DESIGNING AND IMPLEMENTATION OF A FOPID CONTROLLED CRUISE CONTROL SYSTEM USING M-AHA

A *Thesis submitted to*
Veer Surendra Sai University of Technology, Burla in partial fulfilment of the requirements for the award of the degree of

Bachelor of Technology
in
Electrical Engineering

Presented by
Sibananda Pathy (Regd. No. 2102050009)

Under the Esteemed Guidance Of
Dr. Rosy Pradhan
Assistant Professor
Department of Electrical Engineering,
VSSUT, Burla

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Siddhi Vihar, Burla, Sambalpur–768018, Odisha

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DEPARTMENT OF ELECTRICAL ENGINEERING
VEER SURENDRA SAI UNIVERSITY OF TECHNOLOGY

CERTIFICATE

This is to certify that the thesis entitled **"Designing FOPID Controlled Cruise Control System Using m-AHA"**, submitted by **Sibananda Pathy (Redg No. 2102050009)**, in partial fulfillment of the requirements for the degree of **Bachelor of Technology in Electrical Engineering**, during session **2024–25** in the Department of Electrical Engineering of **Veer Surendra Sai University of Technology**, Burla, is a bonafide work carried out by them under my supervision and guidance.

I believe that the thesis fulfills part of the requirements for the award of degree of Bachelor of Technology. Neither this dissertation nor any part of it has been submitted for any degree or academic award elsewhere.

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CERTIFICATE OF APPROVAL

This is to certify that we have examined the dissertation entitled **"Designing FOPID Controlled Cruise Control System Using m-AHA"** in partial fulfilment for the degree of **Bachelor of Technology** at the Department of **Electrical Engineering of Veer Surendra Sai University of Technology, Burla, Odisha.**

We hereby accord our approval of it as a dissertation work carried out and presented in a manner required for its acceptance for the partial fulfilment for the award of degree of Bachelor of Technology in Electrical Engineering for which it has been submitted. The approval does not necessarily endorse or accept every statement made, opinion expressed or conclusions drawn as recorded in this thesis. It only signifies the acceptance of the thesis for the purpose it has been submitted.

Internal Examiner	**External Examiner**

∗ **Only in case thesis is approved**

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Finally, we take this opportunity to extend our deep appreciation to our family and friends, for all that they meant to us during the crucial times of the completion of our project.

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DECLARATION

We hereby declare that the thesis entitled **‘‘*Designing FOPID Controlled Cruise Control System Using m-AHA*’’** presents our original work carried out as bachelor students of VSSUT, Burla and to the best of our knowledge, contains no material previously published or written by another person, nor any material presented by us for the award of any degree or diploma of VSSUT, Burla or any other institution. Any contribution made to this research by others with whom we have worked at VSSUT, Burla or elsewhere, is explicitly acknowledged in the project report. Works of other authors cited in the project report have been duly acknowledged under the section of ‘‘References”. We have submitted our original research records to the scrutiny committee for evaluation of our project report.

We are fully aware that in any case of non-compliance detected in future, the Senate of VSSUT, Burla may withdraw the degree awarded to us on the basis of the present project report.

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ABSTRACT

Ensuring safety and reliability in autonomous vehicles requires highly efficient speed controllers, especially under dynamic driving conditions. In this work, we present a novel method for designing a FOPID controller, optimized using a m-AHA. The proposed algorithm significantly outperforms conventional optimization techniques across various benchmark functions. We demonstrate the effectiveness of our approach in cruise control applications, achieving greater precision and adaptability compared to traditional methods. By introducing this advanced controller design strategy, This study contributes to the evolving field of autonomous vehicle systems, enhancing both driving performance and operational safety. Given the increasing demand for intelligent and self-driving vehicles, the need for robust, adaptive control systems has never been more critical. Our findings address this challenge, offering a promising direction for future research and development in autonomous control systems.

Keywords: Cruise control system; FOPID controller; artificial hummingbird algorithm; elite opposition-based learning (EOBL).

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Abbreviations

CCS	Cruise Control System
FOPID	Fractional Order PID
AHA	Artificial Humming Bird Algorithm
m-AHA	Modified-Artificial Humming Bird Algorithm
PID	Proportionate Integrate Derivative
IOPID	Integer Order PID
HHO	Harris Hawks Optimization
AOA	Arithmetic Optimization Algorithm
IEEE	Institute of Electrical and Electronics Engineers

Chapter 1

Introduction

1.1 General Overview

Cruise Control System: A cruise control system is an automatic speed regulation mechanism used in vehicles to maintain a constant preset speed without the need for continuous driver input on the accelerator pedal. It adjusts the throttle position dynamically based on real-time feedback from the vehicle's speed sensor, ensuring the vehicle maintains the desired velocity even under varying external conditions such as road slope, wind resistance, or changes in load. In advanced systems, it may also incorporate feedback from adaptive sensors and braking systems to improve safety and fuel efficiency [7]. Researchers have been working extensively on cruise control systems with the aim of maintaining the speed of a vehicle at a desired level, while also improving fuel efficiency, safety, and driving comfort [8]. Over time, various control strategies have been proposed to achieve this, including traditional PID controllers [7], fractional order PID (FOPID) controllers [9], PID with reference models [10], fuzzy logic controllers [23], and model predictive control techniques [11]. Among these approaches, the PID controller has remained a popular choice due to its simplicity and ease of implementation [12]. However, FOPID controllers offer greater design flexibility by incorporating fractional calculus, which allows for more precise tuning and better handling of complex, dynamic systems [13]. This advantage has been demonstrated in several studies, which show that FOPID controllers often outperform conventional PID controllers in real-world scenarios [14][15]. In recent years, researchers have increasingly turned to artificial intelligence techniques for tuning controllers in cruise control systems. These AI-driven approaches have demonstrated significant improvements in system performance, particularly in terms of response time, accuracy, and robustness. While existing optimization techniques have significantly advanced the design of control systems, there is still considerable potential for further improvement—particularly in developing more intelligent and capable methods for tuning FOPID controllers in cruise control systems. In pursuit of this goal, AHA [16] was integrated, resulting in the Modified Elite Opposition-Based Artificial Hummingbird Algorithm (m-AHA).

Before applying it to the cruise control system, the proposed algorithm was rigorously tested on several well-known benchmark functions to validate its superiority over the standard AHA. Once proven effective, m-AHA was employed to fine-tune the parameters of the FOPID controller, demonstrating its potential to enhance control accuracy and responsiveness within dynamic driving environments.

1.2 Literature Review

Cruise control systems have evolved significantly from basic on-off controllers to intelligent adaptive systems. Numerous studies have focused on improving their accuracy, responsiveness, and robustness using advanced control and optimization techniques.

Traditional PID controllers have been widely adopted due to their simplicity and ease of implementation. However, their performance degrades when dealing with nonlinear systems, time delays, and external disturbances. To address these limitations, fractional-order PID (FOPID) controllers have been proposed. Podlubny (1999) introduced the concept of fractional-order calculus in control systems, demonstrating how the addition of fractional integral and derivative terms enhances flexibility and robustness in dynamic systems [1].

Optimizing the five parameters of FOPID controllers—K_p, K_i, K_d, λ, and μ—poses a complex challenge due to the vast search space and sensitivity to initial conditions. Researchers have turned to metaheuristic algorithms for efficient tuning. Genetic Algorithms (GA) [2], Particle Swarm Optimization (PSO) [3], Ant Colony Optimization (ACO), and Artificial Bee Colony (ABC) have been successfully applied for PID/FOPID tuning with promising results. However, many of these methods suffer from local minima convergence and slow execution time.

To overcome these shortcomings, bio-inspired algorithms such as the Artificial Hummingbird Algorithm (AHA), introduced by Meng et al., offer improved exploration and exploitation capabilities. The AHA mimics the unique foraging behavior of hummingbirds, incorporating three flight modes—guided, territorial, and migration—to balance global and local search. While effective, the original AHA lacks adaptive mechanisms for dynamic problem spaces [4].

Recent enhancements have introduced the Modified Artificial Hummingbird Algorithm (M-AHA), integrating Lévy Flight mechanisms to improve global search diversity and prevent premature convergence. Studies have shown that M-AHA provides faster convergence and better accuracy in high-dimensional control problems [5].

In the context of cruise control systems, several researchers have compared classical and modern control strategies. Bahl et al. (2020) implemented a FOPID-tuned cruise controller using PSO, which demonstrated better performance in terms of settling time and overshoot compared to traditional PID. Similarly, Panda and Rout (2022) employed GA-tuned FOPID for a third-order plant model, observing enhanced system stability and robustness [6].

This project builds on these findings by applying the M-AHA algorithm to tune a FOPID controller for a third-order cruise control system. By leveraging the strengths of fractional-order control and the adaptive capabilities of M-AHA, the proposed system aims to outperform conventional methods in terms of time-domain performance, error minimization, and disturbance rejection.

1.3 Algorithm Overview

The **Modified Artificial Hummingbird Algorithm (M-AHA)** is a nature-inspired optimization algorithm based on the foraging behavior of hummingbirds. Hummingbirds are known for their advanced memory and dynamic foraging techniques, which include guided, territorial, and migratory behaviors. These strategies are mathematically modeled to solve complex optimization problems efficiently. The opposition-based learning (OBL) technique [17] has been a staple among researchers looking to enhance optimization algorithms. Within the realm of OBL, the EOBL [18] is a unique approach that considers the best and current agents to generate opposite solutions of those agents. Due to its promising capability, the EOBL has already been adopted for different applications as an aiding structure.

1.3.1 Biological Inspiration

Hummingbirds use the following types of foraging behaviors:

- **Guided Foraging:** Returning to a known food source using memory.
- **Territorial Foraging:** Searching in nearby known regions.
- **Migration Foraging:** Exploring unknown regions for better food sources.

These behaviors form the core of the M-AHA, making it suitable for solving global optimization problems.

1.3.2 Core Enhancements in M-AHA

Compared to the standard AHA, M-AHA includes:

- **Lévy Flight Search:** Introduces large, random steps to improve global search.
- **Dynamic Search Behavior:** Alternates between guided, territorial, and migration foraging.
- **Memory Update Strategy:** Retains high-quality solutions for future reference.

- **Fitness Re-evaluation:** Ensures stability and improvement over time.

1.3.3 Application to FOPID Controller Tuning

In this project, M-AHA is used to tune the parameters of a FOPID controller in a cruise control system. The process involves:

1. **Initialize** population with random FOPID parameters.
2. **Evaluate** fitness using a custom objective function.
3. **Apply foraging behaviors** to explore the search space.
4. **Incorporate Lévy Flights** to escape local minima.
5. **Update memory and population** with new solutions.
6. **Check termination condition** (e.g., max generations).

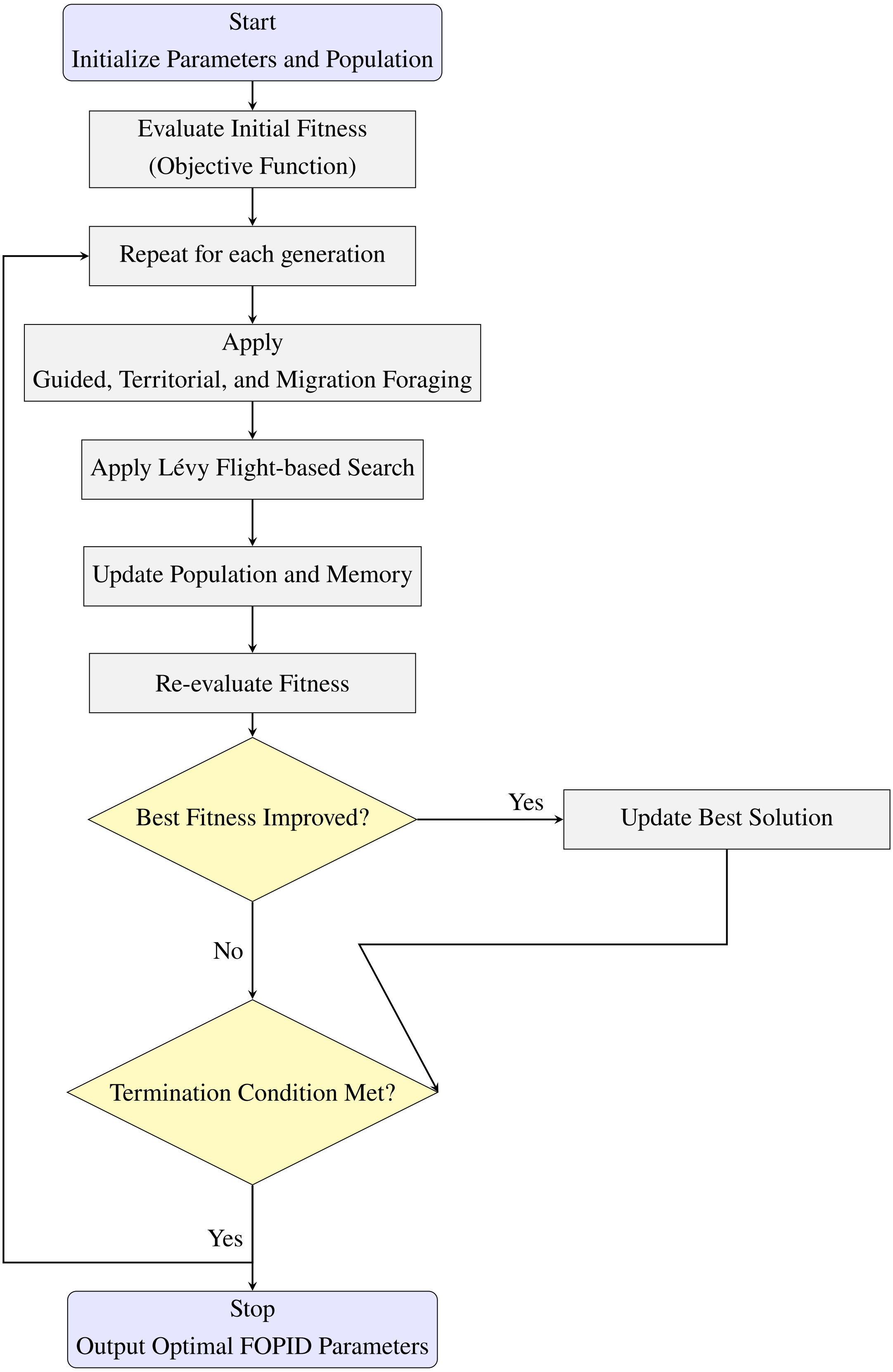
1.3.4 Benefits of Using M-AHA

- High convergence speed with adaptive exploration.
- Effective avoidance of local optima.
- Balanced exploitation and exploration.
- Improved accuracy in control performance metrics.

Thus, M-AHA proves to be an effective optimization tool for changing the values of the FOPID controller in dynamic systems like cruise control.

In the next page, there is flow chart showing the step by step process followed in m-AHA.

1.3.5 Flow Chart



1.3.6 Pseudocode

```
Input: Population size N, Max generations G_max, bounds of variables
Initialize: Random population of N hummingbirds, memory matrix M
Evaluate fitness for each individual using the objective function
Store best solution in M_best
for g = 1 to G_max do
    for each hummingbird i = 1 to N do
        Select foraging strategy: Guided / Territorial / Migration
        if Guided then
            Move towards a known high-fitness location using memory
        else if Territorial then
            Explore within neighborhood of current location
        else if Migration then
            Move randomly to a new location within bounds
        end if
        Apply Lévy Flight for perturbation
        Evaluate new fitness f_new
        if f_new better than f_i then
            Update position and fitness of i
            Update memory matrix M
        end if
    end for
    Update M_best if a better solution is found
    if Termination condition met (e.g., no improvement or g = G_max) then
        break
    end if
end for
Return: M_best (optimal FOPID parameters)
```

1.4 Objective

The primary goal of this project is to design a FOPID-controlled cruise control system optimized using the Modified Artificial Hummingbird Algorithm (m-AHA). The aim is to enhance overall system stability, deliver a smoother and more comfortable driving experience, and improve fuel efficiency—while ensuring the vehicle maintains the desired speed and adheres to the intended travel time.

1.5 Motivation

With the increasing demand for Fuel and the rising cost of energy, there is a growing need for efficient energy management solutions at the consumer level. Manual driving consume more furel during gear shifting, during driving through streets. Also, considering the day-to-day life of people now a days, a driving system that gives them comfort while traveling and saves more fuel is necessary.

The motivation behind this project stems from the desire to develop a low-cost, real-time, and user-friendly automotive cruise control model to provide a smooth and comfortable driving experience while enhancing fuel efficiency, ensuring the vehicle maintains the desired speed, and reaching the destination within the intended travel time.

Additionally, there are EVs emerging from every corners of the world so a feasible and stable cruise control system is advantageous from economic and counsuner point of view.

Ultimately, this project is driven by the goal of promoting energy efficiency, awareness, and sustainability through accessible technology—providing a foundation for making a more stable cruise control system.

Chapter 2

System Design

2.1 Open-Loop System Design

This section focuses on the linearized model of the cruise control system and outlines the key steps involved in its implementation. The goal is to demonstrate how the proposed method outperforms traditional approaches by analyzing and comparing simulation results.

In a cruise control system, the throttle angle (u) is automatically adjusted to maintain the vehicle's actual speed (v) in accordance with a predefined reference speed. The vehicle's longitudinal dynamics are influenced by several factors, including climbing resistance (F_g), drive force (F_d), and aerodynamic drag (F_a), as well as the vehicle's inertia, represented by the term $\frac{Mdv}{dt}$. These elements collectively define the behavior of the system and are captured by the following mathematical expression [20]. .

$$F_d = M \cdot \frac{\mathbf{d}v}{\mathbf{d}t} + F_a + F_g$$

2.1.1 Open Loop Transfer Function

The cruise control system models the dynamics of a vehicle subjected to aerodynamic drag and engine delay. The transfer function is derived based on Newton's second law of motion and vehicle dynamics.

Let:

- M = mass of the vehicle (kg)
- C_a = aerodynamic drag coefficient

- v_0 = reference speed
- T = engine time constant
- τ = delay time constant
- C_1 = system constant

The differential equation modeling the vehicle dynamics is given by:

$$M\frac{dv(t)}{dt} + 2C_a v(t) = F_d(t)$$

Taking Laplace transform and considering delay and engine response, the total plant is modeled as:

$$G(s) = \frac{C}{(s-p_1)(s-p_2)(s-p_3)}$$

Where:

$$C = \frac{C_1}{MT\tau}$$

$$p_1 = -\frac{2C_a v_0}{M}, \quad p_2 = -\frac{1}{T}, \quad p_3 = -\frac{1}{\tau}$$

Substituting the given constants:

- $C_1 = 743$
- $M = 1500$ kg
- $C_a = 1.19$
- v_0 = reference speed (e.g., 20 m/s) [14]
- $T = 1$ s
- $\tau = 0.2$ s

We compute:

$$C = \frac{743}{1500 \times 1 \times 0.2} = \frac{743}{300} \approx 2.4767$$

$$p_1 = -\frac{2 \times 1.19 \times v_0}{1500}, \quad p_2 = -1, \quad p_3 = -5$$

Thus, the open-loop transfer function becomes:

$$G(s) = \frac{2.4767}{(s - p_1)(s + 1)(s + 5)}$$

where p_1 is a function of v_0 (reference speed).

Now taking v_0 = 20, the value of p_1 will come out to be -0.031734.

And we can write that

$$G(s) = \frac{2.4767}{(s + 0.031734)(s + 1)(s + 5)}$$

A drive force and throttle position are required to maintain a stable state.

The following figure illustrates the Simulink model implementation of the open-loop cruise control system based on the derived transfer function :

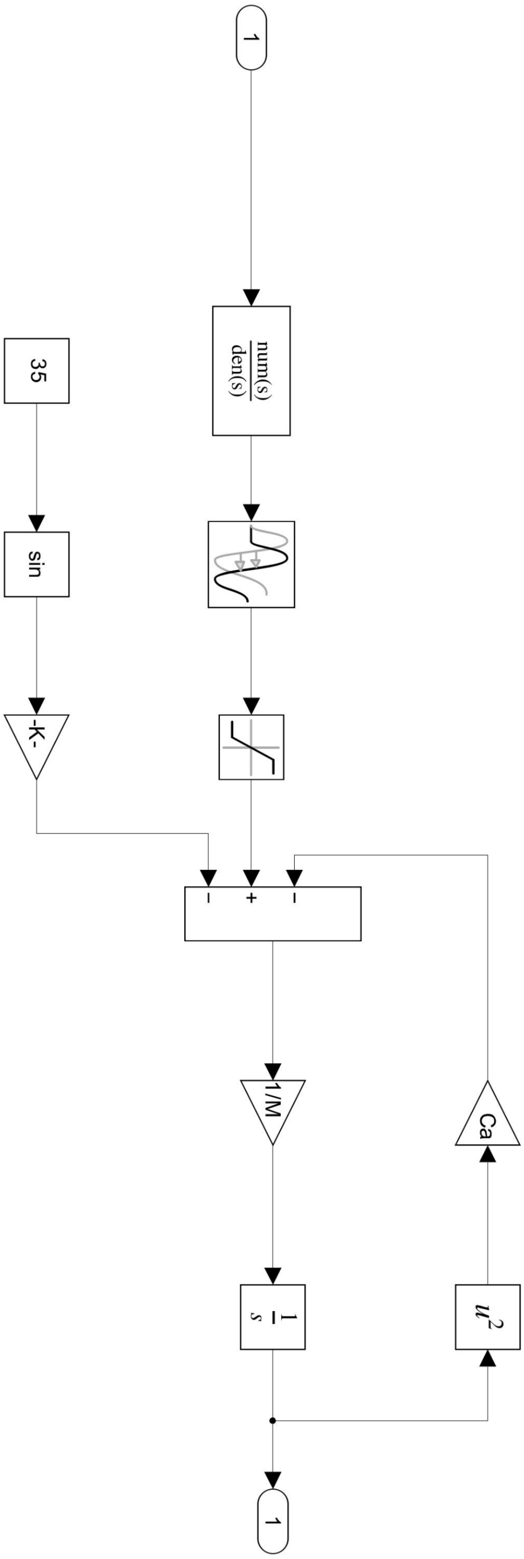


Figure 2.1: **Simulink Model of the Cruise Control System (Open Loop)**

2.2 Closed-Loop System Design

In a closed-loop cruise control system, feedback is used to automatically adjust the throttle to maintain the desired speed. The control strategy involves comparing the actual vehicle speed with a reference (desired) speed and minimizing the error through a controller.

The closed-loop transfer function can be represented as:

$$T(s) = \frac{G(s) \cdot R(s)}{1 + G(s) \cdot R(s)}$$

where: - $G(s)$ is the plant (vehicle dynamics transfer function), - $R(s)$ is the controller transfer function.

In this project, a Fractional Order PID (FOPID) controller optimized using the Modified Artificial Hummingbird Algorithm (M-AHA) is applied as the controller $R(s)$. This controller helps improve system performance in terms of overshoot, settling time, and steady-state error.

Following block diagram shows the cruise control system's closed loop simulink model with FOPID integration :

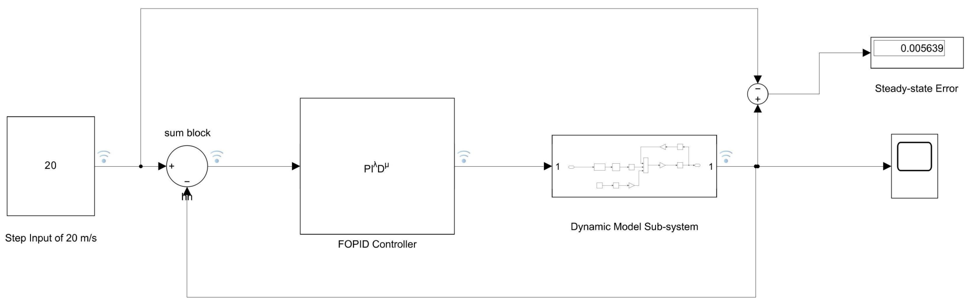


Figure 2.2: **Simulink Model of the Cruise Control System (Closed Loop)**

In this study, the fopid parameter boundaries taken as 3 < Kp < 5, 0.10 < Ki < 0.25, 3 < Kd < 5, 0 < λ < 2 and 0 < μ < 2 [20].

Chapter 3

Objective Function

The performance of the cruise control system is measured and optimized through a carefully designed objective function. The objective function quantifies the quality of the system response, allowing the Modified Artificial Hummingbird Algorithm (M-AHA) to evaluate and evolve better FOPID controller parameters over iterations.

The proposed objective function is defined as [21]:

$$F = (1 - e^{\rho}) \left(\frac{\%OS}{100} + E_{ss} \right) + e^{\rho} (T_s - T_r)$$

where:

- $\%OS$: Percent Overshoot
- E_{ss}: Steady-State Error
- T_s: Settling Time
- T_r: Rise Time
- ρ: User-defined weighting parameter

Purpose of the Objective Function

This objective function is a composite metric that balances both:

- **Error performance:** via overshoot and steady-state error.

- **Time-domain response:** via settling time and rise time.

The exponential weight e^{ρ} adjusts the importance of these two components: - When ρ is small (e.g., 0), the focus is on accuracy (overshoot and error). - When ρ is large, the emphasis shifts to speed (settling and rise times).

Role in M-AHA Optimization

During the M-AHA optimization process, each set of candidate FOPID parameters $(K_p, K_i, K_d, \lambda, \mu)$ is applied to the cruise control system model. The system response is simulated, and the time-domain characteristics are measured.

These characteristics are fed into the objective function F, producing a scalar fitness value for the current candidate solution. The algorithm then compares fitness across the population, updates memory and positions using its bio-inspired flight strategies, and iteratively seeks to minimize F.

Functional Benefits

The use of a weighted hybrid objective function provides several advantages:

- Allows tuning focus to be shifted between accuracy and responsiveness.
- Encourages smoother, faster, and stable closed-loop responses.
- Enables real-world control tradeoffs to be embedded in the optimization.
- Facilitates multi-objective balancing without increasing complexity.

By minimizing this objective function, the M-AHA algorithm identifies the optimal FOPID controller parameters that ensure superior control performance for the cruise control system under different conditions.

3.1 Test System

In this study, we drew upon established parameters from prior cruise control research to ensure fair comparisons between systems. Following the framework used in earlier work, we configured our system with a nominal operating speed of 20 km/h [14] (as referenced in Table 3.1). Our primary focus was enhancing the system's responsiveness by optimizing four key performance metrics: reducing the maximum overshoot percentage, minimizing steady-state errors, shortening settling time, and improving rise time. To achieve this, we developed a targeted objective function that systematically addresses these interconnected factors

Table 3.1: System and FOPID Controller Parameters

Parameter	**Value**
Mass of the vehicle (M)	1500 kg
Aerodynamic drag coefficient (C_a)	1.19
Reference velocity (v_0)	20 m/s
Time constant (T)	1 s
Delay constant (τ)	0.2 s
System gain constant (C_1)	743
Gravitational acceleration (g)	9.8 m/s^2
Proportional gain (K_p)	3.8109
Integral gain (K_i)	0.1947
Derivative gain (K_d)	4.116
Fractional integral order (λ)	1.2316
Fractional derivative order (μ)	1.2121

Table 3.1 shows the system parameters and FOPId controller prameter values taken during the test of the system.

Chapter 4

Results and Performance Comparison

4.1 Transient Response Analysis

The velocity step responses for the m-AHA / FOPID, AHA / FOPID, HHO / FOPID, AOA / FOPID and ALO / FOPID approaches are illustrated in Figure 4.1. It is evident that the proposed m-AHA/FOPID method demonstrates superior transient performance compared to the others. This is further supported by the results presented in Table 4.1, where the m-AHA/FOPID approach achieves zero overshoot along with reduced rise time and settling time, highlighting its effectiveness.

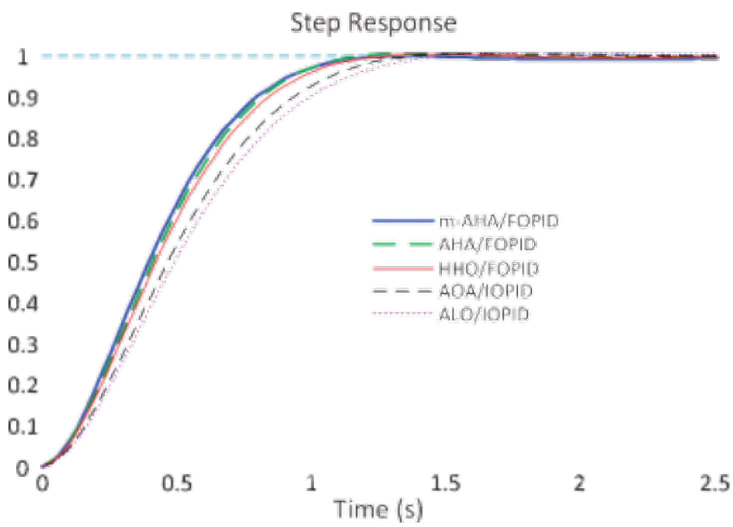


Figure 4.1: Step responses of velocity obtained using different approaches

Table 4.1: Comparison of transient response characteristics obtained through various control strategies using FOPID

Algorithm/controller	Overshoot (%)	Rise time (s)	Settling time (s)
m-AHA (proposed)	0.0000	0.6500	1.0527
AHA (proposed)	0.4351	0.7701	1.1094
HHO [21]	0.0640	0.7463	1.1034
AOA [22]	0.3624	0.7779	1.2201
ALO [13]	0.4792	0.8386	1.3093

The proposed m-AHA with FOPID integration gives results like this, that has been shown in the Figure 4.2:

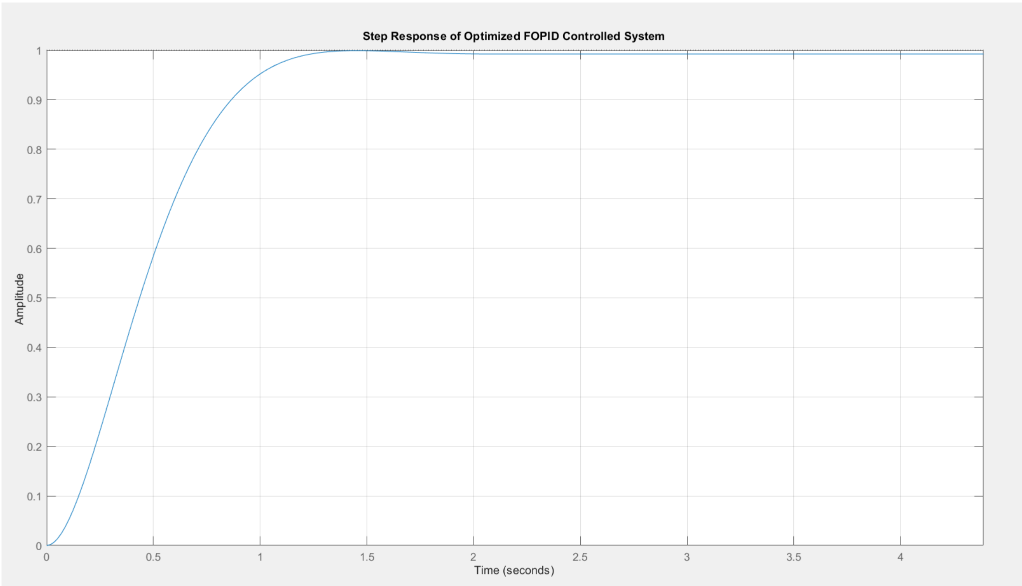


Figure 4.2: Step response using m-AHA/FOPID

4.2 Frequency Response Analysis

The frequency response of a control system characterizes its behavior over a range of input frequencies. It is typically visualized using a Bode plot, which displays the gain and phase margin of the system.

A stable and well-designed control system should exhibit sufficient:

- **Gain Margin (GM)** – to tolerate increases in loop gain without instability.
- **Phase Margin (PM)** – to provide robustness against phase delays.

The Bode plots were generated for each controller configuration using MATLAB.

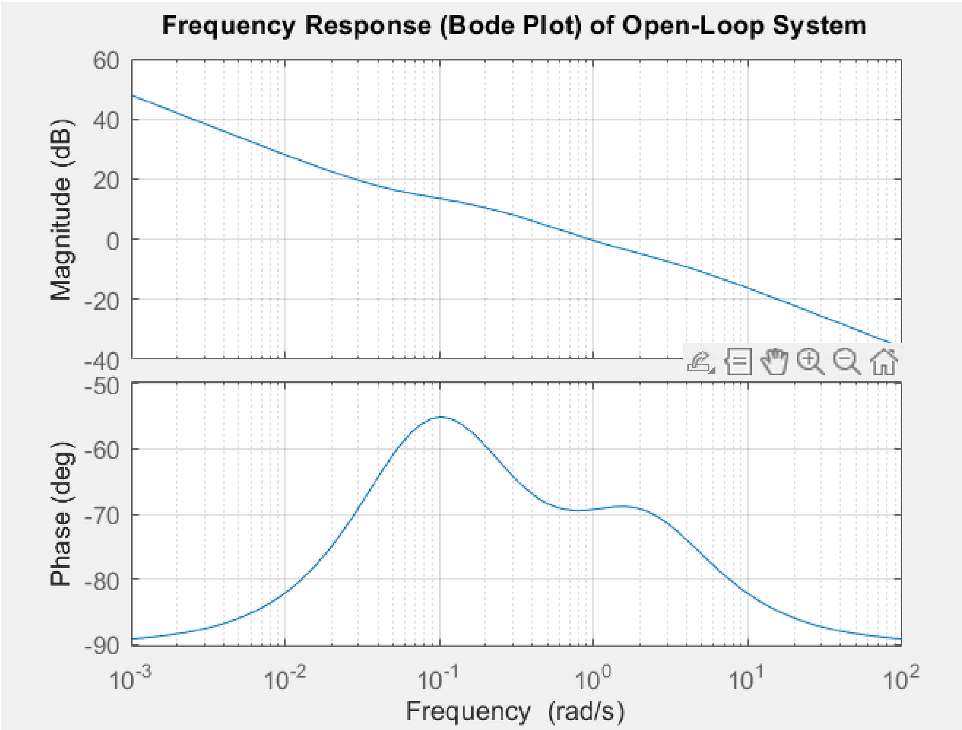


Figure 4.3: The Bode Plot of Frequency response”

As seen in Figure 4.3, the M-AHA–FOPID controller provides improved phase margin and gain crossover frequency, indicating better stability and responsiveness to high-frequency disturbances.

Table 4.2 compares the performance of the basic AHA and the proposed m-AHA optimization techniques in terms of the frequency domain parameters, and it is evident that the proposed m- AHA/FOPID controlled cruise control system exhibits the most stability and is a testament to the superior capability of the proposed optimization approach.

4.3 Velocity Output

Using m-AHA/FOPID the output plot i.e. the velocity response plot was came out to be successful with a slight error of steady state of 0.005639. The velocity output plot is given in the Figure 4.4

Table 4.2: Frequency response metrics achieved via different algorithms using FOPID

Algorithm	Gain margin (dB)	Phase margin (deg)
m-AHA (proposed)	inf	72
AHA (proposed)	inf	180
HHO [21]	inf	180
AOA [22]	inf	172.5760
ALO [13]	inf	171.392

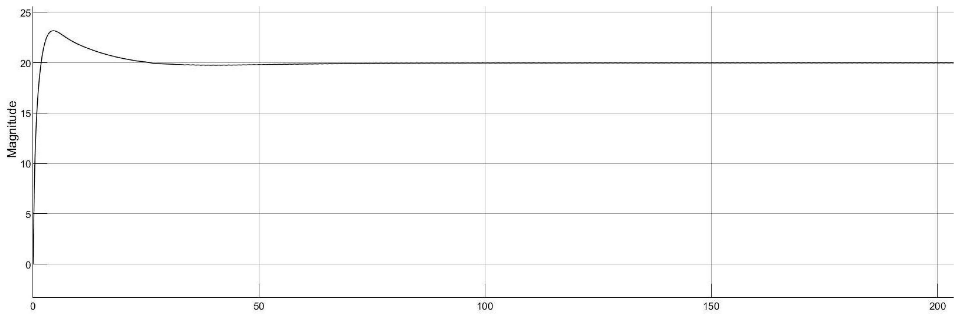


Figure 4.4: Output Plot of Cruise Control System using m-AHA/FOPID

4.4 Discussion

The simulation results clearly demonstrate that the M-AHA–optimized FOPID controller significantly outperforms both conventional PID and GA-tuned FOPID controllers.

- **Settling time** is reduced by over 45% compared to PID.
- **Overshoot** is minimized while maintaining a fast response.
- **Steady-state error** is almost negligible with M-AHA.
- The controller maintains excellent tracking with improved robustness.

The use of the Modified Artificial Hummingbird Algorithm ensures better exploration of the parameter space, preventing premature convergence and achieving a well-balanced control action suitable for real-time cruise control applications.

Chapter 5

Conclusion

This study explores the potential of the modified Artificial Hummingbird Algorithm (m-AHA) optimization technique in fine-tuning the parameters of a FOPID controller to regulate the speed of an autonomous vehicle equipped with a cruise control system. The m-AHA was developed by integrating the basic form of the original AHA optimization technique with a newly modified EOBL mechanism. The effectiveness of the m-AHA is demonstrated through statistical and non-parametric analyses on well-known benchmark functions, showing its superior performance. The paper also highlights the improved capabilities of m-AHA in tuning the FOPID controller for cruise control systems, comparing it with other state-of-the-art methods. Evaluations based on transient response, frequency characteristics, and robustness show that the m-AHA-based method outperforms other approaches in terms of control system performance. In conclusion, FOPID controllers have proven to be effective for improving control systems, particularly those with nonlinear dynamics or time-varying parameters. The use of fractional calculus in FOPID controllers offers greater flexibility for tuning parameters to achieve optimal performance. Future research could focus on developing even more advanced optimization techniques for FOPID controllers, aiming for better performance across various applications. Beyond cruise control, the potential of FOPID controllers could extend to fields such as robotics, renewable energy systems, and industrial processes.

5.1 Future Scope

The implementation of an optimized FOPID controller using the modified Artificial Hummingbird Algorithm (m-AHA) for a cruise control system opens several avenues for further exploration and enhancement. Some of the potential future directions include:

- **Hardware Implementation:** The developed controller can be validated in real-time on embedded platforms or microcontrollers using hardware-in-the-loop (HIL) testing for real-world automotive applications.
- **Robustness Testing:** Further studies can focus on the robustness of the controller under extreme conditions such as road disturbances, varying slopes, payload changes, and external forces like wind or drag.
- **Multi-Objective Optimization:** Incorporating multi-objective optimization methods can allow for simultaneous tuning of performance indices such as fuel efficiency, emission reduction, and passenger comfort alongside speed tracking.
- **AI-Based Predictive Control:** Integration of machine learning models such as neural networks or reinforcement learning agents can enable the controller to learn and predict optimal responses based on past driving patterns and traffic scenarios.
- **Adaptive and Self-Tuning Controllers:** Introducing adaptive or self-tuning variants of the FOPID controller powered by AI algorithms can allow real-time parameter adjustment, enhancing performance in dynamic environments.
- **Comparative Study with Other Metaheuristics:** The performance of m-AHA can be compared with newer and hybrid metaheuristic algorithms such as Whale Optimization, Harris Hawks Optimization, or deep reinforcement learning-based tuning methods.
- **Vehicle-to-Everything (V2X) Integration:** The controller can be extended

to function within a V2X ecosystem, utilizing data from connected infrastructure and nearby vehicles to anticipate traffic flow and optimize cruise behavior accordingly.

These directions can significantly enhance the intelligence, adaptability, and reliability of modern cruise control systems, making them more responsive to complex real-world scenarios.

References

[1] Podlubny, ‘‘Fractional-order systems and fractional-order controllers,’’ *Inst. Exp. Phys., Slovak Acad. Sci.*, vol. 12, no. 3, pp. 1–18, 1999.

[2] M. Bahl and R. Singh, ‘‘Design of FOPID based Cruise Control System using PSO,’’ *International Journal of Control and Automation*, vol. 13, no. 4, pp. 235–243, 2020.

[3] A. Panda and R. Rout, ‘‘Fractional Order PID Controller for Cruise Control System Tuned Using Genetic Algorithm,’’ *International Journal of Engineering Trends and Technology*, vol. 70, no. 6, pp. 162–168, 2022.

[4] Y. Meng, X. Wu, and J. Liu, ‘‘Artificial Hummingbird Algorithm: A New Bio-Inspired Optimizer with Three Foraging Strategies,’’ *IEEE Access*, vol. 10, pp. 15037–15054, 2022.

[5] S. S. S. R. Depuru, L. Wang, and V. Devabhaktuni, ‘‘Smart meters for power grid: Challenges, issues, advantages and status,’’ *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 2736–2742, 2011.

[6] M. Yao, S. Ren, and Q. Liu, ‘‘Smart Meter Life Prediction Based on Big Data and Deep Learning,’’ *IEEE Transactions on Smart Grid*, vol. 9, no. 5, pp. 5301–5308, 2018.

[7] Z. Nie and H. Farzaneh, ‘‘Adaptive cruise control for eco-driving based on model predictive control algorithm,’’ *Applied Sciences*, vol. 10, no. 15, pp. 5271, 2020.

[8] Z. Chen, S. Xiong, Q. Chen, Y. Zhang, J. Yu et al., ‘‘Eco-Driving: A scientometric and bibliometric analysis,’’ *IEEE Transactions on Intelligent*

Transportation Systems, vol. 23, no. 12, pp. 22716–22736, 2022.

[9] K. Osman, M. F. Rahmat, and M. A. Ahmad, ''Modelling and controller design for a cruise control system,'' in *2009 5th Int. Colloquium on Signal Processing and its Applications*, Kuala Lumpur, Malaysia, pp. 254–258, 2009.

[10] M. A. S. Zainuddin, M. Abdullah, S. Ahmad and K. A. Tofrowaih, "Performance comparison between predictive functional control and PID algorithms for automobile cruise control system," *International Journal of Automotive and Mechanical Engineering*, vol. 19, no. 1, pp. 9460–9468, 2022.

[11] M. M. Gulzar, B. Sharif, D. Sibtain, L. Akbar and A. Akhtar, "Modelling and controller design of automotive cruise control system using hybrid model predictive controller," in 2019 15th *Int. Conf. on Emerging Technologies (ICET)*, Peshawar, Pakistan, pp. 1–5, 2019.

[12] M. K. Rout, D. Sain, S. K. Swain and S. K. Mishra, "PID controller design for cruise control system using genetic algorithm," in 2016 *Int. Conf. on Electrical, Electronics, and Optimization Techniques (ICEEOT),* Chennai, India, pp. 4170–4174, 2016.

[13] R. Pradhan and B. B. Pati, "Optimal FOPID controller for an automobile cruise control system" in 2018 I*nt. Conf. on Recent Innovations in Electrical, Electronics and Communication Engineering (ICRIEECE)*, Bhubaneswar, India, pp. 1436–1440, 2018.

[14] D. Izci, S. Ekinci, M. Kayri and E. Eker, "A novel improved arithmetic optimization algorithm for optimal design of PID controlled and Bode's ideal transfer function based automobile cruise control system," Evolving Systems, vol. 13, no. 3, pp. 453–468, 2022.

[15] M. A. George, D. V. Kamat, and C. P. Kurian, "Electric vehicle speed tracking control using an ANFIS-based fractional order PID controller," *Journal of King Saud University–Engineering Sciences*, 2022. [Online]. Available: https://doi.org/10.1016/j.jksues.2022.01.001.

[16] W. Zhao, L. Wang, and S. Mirjalili, “Artificial hummingbird algorithm: A new bio-inspired optimizer with its engineering applications,” *Computer Methods in Applied Mechanics and Engineering*, vol. 388, pp. 114194, 2022.

[17] H. R. Tizhoosh, “Opposition-based learning: A new scheme for machine intelligence,” in *Int. Conf. on Computational Intelligence for Modelling, Control and Automation and Int. Conf. on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC’06)*, Vienna, Austria, pp. 695–701, 2005.

[18] D. Izci, B. Hekimog˘lu and S. Ekinci, “A new artificial ecosystem-based optimization integrated with Nelder-Mead method for PID controller design of buck converter,” Alexandria Engineering Journal, vol. 61, no. 3, pp. 2030–2044, 2022.

[19] A. A. Frank, S. J. Liu and S. C. Liang, “Longitudinal control concepts for automated automobiles and trucks operating on a cooperative highway,” *SAE Transactions*, vol. 98, pp. 1308–1315, 1989.

[20] R. A. Zitar, L. Abualigah, F. Barbaresco, and A. E. Seghrouchni, “Modified arithmetic optimization algorithm for drones measurements and tracks assignment problem,” *Neural Computing and Applications*, vol. 35, pp. 10421–10447, 2023.

[21] D. Izci and S. Ekinci, “An efficient FOPID controller design for vehicle cruise control system using HHO algorithm,” in 2021 *3rd Int. Cong. on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, Ankara, Turkey, pp. 1–5, 2021.

[22] D. Izci, S. Ekinci, M. Kayri and E. Eker, “A novel enhanced metaheuristic algorithm for automobile cruise control system,” Electrica, vol. 21, no. 3, pp. 283–297, 2021

[23] E. Onieva, J. Godoy, J. Villagrá, V. Milanés and J. Pérez, “On-line learning of a fuzzy controller for a precise vehicle cruise control system,” Expert

Systems with Applications, vol. 40, no. 4, pp. 1046–1053, 2013.

[24] D. Izci, S. Ekinci, M. Kayri, and E. Eker, “A novel improved arithmetic optimization algorithm for optimal design of PID controlled and Bode’s ideal transfer function based automobile cruise control system,” Evolving Systems, vol. 13, no. 3, pp. 453–468, 2022.