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МОДЕЛИРОВАНИЕ АДАПТИВНОГО КРУИЗ-КОНТРОЛЯ ЭЛЕКТРОМОБИЛЯ

MODELING OF ADAPTIVE CRUISE CONTROL ON ELECTRIC VEHICLE

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Современным трендом в мировом автомобилестроении является оснащение транспортных средств, и в первую очередь электромобилей, высокотехнологичными интеллектуальными системами помощи водителю для обеспечения безопасности дорожного движения и повышения энергоэффективности в процессе эксплуатации. Одной из таких систем является адаптивная система автоматического поддержания скорости или, так называемый, адаптивный круиз-контроль (АКК), который автономно контролирует заданную водителем скорость движения и поддерживает безопасное расстояние до впереди идущего транспортного средства. В статье рассматривается моделирование системы АКК переднеприводного легкового электромобиля VFe34 с использованием на *программном уровне субмодели контроллера превентивного управления (ПУ-контроллер). Динамическая модель электромобиля, представленная дифференциальными уравнениями, выступает в качестве объекта управления для виртуального контроллера АКК. На основе заранее заданного безопасного и фактического расстояния до впереди идущего автомобиля, желаемой и текущей линейной скорости транспортного средства ПУ-контроллер рассчитывает параметры управления для системы АКК, которая в свою очередь, взаимодействуя с электронными блоками управления тяговым электроприводом и антиблокировочной системой тормозов, формирует управляющие воздействия на модуляторы АБС или инвертор асинхронного электродвигателя привода ведущих колес. Отработка алгоритма управления скоростным режимом электромобиля с учетом фактического расстояния до впереди идущего автомобиля осуществлялась на виртуальном маршруте, имитирующем сценарий движения по типовой скоростной автомагистрали. Результаты исследования подтверждают высокую эффективность системы АКК при управлении автомобилем в автономном режиме, обеспечивающей заданные водителем скоростные параметры движения и соблюдение правил дорожной безопасности.*

The modern trend in the global automotive industry is to equip vehicles, and primarily an electric vehicles (EVs), with Advanced Driver Assistance Systems (ADAS) to ensure traffic safety and enhance energy efficiency during operation. One notable system among these is the Adaptive Cruise Control (ACC), which autonomously controls the vehicle's speed set by the driver and maintains a safe distance from the preceding vehicle. This paper focuses on modeling the ACC system of front-wheel drive passenger electric vehicle VFe34 with using the Model Predictive Controller (MPC) at the software level. The EV's dynamic model, represented by differential equations, is presented as the object for the virtual ACC controller. Based on the preset safe and actual distance to the vehicle in front, the driver desired and current vehicle velocity, the MPC controller calculates the control parameters for the ACC system, which in turn, interacting with the ECU of the electric traction drive and anti-lock brake system, generates control actions to ABS modulators or asynchronous electric motor inverter of the driving wheels. Control algorithm testing of the EV speed mode, taking into account the actual distance to the car in front, was carried out on a virtual route simulating a *driving scenario on a typical highway. The results demonstrate that the ACC system effectively controls in autonomous mode the host vehicle, adhering to driver desired parameters and road safety regulations.*

***Ключевые слова**: электромобиль, интеллектуальная система помощи водителю, адаптивный круиз-контроль, контроллер превентивного управления, имитационное моделирование.*

***Keywords**: electric vehicle, advanced driver assistance system, adaptive cruise control, model predictive controller, simulation.*

INTRODUCTION

Control techniques play an important role in the application of ACC systems to electric vehicles. In the study [1], a fractional step-reference adaptive controller in the ACC system on electric vehicles is introduced. On the other hand, Toroman et al. [2] used the PID-controller to build a model of the car ACC system. Meanwhile, Xu et al. [3] presented an adaptive cruise control strategy based on the Hierarchical Framework. However, a significant portion of ACC research using the MPC framework does not consider vehicle dynamics, which most influence on vehicle's energy efficiency. This paper addresses this gap by developing an MPC algorithm, focusing on the design of the control algorithm through the modeling of the control system. In establishing a simulation scenario on the highway, the behavior of the preceding vehicle is also delineated using a similar vehicle model, incorporating acceleration changes to enhance the realism of the scenario.

The first section of this paper focuses on building EV models, which include vehicle longitudinal dynamics submodels, electric motor submodels, wheel submodels, braking and driving models. Then applying the MPC, the second section builds the ACC model. Subsequently, simulation is conducted under highway conditions to explore the interdependencies among acceleration, velocity, and the gap between the host vehicle and the lead vehicle. The outcomes of these simulations form the basis for assessing the efficacy of the ACC system in electric vehicles and its practical suitability in real-world scenarios.

METHODOLOGY

The methodology employed in this research involves a simulation-based approach, wherein the model is segmented into three key components: ACC model, driving model, and longitudinal dynamics model (fig. 1). The research object used in the article is the VFe34 electric vehicle.

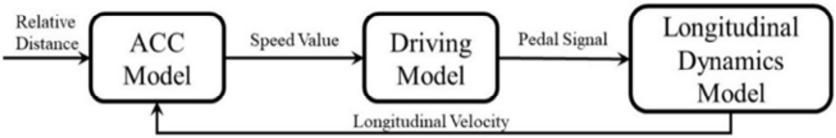

Figure 1 – Interaction diagram of EV’s model key components

The study constructs a representation of the ACC model, integrating MPC methodology. This model is designed to regulate the vehicle's speed effectively and maintain a safe following distance from the lead vehicle.

The driving model links the ACC and longitudinal dynamics models, capturing the interplay between the control system and the vehicle's response. It incorporates the ACC input and transforms it into commands that govern the pedal’s signals.

ELECTRIC VEHICLE MODELING

Based on prior research in electric vehicles [4, 5], the paper presents the methodology for constructing a dynamic model of a front-wheel-drive electric vehicle based on the vehicle's dynamic equations.

Vehicle Longitudinal Dynamics Submodel. From [4–5], the longitudinal dynamics of the vehicle is given by:

$$(m+m_e)\cdot\dot{V}=(F_{xf}+F_{xr})-(F_{rf}+F_{rr}+F_{r\_air}+F_{hc}), \tag{1}$$

where

$$m_e=\frac{1}{r_{wh}^2}\left(J_{fwh}+J_{fd}+J_{gb}\cdot i_{fd}^2+J_m\cdot u_{gb}^2\cdot i_{fd}^2\right). \tag{2}$$

The parameters represented in (1) and (2) are: m and m_e represent the vehicle mass and rotating parts mass refers to the wheel, F_{xf} and F_{xr} is the front wheels and rear wheels traction or brake force (fig. 2), F_{hc} is the slope resistance with slope angle α, F_{rf} and F_{rr} are rolling resistance at front wheels and rear wheels respectively, F_{r_air} is aerodynamic drag. J_{fwh} is the inertia moment of the front wheel, J_{fd} is the inertia moment of the powertrain and the inertia moment of the rotating axle, J_{gb} is the inertia moment of the gearbox, J_m is the moment of inertia of the motor and u_{gb} is the total powertrain gear ratio.

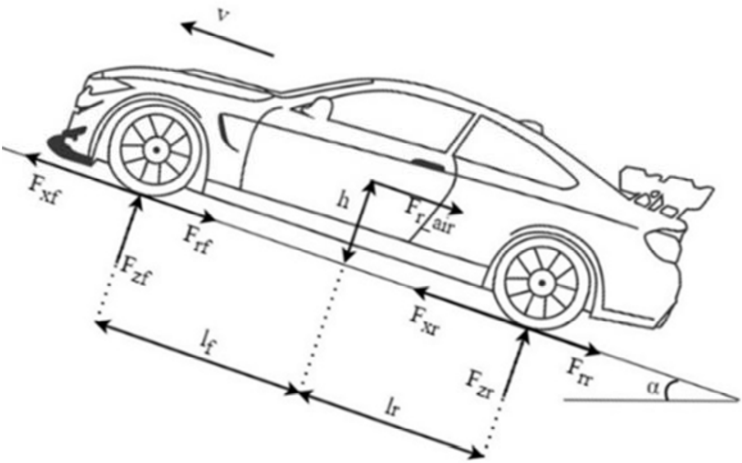

Figure 2 – Forces exerted on the vehicle

The other subsystems of the EV were followed by the references [6–7].

ADAPTIVE CRUISE CONTROL MODELING

Adaptive Cruise Control System (ACC). An ACC system is a methodical approach to automatically adjusting controllers in real time to maintain desired control performance levels when dynamic process model parameters are unknown or change over time [8]. Based on fig. 3, this paper considers two entities: the host vehicle equipped with an ACC system and the lead vehicle, which is the vehicle in the same lane positioned in front of the host vehicle, with the relative distance between them (d_relative).

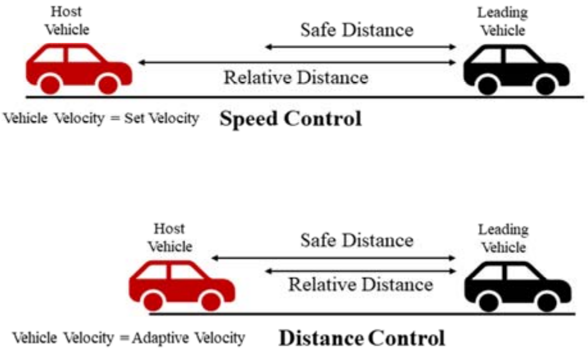

Figure 3 – Working principle diagram of ACC System

When the ACC system is activated, the driver sets the desired speed (v_set). Based on the d_relative data, the ACC system operates in two modes as follows:

– speed Control Mode: the host vehicle travels at a constant speed v_set;

– distance Control Mode: the host vehicle adjusts acceleration and deceleration to sustain a safe gap (d_safe) and relative velocity (v_relative) with the lead vehicle.

The ACC system automatically switches between these two modes based on the following conditions:

– if $d\_relative \geq d\_safe$, the speed control mode is activated. The control objective is to follow the driver-set velocity, $v\_host = v\_set$ with v_host the host vehicle velocity.

– if $d\_relative < d\_safe$, then the distance control mode is engaged. The control objective is to uphold the safe distance, $d\_relative = d\_safe$.

Model Predictive Control. Model Predictive Control operates by forecasting future system actions using a predictive model and the current system state at each sampling moment [9–11]. It employs a feedback scheme to optimize forecasting errors and corrects prediction model inaccuracies based on system output. By solving an online optimization problem, MPC determines an optimal control sequence, with the initial value applied to regulate the system. The process repeats as the control horizon advances. MPC is suitable for systems with multiple inputs, multiple outputs, and potential interactions, allowing constraints on inputs and outputs. Using the ACC system's longitudinal dynamics model [10], the predictive state can be calculated as follows:

$$\hat{X}_p \cdot (t+p\,|\,t) = \overline{C_0} \cdot x(t) + \overline{C_1} \cdot \tilde{c} \cdot (t+c_h) + \overline{C_2} \cdot \tilde{a}_l \cdot (t+p) \qquad (3)$$

$$\hat{Y}_p \cdot (t+p\,|\,t) = \overline{C_3} \cdot x(t) + \overline{C_5} \cdot \tilde{c}(t+c_h) + \overline{C_6} \cdot \tilde{a}_l(t+p) - \overline{C_4} \qquad (4)$$

where $\hat{X}_p \cdot (t+p\,|\,t)$ and $\hat{Y}_p \cdot (t+p\,|\,t)$ represents the predicted state and output vectors calculated at the time step t until the end of the prediction horizon p, c_h denotes the control horizon, $x(t)$ refers to the scaled state at the sampling moment *t*, the calculated control sequence denotes as $\tilde{c} \cdot (t+c_h)$, $\tilde{a}_l$ denotes the acceleration of the preceding vehicle of sampling moment $t-1$, but is measured at the current sampling moment *t*. The limitation of accleration and deceleration control was 2 m/s^2 and –2 m/s^2.

SIMULATION RESULTS

With the input variable being the acceleration of the lead vehicle (a_lead), constructed under the scenario of highway traffic with a cycle time of 80 seconds, this paper provides simulation results of the system based on the execution of the developed models. Overall, the graphs illustrate the stable operation of the ACC System, satisfying safety regulations regarding the distance between two vehicles while moving on the highway.

The speed of the vehicles in the simulation is around 60–90 km/h in highway conditions, so to ensure a safe following distance according to the Safety Distance Regulations [12], the driver needs to maintain a minimum distance of 35 meters with the frontal vehicle.

The relevant input parameters [13] used in the simulation model are listed in table 1.

When the speed of the lead vehicle surpasses the driver-set speed, the host vehicle transitions to the speed maintenance mode, as depicted in fig. 4. As the speed of the lead car decreases below the driver-set speed, the relative speed between the two vehicles remains less than 2 m/s, and the spacing error approaches 0 m, as illustrated in fig. 5 and fig. 6.

Table 1 – Input simulation parameters

Symbol	Value	Symbol	Value	Symbol	Value
m	1558 kg	J_m	0,01 kg.m^2	v_set	26 m/s
J_{fwh}	1,63 kg.m^2	u_{gb}	2,84	l_f	1,07 m
J_{fd}	0,07 kg.m^2	J_{gb}	0.0196 kg.m^2	l_r	1,54 m

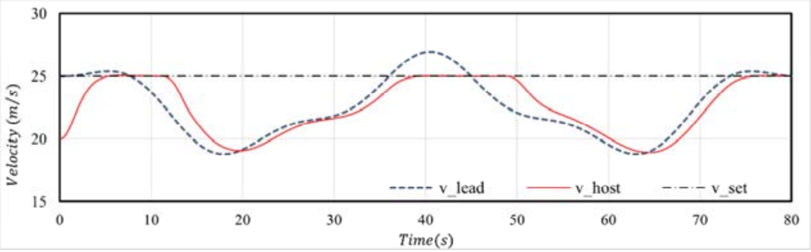

Figure 4 – Velocity graph of the investigated vehicles

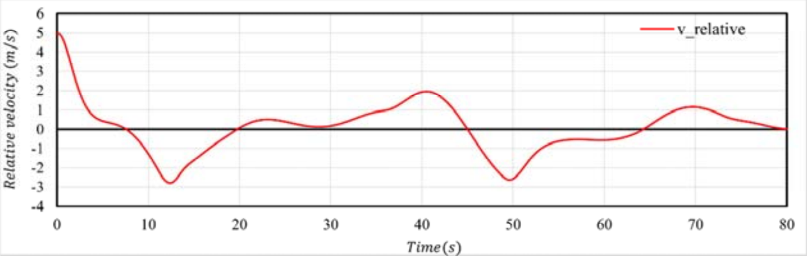

Figure 5 – Relative velocity of the two vehicles

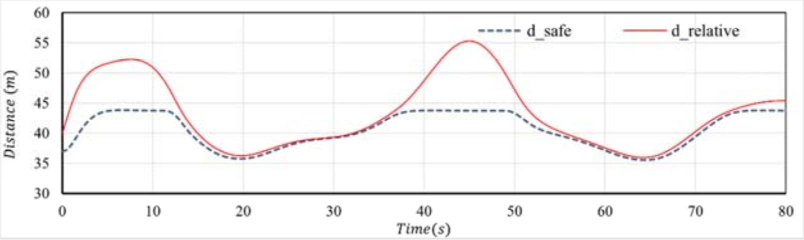

Figure 6 – Relative distance and safe distance between two vehicles

As shown in fig. 6, the relative distance between the two vehicles is consistently greater than the safe distance, ensuring the prevention of accidents while driving. Simulation results also demonstrate that the control system ensures the host vehicle consistently adheres to the driver-set velocity.

CONCLUSION

This paper presents the modeling of an ACC model for electric vehicles using MPC. With an input speed range for the lead vehicle between 19 m/s and 27 m/s and an acceleration varying from –0.9 m/s² to 0.9 m/s², simulation results under highway conditions demonstrate that the velocity and acceleration of the host vehicle consistently closely follow those of the lead vehicle. Simultaneously, the safe distance and the distance based on speed remain within the appropriate values as stipulated by regulations. The highway test scenario we have applied also demonstrates the effectiveness of the system in improving safety. Simulation results indicate that the system responds well to changes in driving conditions and it additionally demonstrates that the ACC system can reduce the number and impact of accidents by controlling the actual distance between vehicles.

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