

Vehicle Adaptive Cruise Controller Based on an Optimal Super-twisting Sliding Mode Control

Lhoussain El Hajjami
Laboratory of Artificial Intelligence, Data
Sciences and Emerging Systems (IASSE)
Sidi Mohamed Ben Abdellah University
Fez, Morocco
lhousain.elhajjami@usmba.ac.ma

El Mehdi Mellouli
Laboratory of Engineering, Systems and
Applications (LISA)
Sidi Mohamed Ben Abdellah University
Fez, Morocco
mellouli_elmehdi@hotmail.com

Vidas Žuraulis
Dept of Automobile Engineering
Vilnius Gediminas Technical University
Vilnius, Lithuania
vidas.zuraulis@vilniustech.lt

Mohammed Berrada
Laboratory of Artificial Intelligence, Data
Sciences and Emerging Systems (IASSE)
Sidi Mohamed Ben Abdellah University
Fez, Morocco
mohammed.berrada@gmail.com

Abstract— This paper provides a new optimal adaptive cruise controller (ACC) for regulating the distance inter-vehicles. The proposed approach is based on a super-twisting sliding mode control. The Butterfly Optimization Algorithm (BOA) was applied to identify the controller optimal parameters. The effectiveness of the proposed methodology is examined through a speed scenario frequently encountered on the roads. The suggested control structure offers a high tracking accuracy.

Keywords—Autonomous vehicles, ACC, Optimization, BOA Algorithm, Super-twisting SMC, longitudinal control.

I. INTRODUCTION

A. Context and Background

The report of the second quarter of 2020 (Q2) published by the United States Highway Traffic Safety Administration reveals that the fatality rate during Q2 was 1.42 fatalities per 100 million vehicle miles traveled[1]. As well in 2019, the 27 European Union member states are recorded almost 22 800 road traffic fatalities[2]. Besides, it is estimated that 90% of all automobile accidents are a result of human error, whereas only 2% are due to car failures. Moreover, with the ever-increasing road traffic problems like pollution, congestion, and road security are critical issues. Autonomous vehicles, also called ego vehicles [3], have received significant attention as a potential solution to these issues[4].

Since DARPA's Grand-Challenges, autonomous-ground vehicle (AGV) technology has become progressively mature[5]. Aside from the academic challenge, automakers have launched over the challenge among themselves, which has pushed this technology towards exponential development. This has resulted in the implementation of several advanced-Driver-Assistance-Systems (ADAS) from Adaptive-Cruise-Control (ACC) to the Robot-Taxi. These systems reflect the advances made at the AGV control unit that encompasses longitudinal and lateral control, which are in charge of adjusting the speed and ensuring the car's lateral-stability according to the road conditions.

In this respect, various control procedures are applied, in order to satisfy the lateral stability and avoid collision

inter-vehicles, such as Proportional-Integral-Derivative control (PID) [6], Model-Predictive Control (MPC) [7], Sliding-Mode Control[8], Backstepping, H_∞ control, fuzzy control, adaptive-control and Linear-quadratic-Regulator control (LQR) [9], super-twisting SMC [10], and others.

On the other hand, the optimal control strategy obsession is taken into account in several methods by taking advantage of intelligent algorithms to design an optimal controller such as the H_∞ optimized by type-2 fuzzy method [11], the PID optimization by PSO, GA, ABC, and BOA [6], the Backstepping and SMC optimization by PSO, ABC, and ACO [12], [13].

B. Related Works

Lateral and longitudinal control represent the main elements of ego vehicle control. The first one is in charge of providing lateral guidance in stable mode. While the second one is in charge of controlling longitudinal speed, acceleration rate, in other words, the longitudinal position of any other vehicle in the front lane[14], [15]. In this connection, various control processes are suggested to improve the longitudinal control unit. In reference [16], a longitudinal-control approach utilizing an Adaptive-Cruise-Control (ACC) system is developed. The ACC generates a speed control according to desired safe distance utilizing the information about the following path, taking into account the vehicle current-speed and acting resistance forces and the command speed, the required wheel-torque is calculated. The ACC system has been experimentally tested. The authors of [17] addressed the trajectory-tracking problem by proposing a PID speed-controller based on MPC to manage a longitudinal and lateral control coupled structure. In reference[18], an optimal linear-quadratic-control supports the design of an algorithm able to regulate the speed and distance of the vehicle. A non-linear dynamical approach of longitudinal-vehicle-full-speed-cruise-system (LFS) is proposed in[19] by incorporating inter-vehicle dynamics and the commanded vehicle. The LFS includes a robust perturbation decoupling control methodology for non-linearity, extraneous perturbations, and uncertainties. For the longitudinal control purposes, the[20] evokes that incorporating the features of ACC and collision-avoidance (CA) systems into a unique control system, not only decreased the vehicle deceleration effect but also deteriorated

driving safety in the event of an emergency situation. In the same sense, a control approach merging the ACC, CA, and driver behavior is applied in [21] to increase the comfort and adaptability of the drivers. Such a strategy has been verified through virtual experiments. In reference [22], an au-adaptive PID based on radial-basis-function neural-networks(RBFNN) methodology has been developed to enhance the accuracy of longitudinal velocity control for ego vehicles. Using the car dynamic model, driver model, and the auto-adaptive PID-RBFNN a longitudinal speed controller is developed. [23], [24] investigate the development of a longitudinal control algorithm related to spacing Platoon Of Vehicles. Also, the sliding-mode procedure (SMC) is largely exploited for longitudinal-control goals. In reference [25], an ACC system is provided for the control of a hybrid-electric-vehicle. An innovative adaptive structure that combines the sliding mode and fuzzy logic, taking into account external disturbances and non-linearities, is defined by [26] to manage the lateral and longitudinal motions of a platoon of stand-alone vehicles. The authors of [27] present a non-singular-terminal SMC method incorporated with the RBFNN algorithm in order to offer a precise and coherent acceleration follow-up control of the car's longitudinal velocity. Lyapunov-based controller is suggested in [28] to control lateral and longitudinal dynamics. The controller determines the drive/braking torque required to reach a certain desired velocity.

On the other hand, the conception of an optimized control system has become a real challenge for researchers. In this respect, many algorithms are used to get the optimal setting of the controllers, among them the metaheuristic-algorithms. The particle-swarm-optimization (PSO), genetic-algorithm (GA), ant colony-optimization(ACO), are extensively utilized either for lateral or longitudinal control [12], [29]–[32]. In this framework, new metaheuristic-algorithms have been introduced in the literature for instance butterfly-optimization-algorithm (BOA)[6], [33], [34].

C. Contribution & Organization

Motivated by the aforementioned points, this article exhibits a novel optimal longitudinal-control technique aimed at controlling the speed of autonomous vehicles.

The manuscript major contributions are:

- i. A fully modeling of the vehicle longitudinal dynamics.
- ii. Proposal of an adaptative cruise control (ACC) structure-based super-twisting sliding mode control.
- iii. Control optimization by a new met-heuristic algorithm.

The content of this paper is structured as follows: In Section 2, the vehicle longitudinal model is given; Section 3 discusses the proposed approaches. The simulation results are given in Section 4; Section 5 closes the manuscript.

II. LONGITUDINAL VEHICLE-DYNAMICS

When the vehicle is moving on the road, it is subjected to the following external longitudinal forces: longitudinal tire-forces, aerodynamic drag-forces, gravitational forces, and rolling resistance-forces, see Fig.1 [14], [35].

A. Full Longitudinal Model

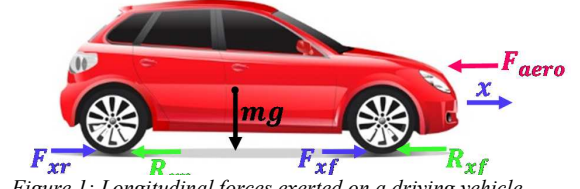


Figure 1: Longitudinal forces exerted on a driving vehicle

The equilibrium of forces along the longitudinal axis of the vehicle results in:

$$m\ddot{x} = F_{xf} + F_{xr} - F_{aero} - R_{xf} - R_{xr} - mgsin(\alpha) \quad (1)$$

Where :

F_{xf} and F_{xr} : are the longitudinal-forces resulting from tire/road contact for the front and rear tires respectively.

F_{aero} : is the longitudinal aerodynamic-drag-force.

R_{xf} and R_{xr} : are the force resulting from the rolling resistance of the front and rear tires respectively.

m : is the vehicle mass.

g : is the acceleration caused by gravity.

α : is the road inclination angle.

1) Longitudinal aerodynamic-drag-force :

The aerodynamic drag force is modeled by the following expression[14]:

$$F_{aero} = \frac{1}{2}\rho C_{ad}A_f(v_w \pm v_x)^2 \quad (2)$$

Where :

ρ is the air density, C_{ad} is coefficient of aerodynamic-drag, A_f is the vehicle front surface, v_w is the wind speed, and v_x is the vehicle longitudinal-speed.

2) Longitudinal tire-forces

Either empirical or semi-empirical studies have concluded that longitudinal-forces are a function of slip-ratio, normal load (i.e. vertical forces F_{zf}/F_{zr}), and friction-coefficient.

Various models of longitudinal-forces, F_{xf} and F_{xr} , are provided in the literature among them linear-model Pacejka, and Dugoff[14], [35]. In this work, the linear model is adopted.

The linear representation of the longitudinal-forces is expressed as:

$$F_{xf} = C_{xf}\sigma_{xf} \quad (3)$$

$$F_{xr} = C_{xr}\sigma_{xr} \quad (4)$$

Where :

C_{xf} and C_{xr} are the front and rear longitudinal tire-stiffness respectively.

σ_{xf} and σ_{xr} are the front and rear longitudinal slip-ratio respectively.

3) Rolling Resistance

In general, rolling resistance is expressed as approximately proportionate to the vertical force exerted on each tire [14].

$$R_{xf} = f(F_{zf}, r_{sat}, v_x) \quad (5)$$

$$R_{xr} = f(F_{zr}, r_{sat}, v_x) \quad (6)$$

Where:

F_{zf} and F_{zr} are the vertical forces.

r_{sat} is the tire statically loaded radius.

B. Simplified Longitudinal-Model

For the aims of synthesizing the controllers, the bicycle model, which presents a simplified version of the 4 wheels model, is often used (see Fig. 2).

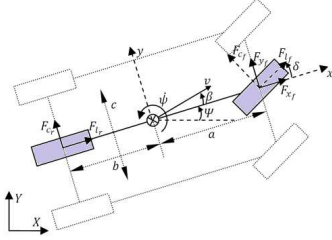


Figure 2: Bicycle model

By consideration, only, of the vehicle front wheel. The equation (1) that expresses total longitudinal-forces exerted on the vehicle CoG becomes [36]:

$$m\dot{v}_x = F_{xf} - F_{aero} - R_{xf} - mgsin(\alpha) \quad (7)$$

Where F_{xf} , F_{aero} , and R_{xf} are given by:

$$F_{aero} = \frac{1}{2} \rho C_{ad} v_x^2$$

$$R_{xf} = C_{re} mg \cos(\alpha)$$

C_{re} denotes rolling resistance-coefficient

The bicycle model front-wheel dynamics is expressed as [36]:

$$I_{wf} \dot{\omega}_f = -F_{xf} R_{wf} + T_p - T_b \quad (8)$$

Where :

ω_f front-wheel rotation speed

I_{wf} is the front-wheel moment of inertia

R_{wf} is the front-wheel radius

T_p , and T_b are, respectively, the propulsion torque and the braking torque T_b and

From (8) we can write :

$$F_{xf} = \frac{1}{R_{wf}} (T_p - T_b - I_{wf} \dot{\omega}_f) \quad (9)$$

Based on the hypothesis defined in [36], the equations (10), (11), and (12) are given:

$$v_x = R_{wf} \omega_f \quad (10)$$

$$\omega_f = r_g \omega_e \quad (11)$$

$$T_e = r_g T_p \quad (12)$$

Where :

r_g denotes the gearbox-ratio

ω_e is the engine speed

T_e is the engine-torque

Based on the equations (9)-(12), the equation (7), which represents the vehicle longitudinal dynamics, is written as:

$$\dot{v}_x = -\frac{R_{wf}}{mR_{wf}^2 + I_{wf}} \left(T_b + R_{wf} (F_{aero} + R_{xf} + mgsin(\alpha)) \right) + \frac{R_{wf}}{r_g(mR_{wf}^2 + I_{wf})} T_e \quad (13)$$

III. PROPOSED CONTROL STRATEGY

In this section, we implement the suggested longitudinal control approach. Firstly the system dynamic is reformulated, secondly, the controller is devolved. Lastly, the control structure is optimized.

A. Controller Design

In an attempt to overcome the issues resulting from Conventional SMC, mainly the chattering effect, the super-twisting algorithm is considered effective to surmount this undesired effect [37] [38]. In this regard, we present a longitudinal speed controller based on the super-twisting algorithm. To this end, the system (13) is expressed as follows :

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = f(x, t) + g(x, t)\tau \end{cases} \quad (14)$$

Where :

$x = [x_1 \ x_2]^T$, denotes the system state.

τ is the control input indicating the vehicle engine torque T_e .

$$f = -\frac{R_{wf}}{mR_{wf}^2 + I_{wf}} \left(T_b + R_{wf} (F_{aero} + R_{xf} + mgsin(\alpha)) \right),$$

and $g = \frac{R_{wf}}{r_g(mR_{wf}^2 + I_{wf})}$ are continuous functions.

The error and sliding variable are given by:

$$\begin{cases} \ddot{e} = \dot{v}_x - \dot{v}_{xref} = a_x - a_{xref} \\ s = \dot{e} + \eta e \end{cases} \quad (15)$$

The s time-derivative is written as:

$$\dot{s} = \Gamma(t, s) + \phi(t, s)\tau$$

Where :

$$\begin{cases} \Gamma = -\frac{R_{wf}}{mR_{wf}^2 + I_{wf}} \left(T_b + R_{wf} (F_{aero} + R_{xf} + mgsin(\alpha)) \right) - \dot{v}_{xref} + \eta \dot{e} \\ \phi = \frac{R_{wf}}{r_g(mR_{wf}^2 + I_{wf})} \end{cases}$$

τ is a superimposition of two terms an equivalent, τ_{eq} and the switching term τ_{st} as:

$$\tau = \tau_{eq} + \tau_{st} \quad (16)$$

By resolving $\dot{s} = 0$, the equivalent command τ_{eq} is calculated as:

$$\tau_{eq} = -\frac{\Gamma}{\phi} \quad (17)$$

The system should verify the requirements (18):

$$\begin{cases} |\tau| \leq \tau_{max} \\ |s| < S_0 \\ \lambda_{min} \leq |\phi| \leq \lambda_{max} \\ |\Gamma| < \mathcal{M}_0 \end{cases} \quad (18)$$

Where $S_0, \tau_{max}, \lambda_{min}, \lambda_{max}$ and $\mathcal{M}_0$ are positive constants.

The switching law is given by[39], [40]:

$$\tau_{st} = \tau_{st1} + \tau_{st2} \quad (19)$$

Where τ_{st1} , and τ_{st2} are defined as follows:

$$\begin{cases} \tau_{st1} = -\alpha_1 |s|^\xi sign(s), \ \xi \in]0, 0.5] \\ \dot{\tau}_{st2} = -\alpha_2 sign(s) \end{cases} \quad (20)$$

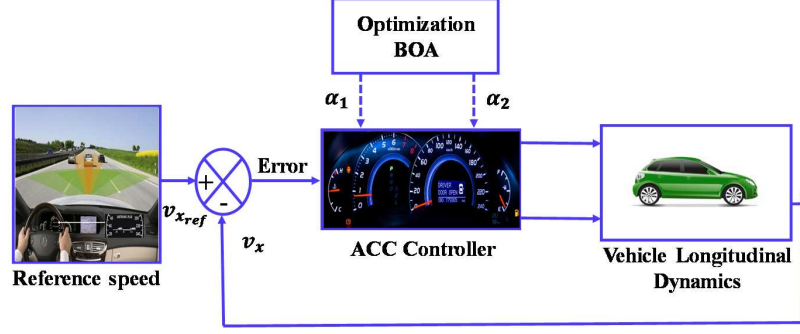


Figure 3: Proposed System Architecture Diagram

With α_1 , and α_2 should verify the requirements (21) [39], [40]

$$\begin{cases} \alpha_1 \geq \sqrt{\frac{4\mathcal{M}_0(\alpha_2\lambda_{max}+\mathcal{M}_0)}{\lambda_{min}^2(\lambda_{min}\alpha_2-\mathcal{M}_0)}} \\ \alpha_2 > \frac{\mathcal{M}_0}{\lambda_{min}} \end{cases} \quad (21)$$

Hence, the control law is given by:

$$\tau = -\frac{\gamma}{\phi} - \alpha_1 |s|^\xi \text{sign}(s) - \int \alpha_2 \text{sign}(s) dt \quad (22)$$

Inspired by the approach described in [41], which presents the super-twisting algorithm optimized by the PSO. Also based on this work [38], indicating the super-twisting control structure gains can be chosen in terms of the control performances. In this context, an optimization procedure is discussed in the next subsection.

B. Controller optimization procedure

The performance of the controller depends on its internal parameters, therefore an important effort must be invested to identify the right parameters. However, a wrong choice of these settings may take the vehicle out of its range of stability and lead to undesirable behavior. An optimization algorithm can help to reduce all these disadvantages by selecting the optimal parameters of the control structure that can improve the response quality of the controller. To this end, in this paper, we have used the Butterfly Optimization Algorithm (BOA).

This algorithm was well known for its ability to resolve global optimization issues including optimal control structure settings.

This algorithm was first proposed by [42]. BOA is part of the metaheuristics algorithms, being inspired by nature, it imitates the behavior of butterflies when looking for food. For over details about this algorithm, the reader can refer to [6], [42]. We expose above the general description of BOA [6]. The global diagram of the proposed structure is shown in Fig. 3.

IV. SIMULATION RESULTS

In this section, we present the optimization process results as well as the simulation results for a reference speed scenario that can be confrontable during normal driving in the field, using vehicle parameters given in [36].

According to the fixed value of the BOA algorithm, presented in Table 1, and after performing the whole optimization process, the optimal controller parameters and the best fitness function are shown in Table 2. The BOA convergence is plotted in Fig. 4. We point out that the objective function considered is the integral of the absolute error

$$IAE = \int_0^t |e| dt \quad (23)$$

BOA algorithm
1: The choice of the objective function $f(x)$, $x=(x_1, x_2, \dots, x_n)$, with n : the number of variables.
2: The generation of the initial population of butterflies x_i , with $i=(1, 2, \dots, n)$.
3: Through the objective function $f(x)$ we calculate each stimulus Intensity, l_i relative to each x_i
4: Define the sensor modality, c , performance exponent a , and probability of switching p .
5: While the stop condition is not satisfied do
6: for each butterfly, bf , in population do
7: calculate fragrance for, bf , by: $f = cl^a$
8: end for
9: Looking for the best bf
10: for each butterfly, bf , in population do
11: the generation of a random number, r , between 0 and 1.
12: if $r < p$ then
13: move towards the best solution
14: else
15: random movement
16: end if
17: end for
18: Update the value of a
19: end while
20: The best solution is given

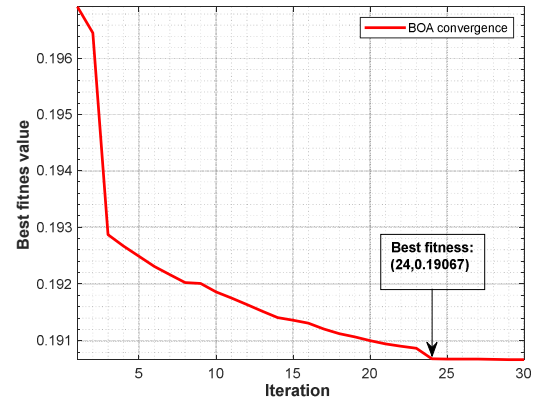


Figure 4: BOA convergence characteristic

TABLE I. CONTROLLER OPTIMAL PARAMETERS RETURNED BY BOA

	α_1	α_2	Fitness
Best value	0.77361844	0.12953669	0.19067

TABLE II. BOA PARAMETERS

Parameters	Nomenclature	Value
Lower/upper bounds of variables	LB and UB	[0 0] and [35 35]
Max_it	Number Max of Iterations	30
An	Search Agents number	10
p	Probability switch	0.8
Pe	Power exponent	0.1
Sm	Sensory modality	0.01

Thereafter the effectiveness of the proposed methodology is examined through a speed scenario characterized by an ascent and a descent of speed.

In this simulation, we take into account only throttle (when the throttle is active and the brake is inactive $T_b = 0$).

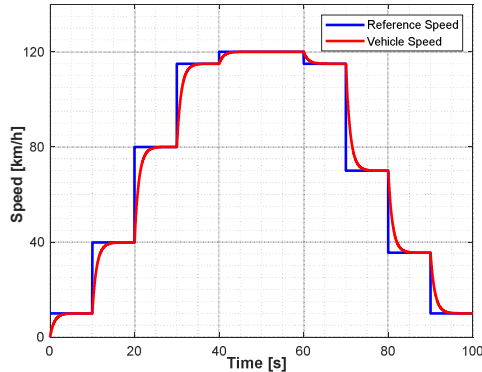


Figure 5: The target speed tracking

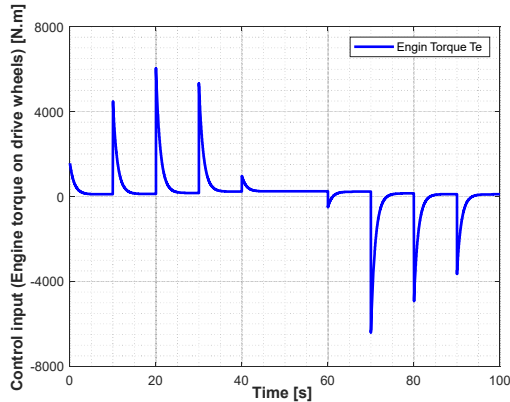


Figure 6: Engine torque on drive wheels

Figure 5 shows that the proposed controller has enabled the car's speed adaptation by tracking a speed profile, which designates the adjustment of the distance inter-vehicles, with a high degree of accuracy. In this connection, the developed strategy, permits the generation of engine torque, as shown in Fig. 6, enabling the vehicle to adjust its speed, as required by the reference value, in a smooth manner with no unwanted behavior, thus keeping the vehicle operating in a precise and stable mode, i.e. ensuring road safety and passenger comfort.

V. CONCLUSION

In this work, a design of an ACC is presented using the super-twisting algorithm. The optimal setting of this speed control unit is generated by a bio-inspired-metaheuristic algorithm. The controller performance has been examined by a very frequent scenario. As a close perspective, we envisage examining the robustness of the strategy through the consideration of perturbation and unmodelled vehicle dynamics.

REFERENCES

- [1] E. Wagner, R. G. Atkins, A. Berning, A. Robbins, C. Watson, et J. Anderle, « Examination of the Traffic Safety Environment During the Second Quarter of 2020: Special Report », United States. National Highway Traffic Safety Administration. Office of ..., 2020.
- [2] « 2019 road safety statistics: what is behind the figures? », *European Commission - European Commission*. https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_10_04 (consulté le 15 janvier 2021).
- [3] L. El Hajjami, E. M. Mellouli, et M. Berrada, « Robust adaptive non-singular fast terminal sliding-mode lateral control for an uncertain ego vehicle at the lane-change maneuver subjected to abrupt change », *International Journal of Dynamics and Control*, p. 1-18, 2021.
- [4] S. Kuutti, R. Bowden, Y. Jin, P. Barber, et S. Fallah, « A survey of deep learning applications to autonomous vehicle control », *IEEE Transactions on Intelligent Transportation Systems*, 2020.
- [5] C. Badue et al., « Self-driving cars: A survey », *Expert Systems with Applications*, p. 113816, 2020.
- [6] L. El Hajjami, E. M. Mellouli, et M. Berrada, « Optimal PID control of an autonomous vehicle using Butterfly Optimization Algorithm BOA », in *Proceedings of the 4th international conference on big data and internet of things*, 2019, p. 1-5.
- [7] Q. Cui, R. Ding, C. Wei, et B. Zhou, « Path-tracking and lateral stabilisation for autonomous vehicles by using the steering angle envelope », *Vehicle System Dynamics*, p. 1-25, 2020.
- [8] L. EL HAJJAMI, E. M. MELLOULI, et M. BERRADA, « Neural Network Based Sliding Mode Lateral Control For Autonomous Vehicle », in *2020 1st International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET)*, 2020, p. 1-6.
- [9] A. Norouzi, R. Kazemi, et S. Azadi, « Vehicle lateral control in the presence of uncertainty for lane change maneuver using adaptive sliding mode control with fuzzy boundary layer », *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, vol. 232, n° 1, p. 12-28, 2018.
- [10] L. El Hajjami, E. M. Mellouli, et M. Berrada, « Autonomous Vehicle Lateral Control for the Lane-change Maneuver », in *WITS 2020*, Springer, 2022, p. 285-295.
- [11] E. M. Mellouli, S. Massou, et I. Boumhidi, « Optimal Robust Adaptive Fuzzy Tracking Control without Reaching Phase for Nonlinear System », *Journal of Control Science and Engineering*, vol. 2013, 2013.
- [12] A. Norouzi, M. Masoumi, A. Barari, et S. Farrokhpour Sani, « Lateral control of an autonomous vehicle using integrated backstepping and sliding mode controller », *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics*, vol. 233, n° 1, p. 141-151, 2019.
- [13] M. J. Blondin, « Controller Tuning by Metaheuristics Optimization », in *Controller Tuning Optimization Methods for Multi-Constraints and Nonlinear Systems*, Springer, 2021, p. 11-51.

- [14] R. Rajamani, *Vehicle dynamics and control*. Springer Science & Business Media, 2011.
- [15] J. Zhao, H. Fu, D. Liu, G. Wang, et A. El Kamel, « Integrated Longitudinal and Lateral Control System Design and Case Study on an Electric Vehicle », *Mathematical Problems in Engineering*, vol. 2019, 2019.
- [16] S. Kuragaki *et al.*, « An adaptive cruise control using wheel torque management technique », SAE Technical Paper, 1998.
- [17] S. Chen, G. Xiong, H. Chen, et D. Negrut, « MPC-based path tracking with PID speed control for high-speed autonomous vehicles considering time-optimal travel », *Journal of Central South University*, p. 1-19, 2020.
- [18] K. Yi, J. Hong, et Y. D. Kwon, « A vehicle control algorithm for stop-and-go cruise control », *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 215, n° 10, p. 1099-1115, 2001.
- [19] Y. Bin, K. Li, et N. Feng, « Disturbance decoupling robust control of vehicle full speed cruise dynamic system », *Science in China Series E: Technological Sciences*, vol. 52, n° 12, p. 3545-3564, 2009.
- [20] Y. Ba, W. Zhang, G. Salvendy, A. S. Cheng, et P. Ventsislavova, « Assessments of risky driving: a Go/No-Go simulator driving task to evaluate risky decision-making and associated behavioral patterns », *Applied ergonomics*, vol. 52, p. 265-274, 2016.
- [21] J. Huang, Y. Chen, X. Peng, L. Hu, et D. Cao, « Study on the driving style adaptive vehicle longitudinal control strategy », *IEEE/CAA Journal of Automatica Sinica*, vol. 7, n° 4, p. 1107-1115, 2020.
- [22] L. Nie, J. Guan, C. Lu, H. Zheng, et Z. Yin, « Longitudinal speed control of autonomous vehicle based on a self-adaptive PID of radial basis function neural network », *IET Intelligent Transport Systems*, vol. 12, n° 6, p. 485-494, 2018.
- [23] J. K. Hedrick, D. McMahon, V. Narendran, et D. Swaroop, « Longitudinal vehicle controller design for IVHS systems », in *1991 American Control Conference*, 1991, p. 3107-3112.
- [24] A. Farag, A. Hussein, O. M. Shehata, et E. I. Morgan, « Design and Validation of A Novel Adaptive Cruise Control Law for a Platoon Of Vehicles », in *2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES)*, 2020, p. 81-86.
- [25] B. Ganji, A. Z. Kouzani, S. Y. Khoo, et M. Nasir, « A sliding-mode-control-based adaptive cruise controller », in *11th IEEE International Conference on Control & Automation (ICCA)*, 2014, p. 394-397.
- [26] J. Guo, Y. Luo, et K. Li, « Adaptive fuzzy sliding mode control for coordinated longitudinal and lateral motions of multiple autonomous vehicles in a platoon », *Science China Technological Sciences*, vol. 60, n° 4, p. 576-586, 2017.
- [27] S. Wang, Y. Hui, X. Sun, et D. Shi, « Neural Network Sliding Mode Control of Intelligent Vehicle Longitudinal Dynamics », *IEEE Access*, vol. 7, p. 162333-162342, 2019.
- [28] A. Chebly, R. Talj, et A. Charara, « Coupled longitudinal/lateral controllers for autonomous vehicles navigation, with experimental validation », *Control Engineering Practice*, vol. 88, p. 79-96, 2019.
- [29] Z. Wu, Z. Gao, W. Hao, et J. Ma, « An Optimal Longitudinal Control Strategy of Platoons Using Improved Particle Swarm Optimization », *Journal of Advanced Transportation*, vol. 2020, 2020.
- [30] L. Yang, J. Mao, K. Liu, J. Du, et J. Liu, « An Adaptive Cruise Control Method Based on Improved Variable Time Headway Strategy and Particle Swarm Optimization Algorithm », *IEEE Access*, vol. 8, p. 168333-168343, 2020.
- [31] M. H. A. Sidi, K. Hudha, Z. Abd Kadir, M. A. Subari, N. H. Amer, et S. M. F. S. M. Dardin, « Speed Tracking Control of Tracked Vehicle using PID Controller Optimized by Particle Swarm Optimization », in *2020 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS)*, 2020, p. 107-111.
- [32] P. Hang, S. Huang, X. Chen, et K. K. Tan, « Path planning of collision avoidance for unmanned ground vehicles: A nonlinear model predictive control approach », *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, p. 0959651820937844, 2020.
- [33] B. Zhang, X. Yang, B. Hu, Z. Liu, et Z. Li, « OEBBOA: A Novel Improved Binary Butterfly Optimization Approaches With Various Strategies for Feature Selection », *IEEE Access*, vol. 8, p. 67799-67812, 2020.
- [34] Z. Wang, Q. Luo, et Y. Zhou, « Hybrid metaheuristic algorithm using butterfly and flower pollination base on mutualism mechanism for global optimization problems », *ENGINEERING WITH COMPUTERS*, 2020.
- [35] R. N. Jazar, *Vehicle dynamics: theory and application*. Springer, 2017.
- [36] R. Attia, R. Orjuela, et M. Basset, « Longitudinal control for automated vehicle guidance », *IFAC Proceedings Volumes*, vol. 45, n° 30, p. 65-71, 2012.
- [37] E. M. Mellouli, M. Alfidi, et I. Boumhidi, « Fuzzy sliding mode control for three-tank system based on linear matrix inequality », *International Journal of Automation and Control*, vol. 12, n° 2, p. 237-250, 2018.
- [38] J. Liu, L. Gao, J. Zhang, et F. Yan, « Super-twisting algorithm second-order sliding mode control for collision avoidance system based on active front steering and direct yaw moment control », *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 235, n° 1, p. 43-54, 2021.
- [39] G. Tagne, R. Talj, et A. Charara, « Higher-order sliding mode control for lateral dynamics of autonomous vehicles, with experimental validation », in *2013 IEEE Intelligent Vehicles Symposium (IV)*, 2013, p. 678-683.
- [40] A. Levant, « Robust exact differentiation via sliding mode technique », *automatica*, vol. 34, n° 3, p. 379-384, 1998.
- [41] R. Alik, E. M. Mellouli, et E. H. Tissir, « Optimization of higher-order sliding mode control parameter using particle swarm optimization for lateral dynamics of autonomous vehicles », in *2020 1st International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET)*, 2020, p. 1-6.
- [42] S. Arora et S. Singh, « Butterfly optimization algorithm: a novel approach for global optimization », *Soft Computing*, vol. 23, n° 3, p. 715-734, 2019.