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Optimal Design of Pid-Controller For Adaptive Cruise Control Using Differencial Evolution

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ABSTRACT: *This thesis presents an Adaptive Cruise Control (ACC) system which is an automotive feature that allows drivers to maintain preset speed while the system automatically monitors the traffic patterns and adjust the closing distance by acting on the throttle and the brakes to maintain a safe distance behind the vehicle ahead. It employs radar to measure the distance from the ACC vehicle to the vehicle in front and its speed relative to the ACC vehicle. The controller used is Proportional, Integral and Differential (PID) and tuned using Differential Evolution (DE) scheme which is used to choose the correct actuator for the current driving situation. The structure combines the speed control model and an additional control loop that is charged of verifying some safety and comfort constraints while the latter is charged with assuring a good tracking of the desired reference inter-vehicle distance. The system performance during Speed Control (Cruise Control), Following Distance Control (Headway Control) and Stop-and-Go situation on all road grades and for all speed ranges has been satisfactory and the proposed controller yields favourable overshoot, rise time and settling time as compared to similar works. The average safe stoppage distance behind a stationary object is 2 m.*

Keywords: *Adaptive Cruise Control, Differential Evolution, PID Controller, Optimal control.*

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I. INTRODUCTION

The rate of road accidents today, the world over is quite alarming that in every minute on the average at least one person dies in a crash; [1]. The Postnote [2] also, reported that in UK alone, 2,946 people were killed and 245,000 injured in road accidents in 2007. The scenario is not quite different in Nigeria as reported by [3] in which the World Health Organisation (WHO) reported in 2008 that Nigeria recorded the highest number of deaths through auto crash in the world. With this statistics, colossal amount of money is lost globally in terms of hospital bills, damaged property, and other costs; not to talk of the losses that matter most which we cannot put monetary value on; lives.

In an effort to reduce loss of lives by auto crash, automakers introduced air bags, seat belts and with the use of supercomputers they created car frames and bodies that protect the people inside by absorbing as much of the energy of a crash as possible. But, the ultimate, solution and the only one that will save far more lives, limbs and money is to keep cars from smashing into each other in the first place and this is exactly what this paper is proposing; an extension of the conventional cruise control that allows drivers to maintain a preset speed while the system automatically monitors the traffic patterns and adjusts the closing distance by acting on the throttle and the brakes to maintain a safe distance behind the vehicle ahead. The Adaptive Cruise Control (ACC) system in this case shall work on all speeds and even in stop-and-go situation.

PID (Proportional, Integral and Derivative) control is one of the earlier control strategies. Its early implementation was in pneumatic devices, followed by vacuum and solid-state analogue electronics, before arriving at today's digital implementation of microprocessors [4]. It has a simple control structure which was understood by plant operators and which they found relatively easy to tune. Since many control systems using PID controllers have proved satisfactory, it still has a wide range of applications in industrial control [5].

This paper focuses mainly on the optimal design of a Differential Evolution (DE) based PID Controller for longitudinal Adaptive Cruise Control system that senses any object along its longitudinal path and cause it to automatically adapt to the traffic environment thereby adjusting its speed to a safe followed distance or decelerate to a standstill, 1.0 m to 2.0 m away from the object if it is stationary. The paper is organized as follows: In section two the adaptive cruise control system is described and the speed control model is shown, section three is the overview of the differential evolution scheme, section four is the Implementation of the DE-PID controller and section five is conclusion.

II. ADAPTIVE CRUISE CONTROL (ACC) SYSTEM

Adaptive cruise control (ACC) is also known as "active cruise control" or "intelligent cruise control"[6]. ACC uses a forward-looking sensor, usually radar or laser, to monitor the distance to leading vehicles [1],[7]. If the system is active and the time gap to the leading vehicle falls below a certain threshold, the vehicle will automatically brake in order to maintain safe distance between it and the lead vehicle [8]. In cases where there are government restrictions, which limit the permitted braking rate as such audible warning devices are included to alert the driver if a higher deceleration is required to avoid colliding with the leading vehicle otherwise, if there is no vehicle in front, ACC operates in the same way as cruise control [9].

3. Model of the ACC Control System

The dynamics of an automobile are given by equations (1) and (2); [10].

$$\dot{V}(t)=\frac{1}{m}\left(-A_r V^2(t)-(d+mg\sin\theta)+F(t)\right)$$

...(1)

$$\dot{F}(t)=\frac{1}{\tau}\left(-F(t)+u(t)\right)$$

...(2)

Where u = the control input (if u > 0, it represents a throttle input but if u < 0, it represents a brake input)
V = Vehicle speed
$F(t)$ = Instantaneous value of the driving/braking force
m_c = Mass of the vehicle
A_r = Aerodynamic drag constant
d = Constant frictional force
τ = Engine/Brake Time Constant.
mg$sin\theta$ = Weight of the automobile
From equations (1) and (2) the automobile transfer function is given by equation (3)

$$\frac{V(s)}{U(s)}=\frac{\frac{1}{m\tau}}{s^2+s\left(\frac{1}{\tau}+\frac{2}{m}\sqrt{A_r\left(y_0-(d+mg\sin\theta)\right)}\right)+\frac{2}{m\tau}\sqrt{A_r\left(y_0-(d+mg\sin\theta)\right)}}$$

... (3)

Equation (3) conforms to the standard second order dynamics given by equation (4).

$$G(s)=\frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$$

... (4)

Where: ξ is the damping factor, ω_n is the natural frequency

So, comparing equations (3) and (4) gives:

$$\xi=\frac{\tau+m}{2\sqrt{\tau m}}$$

... (5)

$$\omega_n=\frac{1}{\sqrt{m\tau}}$$

... (6)

3.1 The DE-PID Controller

Differential Evolution (DE) is an optimization algorithm that in this case is employ to optimally tune the PID Controller. Turning a PID Controller means setting the Proportional, Integral and Derivative values to get the best possible control for a particular process which means adjusting the controller gains to satisfy the performance specification like margins of stability, transient response and bandwidth; [11]. The DE is used to compute the gain that can minimize the performance index which is a function of the system error, e(t) [12]. The commonly employed performance indices are the IAE, ISE, and ITSE performance criterion which formulas are as follows; [13]:

$$IAE = \int_0^\infty |r(t) - y(t)|$$

$$= \int_0^\infty |e(t)|dt \qquad \ldots(7)$$

$$ISE = \int_0^\infty e^2(t)dt \qquad \ldots(8)$$

$$ITSE = \int_0^\infty t.e^2(t)dt \qquad \ldots(9)$$

3.2 The Differencial Evolution (DE) Scheme

Differential Evolution (DE) is a novel parallel direct search method which utilizes NP parameter vectors, $X_{i,\ G}$, i = 0, 1, 2, ..., NP-1 as a population for each generation G. NP doesn't change during the minimization process. The initial population is chosen randomly if nothing is known about the system [5]. A uniform probability distribution was assumed for all random decisions unless otherwise stated. In case, a preliminary solution is available, adding normally distributed random deviations to the nominal solution $X_{nom,\ 0}$, often generates the initial population. The crucial idea behind DE is a new scheme for generating trial parameter vectors. DE generates new parameter vectors by adding the weighted difference vector between two population members to a third member. If the resulting vector yields a lower objective function value than a predetermined population member, the newly generated vector replaces the vector with which it was compared. The comparison vector can, but need not be part of the generation process mentioned above. In addition, the best parameter vector $X_{best,\ G}$ is evaluated for every generation G in order to keep track of the progress that is made during the minimization process [5]. The flowchart of the DE-PID control system is shown in Fig. 1.

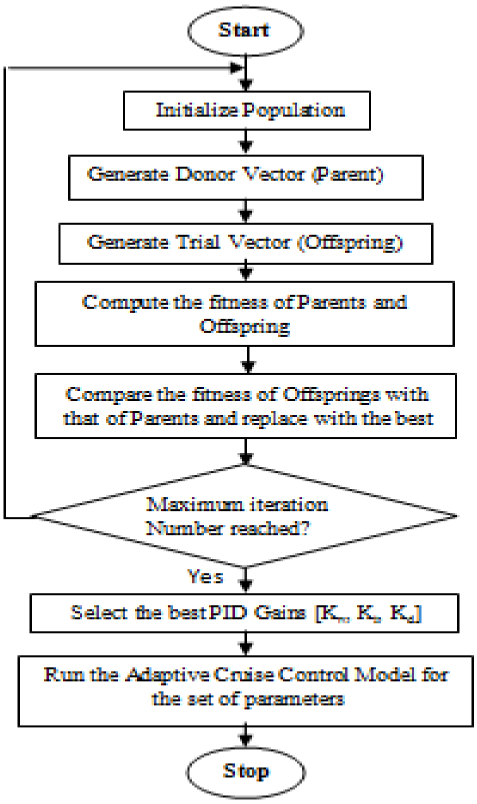


Figure 1 The flowchart of the DE-PID

3.3 Control Objectives

- To minimize the error.
- To calculate the step response of the system and out of which the error is estimated.
- The iterations are run till the error minimizes.

III. SIMULATION RESULTS AND DISCUSSION

Table 1: Definition of Simulation Parameters

Parameter	Description
M_c	Mass of Vehicle
θ	Road Slope Angle
d	Road Frictional Force
A_r	Aerodynamic Drag of Surrounding Air

Table 2: Road Grade and Simulation Conditions Settings

Condition	M_c (Kg)	θ (°)	d (N)	A_r
Flat Road	-	0	-	-
Normal Road	-	-	≤ 100	-
Hilly Road	-	30	-	-
Sloppy Road	-	-30	-	-
Rough Road	-	-	> 100	-
Loaded Vehicle	> 1000	-	-	-
Windy Environment	-	-	-	> 10
Worst Scenario	> 1000	30	> 100	> 10
Smooth Road	-	-	< 50	-

Table 3: Research Constraints

Overshoot (%)	Rise Time (T_r) (s)	Settling Time (T_s) (s)
0.1 – 4.0	≤ 1.5	≤ 5.0

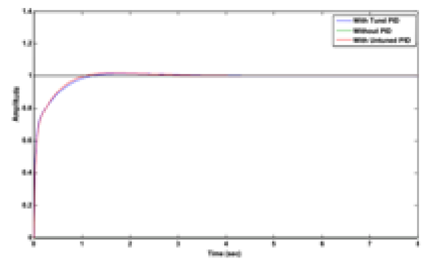


Figure 2. system step response

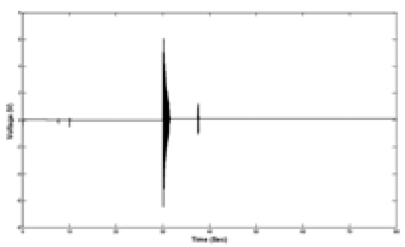


Figure 5. PID signal under ACC

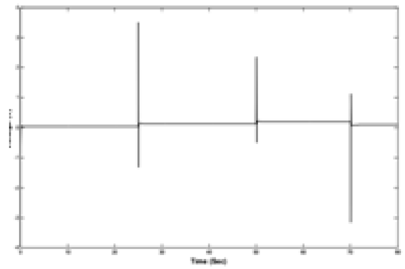


Figure 3. control signal

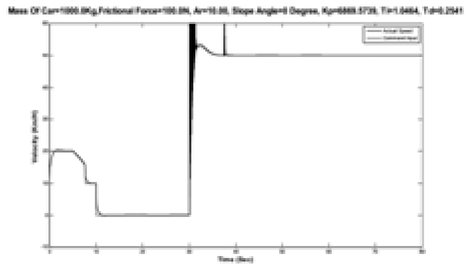


Figure 6. automated car speed with tuned PID

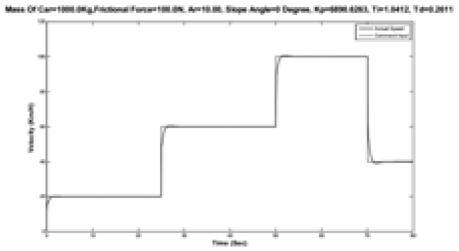


Figure 4. automated car speed with tuned PID'

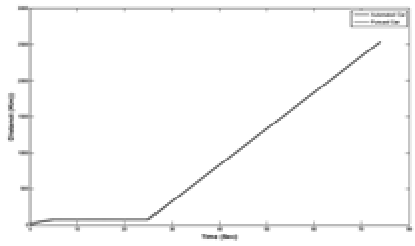
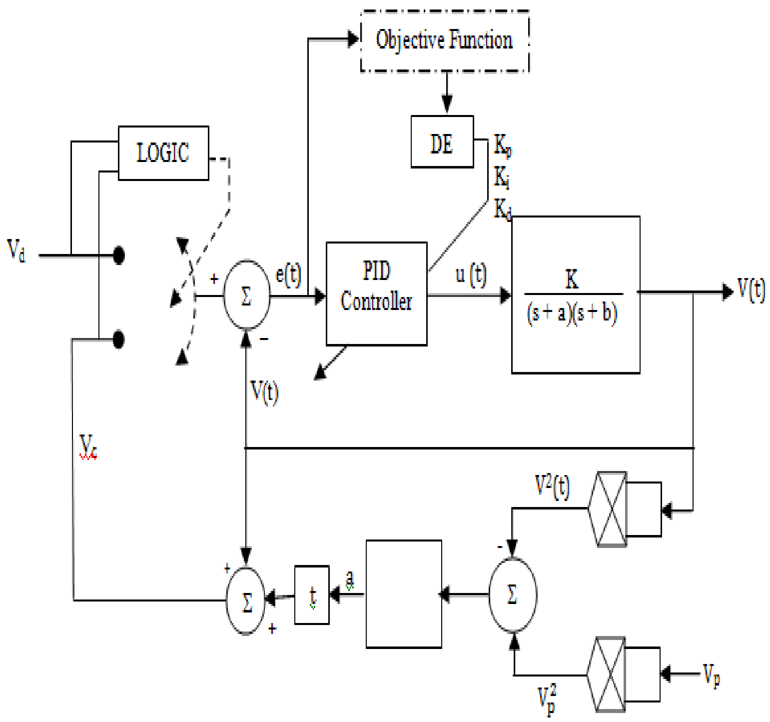


Figure 7. distance covered

Figure11. relative velocity

The generalized control structure for ACC is as shown in Fig. 12



TABLES 1, 2 and 3 provides definition of Simulation Parameters, Road Grade and Simulation Conditions Settings and Research Constraints respectively.
The system performance for all road grade, vehicle condition and environmental conditions settings as shown in TABLE 2 is very good with a rise time (t_r) of 0.5s, maximum overshoot of 1.46% and a settling time of 0.94s which are within the research constraints as shown in TABLE 3. The PID-Controller effective performance is demonstrated by the almost zero response to command input as depicted by Fig. 2. Figs. 3 and 5 are the PID control signal plot that modulates the vehicle throttle and braking system under Cruise Control (CC) and Adaptive Cruise Control (ACC) scenarios respectively while Fig. 4 reveals the speed control (Cruise Control) ability of this research work and the system performance (Speed Control) over different speed ranges.
Fig. 6 depicts the system under Followed Distance Control i.e. ACC as the speed response of the system no longer follows the command signal due to the presence of a lead vehicle, but adjust itself in such a way as to attend a speed that will allow a safe distance between them, while Fig 7 shows the distance covered by both the automated and the lead vehicle with a varying constant time gap between them depending on the speed. The appearance of the lead vehicle curve on top of the automated car curve throughout the simulation period indicates that it is a “Followed Distance control scenario” and the apparent parallel nature of the curves further demonstrates a strict ‘Headway Control’. The inter-vehicle space plot of Fig. 8 gives the safe distance between the vehicles at any point in time therefore, ACC is a welcome additional vehicle system that will add comfort and convenience to the driver in addition to its safety tendencies [8],[14].
The velocity plot of Fig 9 depicts the capability of this system to work in a stop-and-go situation as at t=0 to t=5s the automated car was pursuing the lead car and after this time the lead car came to a standstill (v_p=0) therefore, the automated car decelerated to a standstill (v(t)=0) about 2m away from the stationary lead car they remain like that for about 8s when the lead car started moving, the automated car followed and as well as tracking it for headway control. Figs. 7 and 8 further supported the capability of the system to work in stop-and-go situation. [15] Demonstrates this capability but with a poor rise time. Fig. 10 illustrates the acceleration and deceleration capabilities of the system due to the presence of a lead vehicle. At t=0 the automated vehicle noticed a stationary vehicle ahead (V_p = 0), so it started retarding to a standstill some few metres away, but at t=25s the lead vehicle speed jumped to some positive value, hence the automated vehicle automatically accelerates and later decelerates so as to track the lead vehicle in order to maintain a safe distance between them. Fig. 11 shows the relative speed of the system thereby further emphasizing the ‘stop-and-go’ capability of this research work.

IV. CONCLUSION

This research work presents a PID based control approach for automotive longitudinal adaptive control. The structure is charged with both verifying some safety and comfort constraints and assuring a good tracking of the desired reference inter-vehicle distance. The simulated results depicts that the system exhibits capabilities of Cruise Control, Following Distance Control for all speed ranges and it also shows a good performance in Stop-and-Go scenario. The results further show that the system is doing well on all road grades i.e. Rough, Smooth, Hilly, Sloppy and Windy. A safe inter-vehicle space distance of about one car length is achieved.

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