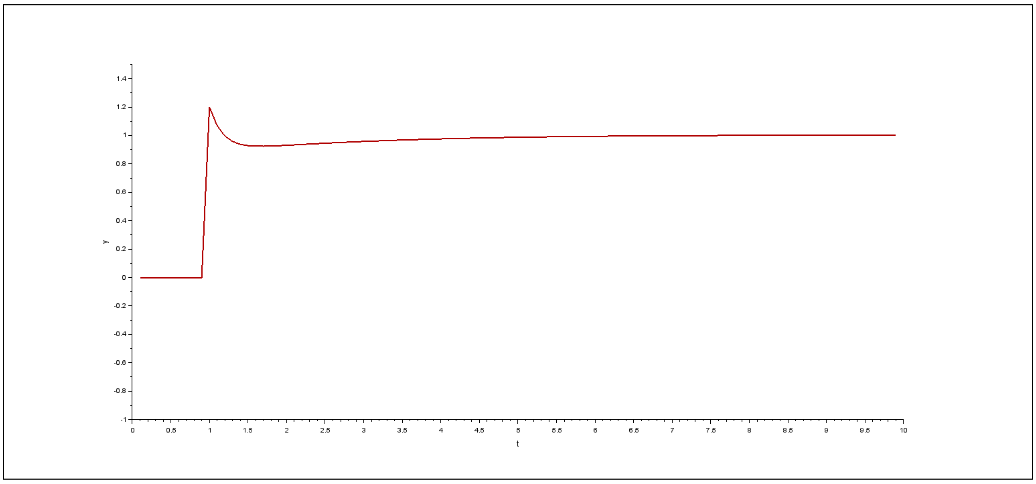

Figure 6: PID Signal for the Improved Model (*Step Input*)

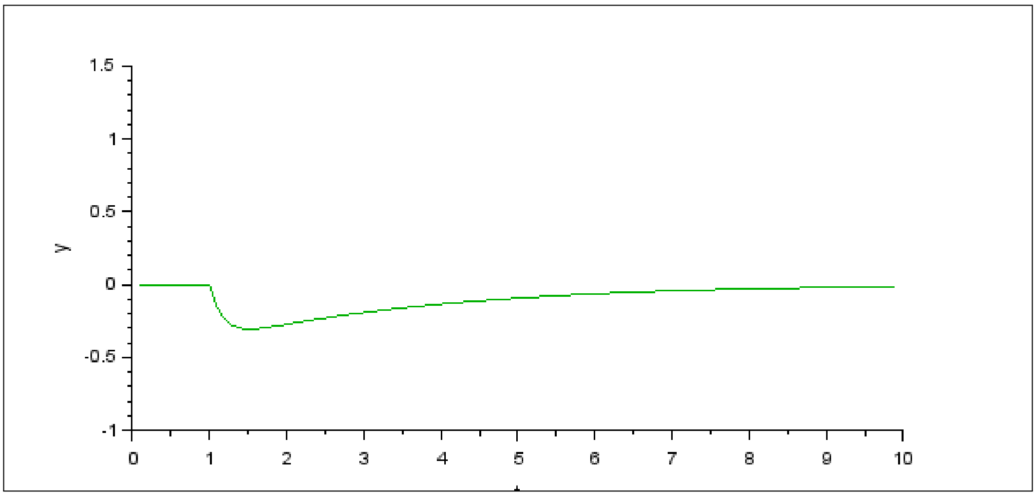

Figure 7: Error Derivative

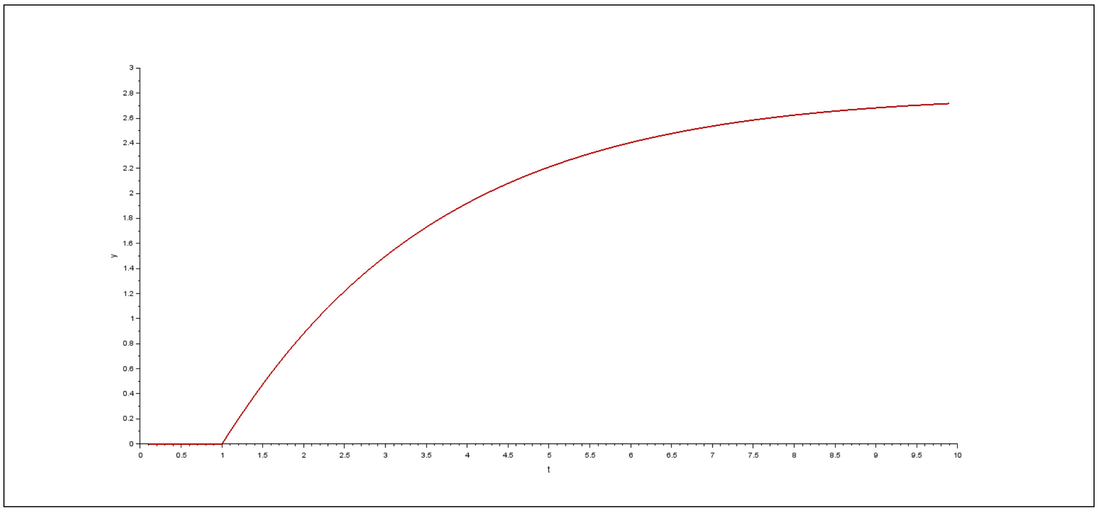

Figure 8: Error Integral

8 Observations

We examine the results obtained in the study on the same topic by Tran et al. [2]

Parameter	Starting Time (s)	Stable Time (s)	Maximum Range Value
PID Controller	1	10	1.2
Improved PID Controller	1	8.5	1

Table 1: Comparison Between Conventional and Improved PID Controllers in Reference[2]

While examining the similarity of the data obtained on Xcos diagram execution, certain differences can be observed , quite possibly due to solver scheme, which is not explicitly mentioned in the referred paper. It has been assumed that the basic controller model inherits PID from the optimization of the HIWOPSO algorithm [1]. The results thus obtained by the concerned Xcos diagram maybe gisted down as below.

Parameter	Starting Time (s)	Maximum Range Value	Rise Time (s)
PID Controller	1	1.1016	0.905
Improved PID Controller	1	1.003	10

Table 2: Comparison Between Conventional and Improved PID Controllers with Scilab Xcos

Even though the values differ in regard to maximum range a bit, it is quite event that the improved PID controller meticulously evades the need of additional actuation, additional jerk and improves the response curve.

References

[1] A. S. Alkhafaji, A. A. Al-Hayder, and A. S. Hassooni, "Hybrid iwopso optimization based marine engine rotational speed control automatic system.," *International Journal of Electrical & Computer Engineering (2088-8708)*, vol. 10, no. 1, 2020.

[2] T. A. Tran, "Analysis of the pid controller for marine diesel engine speed on simulink environment," in *2020 International Conference on Electrical Engineering and Control Technologies (CEECT)*, pp. 1–5, IEEE, 2020.