Smooth Transition of Vehicles' Maximum Speed for Lane Detection based on Computer Vision

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***Abstract*—This paper presents a prototype electric scooter designed to detect the driving lane via computer vision and automatically set the vehicular configuration. The electric scooter can drive on the pedestrian, bicycle, or car lanes. The government enforces maximum speeds on each lane for the electric scooter. Our prototype scooter would apply those regulations securely, with the help of a computer vision component. However, the safety of such a system is still part of the concern and research is going on the security and safety aspects of such vehicular systems. The maximum speed changes while the driver is riding the vehicle at the fastest possible speed could cause a safety hazard. To prevent that, we proposed to use the logarithmic speed reduction or acceleration. The results show that such an algorithm will smooth the transition between the maximum of the vehicle.**

***Index Terms*—Electric Vehicles, Automated Configuration, Lane Detection**

I. Introduction

Detection of the lanes requires advanced vehicular technologies that can classify the current lane from the images taken from the front camera of the scooter and process those images with computer vision techniques. Once the lane is detected, the electric scooter will apply the maximum possible speed based on government regulations.

Electric scooters are a popular medium of transport in urban mobility that, together with the other mediums of public transportation, can provide a better mobility solution and reduce the need for personal mobility mediums such as cars [3], [7], [9], [16]. However, due to the legal frameworks of those vehicles, we need to revisit the technologies used inside the electric scooters and adapt the vehicle to the requirements of the vehicular technology and applied legal framework. As an example, the maximum speed that an electric scooter can drive is based on the lane that the scooter is in, and the legal frameworks of Germany define it as three lanes of pedestrian, cycling, and car lanes.

Road and lane detection have been discussed in the literature in the past four decades, and there is a wide range of promising solutions for cars. The authors of [1] surveyed road and lane detection technologies. As the authors acknowledged, there are several possible modes of perception for lanes and roads, but monocular vision is the most commonly used modality. Most works do not discuss it directly but acknowledge it as a viable alternative. We used a similar approach, which includes computer vision, for our scooter, which is cost-efficient and provides reliable performance. However, in this paper, we will not discuss computer vision performance.

VESC is a motor controller that is widely used in vehicular systems. The authors of [19] presented a VESC-based balancing mechanism that enables autonomously driving for E-Scooters. The VESC platform is also used in autonomous robots. The authors of [15] used AI, and machine vision, together with the VESC platform, to achieve the flexibility and cost-effectiveness of autonomous logistic robots.

Adaptive cruise controller [14] (ACC) is a cruise control advanced driver-assistance system for road vehicles that automatically adjusts the vehicle speed to stay up a certain distance from vehicles ahead. Control depends on device information from vehicle sensors [11], [13], [20]. Such systems may use a measuring instrument, optical device, or a camera setup allowing the vehicle to brake once it detects the automotive is approaching another vehicle ahead, then accelerate once traffic permits it to accelerate. Similarly, we imply the vehicle's maximum speed based on the computer vision component. We now enforce the maximum speed based on our prototype's detected lane from the computer vision component to the motor controller (VESC platform). We transit smoothly from the current speed to the desired speed with a logarithmic increment/decrement of the speed over a window of two seconds. This is crucial to maintain a smooth speed transition to ensure the system's safety [6], [10], [12], [21].

To our best knowledge and knowledge of the European electric mobility manufacturer and the academic bodies involved in this project, this paper is the first paper that presents the requirement of such a prototype of lane detection for scooters. The rest of the paper will present the vehicular setup, numerical modelling, and experimental results.

II. Vehicular Setup

The scooters typically consist of four primary equipment Motor controllers (MC), Sensors, and Actuators. The sensors are, for example, the driver commands, gyroscope, accelerometer, and so on. The actuators are electric motors, displays, lights, and so on. We added a camera and Main Control Unit (MCU) to the system to detect the lanes and apply the maximum speed based on the detected lane.

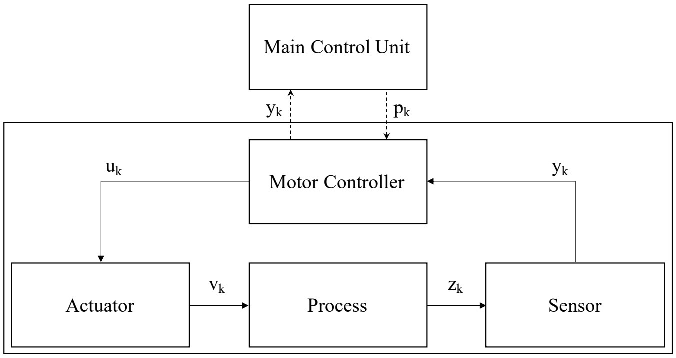


Fig. 1: The control loop of the motor controller. The Main Control Unit receives a copy of sensor readings (y_k) and processes them. The high-level control policies will be implied by p_k to the Motor Controller.

The control loop is used to model most of the control processes [5], and we also used it to represent the policies that we imply to control the vehicular system. Figure 1 represent the control loop of the motor controller. The sensor reads the system's state from the process (z_k). The motor controller receives sensor readings (Y_k) from the sensors. The motor controller process those sensor readings, updates the vehicle's space and sends the actuator commands (u_k). The actuators update the system's state by applying the actuation commands (v_k.)

Main Control Unit (MCU) receives a copy of sensor readings from the Motor Controller to measure the system's state. Due to the high computing power available at the MCU rather than the MC, many advanced state estimations will be done in the MCU. Finally, the MCU implies the policies (p_k) to the motor controller, which in this paper, we focused on the maximum speed.

III. Numerical Modeling

A set of mathematical models can model a control system. The most used system model in the literature is the Linear Dynamical State-space (LDS) model [8], [17] to perform the physical modelling of the processes (P):

$$P : \begin{cases} x_{k+1} = Ax_k + Bu_k + \epsilon_k \\ y_k = Cx_k + Du_k + e_k \end{cases} \quad (1)$$

where A, B, C, and D are the system matrices determined by the system identification, k is the current state of the system, $k+1$ is the next state of the system, u_k is control commands, x_k is the state of the estimated model, x_{k+1} is next state of the system, and y_k is sensor measurements [4].

The MCU will imply the maximum speed ($S_{max} \in p_k$) based on the detected environment and intelligence models. The current speed($S(t)$) will be derived from sensor readings (y_k). Finally, to reach a smooth increment/decrement of the speed to the maximum possible speed of the lane, we used the logarithmic function to enforce the maximum speed over a window of time. We can formulate our maximum speed enforcement as follows:

$$\begin{aligned} & while(|S_{max}(t) - S_{max}| > 0) \\ & \quad S_{max}(t+1) - S(t) = \pm log_c(1 + (S(t) \mp S_{max}(t))) \end{aligned}$$

where c is a constant value (two in our paper). The constant value can be set based on the time window of reaching from the current speed to the maximum allowed speed. Our numerical modelling considers the noise of the process, which is an essential factor that should be considered to ensure the system's safety.

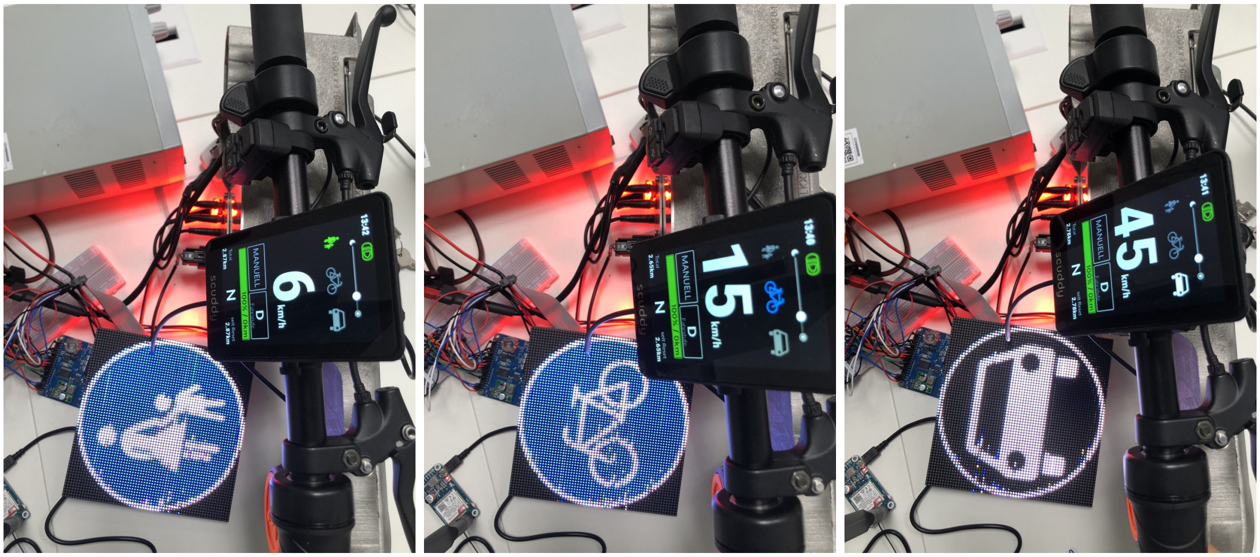
IV. Implementation

Our prototype consists of following major components: 1) Main Control Unit (MCU) 2) Human-Machine Interface (HMI) 3) Motor Controller (MC) 4) Environmental Recognition (ER) 5) Battery Management System (BMS) 6) Cellular Communication. The Main Control Unit is responsible for the processing and decision-making of the inputs received from the sensors, ER and MQTT Broker. The MCU applies the required actions to the actuators and the MC. The ER has a camera connected to it and is responsible for detecting the current lane and classifying it into the three categories of pedestrian, bike, or car lanes. It includes a TPU that facilitates deep learning and computer vision algorithms. The HMI consists of 64×64 LEDs that show the current state of the scooter, with a traffic symbol of the pedestrian, bike, or car. Cellular Communication is an NB-IoT connection of Waveshare that includes the SIM7080G chip. Figure 3 represent the general setup of our prototype components.

The motor controller and other scooter components communicate via a CAN bus. The CAN controller is attached to the MCU, a Raspberry Pi 4 Model B, with a real-time camera, a Coral USB Accelerator, an LED display, and an LED driver. Coral USB Accelerator is an edge TPU coprocessor that enables high-speed inferencing for machine learning on various systems and is mainly used for image processing.

Figure 2 represents snapshots of the implemented prototype of the scooter. The Motor Controller is a modified version VESC [18], which enables the construction of flexible, efficient, reliable power supply systems. The resources provided by the VESC program can help researchers achieve their goals faster. VESC environments face engineering challenges ranging from small to large complex vehicle systems. The motors are BLDC motors that are controlled directly by the motor controller. Like brushed DC motor controllers, BLDC motor controllers perform an equivalent function and apply analogous styles. They still differ in their arrangement and execution in some abstract ways. Motor controllers regulate the speed and torque of BLDC motors as well as start, stop, and reverse their rotation.

Finally, the scooter is connected to an MQTT broker to send information such as debugging notifications and, when required, the positioning pieces of information.



(a) The maximum possible speed in the pedestrian lane is 6km/h, and also, we requested the maximum gas from the motor controller, the implied policies from MCU maintained the speed at 6km/h.

(b) The maximum possible speed in the bike lane is 15km/h, and also, we requested the maximum gas from the motor controller, the implied policies from MCU maintained the speed at 15km/h.

(c) The maximum possible speed in the car lane is 45km/h, and also, we requested the maximum gas from the motor controller, the implied policies from MCU maintained the speed at 15km/h.

Fig. 2: An illustration of the states of the MCU and implied maximum speed with the request of maximum gas power from the driver.

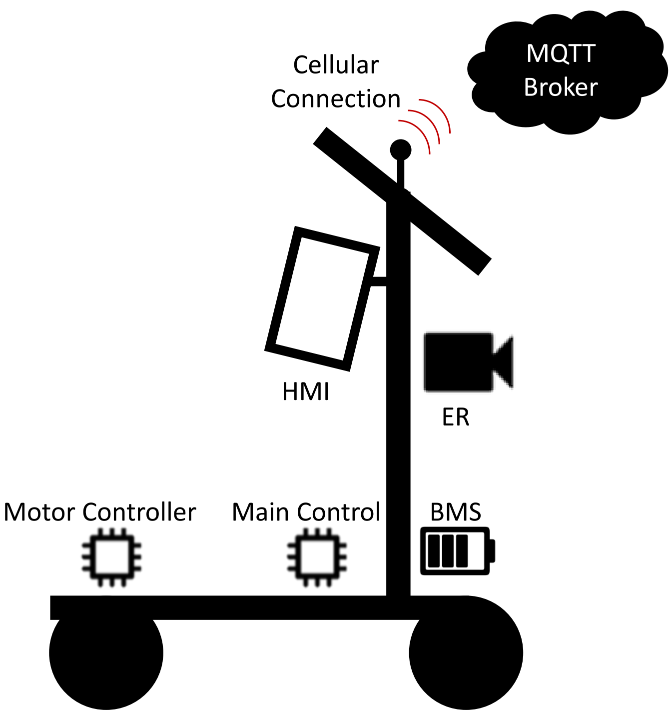


Fig. 3: The components of the prototype.

V. Experimental Results

Figure 4 represents our obtained results from our experimental evaluations. We used the maximum gas power to measure the situation where the current speed ($S(t)$) is close (ideally equal) to the implied maximum speed ($S_{max}(t)$) at the time of t. However, with some random error of estimation, as we see in Figure 4, the current speed will reach the maximum speed (S_{max}) in about two seconds.

Figure 4a shows the results of our experimental results for a transition from car lanes (45km/h) to bike lane (15km/h). As we can see in our five traces taken with the maximum gas power, the vehicle's speed converges to the maximum possible speed of the bike lane (15km/h) in around two seconds. Figure 4b shows the results of our experimental results for a transition from bike lane (15km/h) to car lanes (45km/h). As we can see in our five traces taken with the maximum gas power, the vehicle's speed converges to the maximum possible speed of the car lane (45km/h) in around two seconds.

As our results show, the scooter's speed will be closely maintained with the maximum allowed speed with the maximum gas requested. However, due to the impact of the acceleration of the motor on the current speed to the scooter's speed, it will take time to reach the maximum allowed speed. For example, in our mathematical modelling (blue line) in Figure 4a, ideally, the scooter should maintain the maximum speed of the bike lane (15km/h) after 1100 ms from the start of the speed reduction process. However, due to the physics of the implemented scooter, in most of our experiments, the scooter reaches the bike lane (15km/h) roughly after 2000 ms.

On the other hand, while we try to increase the speed to the maximum speed, the scooter requires time to reach the maximum allowed speed maintained by our mathematical modelling. As we can see in figure 4b, the scooter is behind the maximum allowed speed of car lanes (45km/h) for two seconds. However, our mathematical modelling reaches the maximum allowed speed of car lanes (45km/h) and issues the policy to the motor controller at roughly 1100 ms from the start of the speed-increasing process. This happens due to the acceleration requirements, friction, and also delays in communication.

During our experiments in our lab setup, the scooter showed matching behaviour in the speed increase/decrease. The fact that our investigation is limited to only one device affects such a result. However, we argue that the provided e-scooter setup from the manufacturer is produced with the exact standards of the commercial scooters, and we expect a similar experience in commercial e-scooters.

To conclude our experimental results and mathematical modelling, the MCU computes the maximum speed over the logarithmic increase/decrease of the maximum allowed speed. Depending on the constant value chosen in the equation (c), it will logarithmically speed up the increase/decrease of the maximum allowed speed. However, in real-world scenarios, the motor has a physical process that gets impacted by the actuation commands of the motor-controller (v_k), apply those commands, and the sensor will read the updated state of the system (z_k). As expected, the modelling errors and the system's noise (ϵ_k, e_k) always is present, and multiple factors will define the system's behaviour.

In the future, we plan to evaluate our scooter by driving it and measuring the different parameters' impact on the system's safety and hazard prevention. In particular, the constant value of the c in our equation can be calculated again based on the driver's experiences.

VI. Conclusion

We presented our implementation of a scooter that detects the lanes, including pedestrian, bike and car lanes. The government defines each lane's maximum possible speed based on the lane. In this paper, we presented the maximum speed implication of the electric scooters and a logarithmic method of transition of vehicle's maximum speed based on the detected lane from the computer vision. Our results prove that in a window of time (two seconds), we smoothly reduce the scooter's maximum speed to imply the government rules and prevent possible safety hazards from immediate speed changes. In future work, we will compute the window of time that the driver feels much noncontroversial via the field experiments. In particular, we will work on the parameters of the logarithmic equation to well-tune the state transition of the maximum speed of the e-scooter based on user experiences.

VII. Acknowledgment

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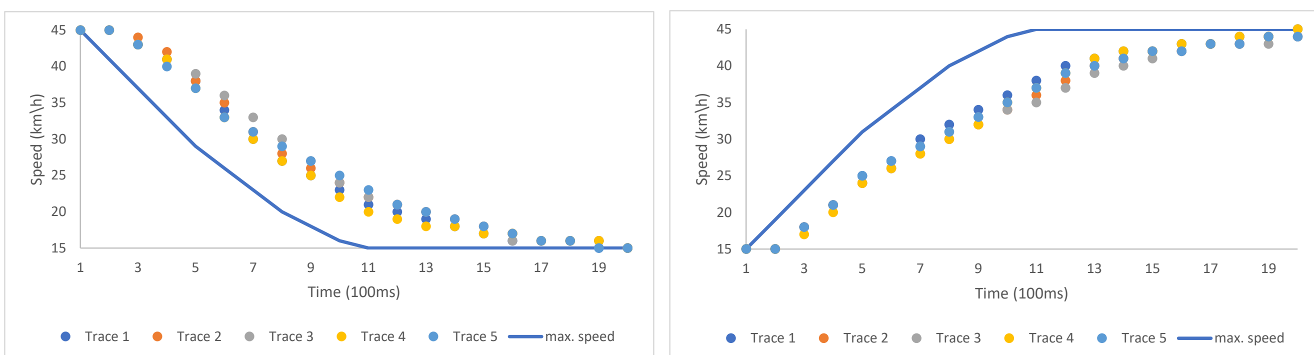

(a) An example of state transition with maximum gas and enforced maximum speed from car lanes (45km/h) to bike lane (15km/h).

(b) An example of state transition with maximum gas and enforced maximum speed from bike lane (15km/h) to car lanes (45km/h).

Fig. 4: An illustration of smooth vehicle state transition with the maximum gas requested by the driver.