AUTONOMOUS INDOOR NAVIGATION SYSTEM CONCEPT: HARDWARE AND SOFTWARE INTEGRATION FOR ELECTRIC VEHICLES

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Abstract: This paper presents a comprehensive investigation into the development of an autonomous electric vehicle specifically designed for indoor use. The research focuses on two critical aspects: the hardware-based steering system and the software algorithm for autonomous navigation. The steering system integrates a set of sensors and a closed-loop control algorithm to accurately determine the wheel positions relative to the steering wheel, utilizing a microcontroller and a LiDAR sensor for precise directional control. Concurrently, an interactive dashboard was developed, using Python and Qt, to display real-time data including motor temperature, battery voltage, and current consumption. The autonomous navigation algorithm, implemented and tested in MATLAB Simulink, uses LiDAR-generated maps to define the vehicle's trajectory within a physical space. The algorithm guides the vehicle through predefined coordinates, adapting to environmental changes and obstacles. The integration of these hardware and software components aims to achieve reliable autonomous navigation in confined indoor spaces, enhancing the vehicle's performance and safety. This research contributes significantly to the field of intelligent electric vehicles, promoting advancements in autonomous mobility solutions for industrial, commercial, and residential applications.

Key words: navigation, closed space, Simulink, Lidar, dashboard, monitoring.

1. INTRODUCTION AND STATE OF THE ART

In the age of technological advancement and the push for sustainable transport, the development of autonomous electric vehicle prototypes is increasingly gaining interest across various sectors. The creation of these vehicles hinges on several critical components, including the architecture and control system, environmental perception, navigation, energy efficiency, and specific hardware like BLDC and servo motors. These elements are crucial for the vehicles' safe and efficient operation, requiring seamless integration and coordination. Key aspects include flexible and modular design for easy updates, real-time decision-making capabilities through advanced algorithms, and the use of sensors and machine learning for environmental understanding. Additionally, precise navigation and localization technologies, alongside energy optimization and

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storage solutions, are essential. The synergy and optimization of these components are vital for achieving reliable autonomous driving, underscoring the importance of comprehensive studies and research in the field for the successful realization of autonomous electric vehicle prototypes [1].

Ajao and Sadeeq [2] provide a detailed overview of recent advances in autonomous electric vehicles. The paper begins by highlighting the importance of the development of autonomous electric vehicles and how it can revolutionize the way we move and transport goods, providing safer and more efficient solutions for our transportation needs. The authors then analyze the various subsystems that make up an autonomous electric vehicle, including energy storage systems, battery management systems, vehicle charging systems, electric motor mechanisms, and braking systems. Within each subsystem, the authors provide a detailed overview of recent advances and comparisons with other similar technologies. The paper also presents several prototypes of autonomous electric vehicles, providing an overview of how these technologies are implemented in practice.

In the paper done by Wang et al. (2020) [3], the authors focus on the development of intelligent functions on autonomous electric vehicle platforms and explore the fascinating world of autonomous driving and the challenges it presents for safety engineering and human-vehicle interaction. In the paper, the authors present an experimental study on human-autonomous vehicle interaction, which was carried out on a robot platform. Also, theoretical models for the analysis of human-autonomous vehicle interaction are presented and the main challenges and objectives of the development of autonomous driving technology are discussed. In addition, the paper addresses policy and societal issues such as user information and acceptance, as well as the regulatory adaptations needed to ensure the safety and efficiency of autonomous vehicles.

The paper done by Parekh et al. [4] presents a review of the progress, methods and challenges encountered in the development of autonomous vehicles. The authors performed a bibliometric and scientific analysis of the existing literature, examining previous studies and research in the field. They identified a number of challenges, such as safety, regulation and public acceptance, but also a number of potential benefits, such as reducing road accidents and improving mobility. In addition, the authors examined the various methods used to develop autonomous vehicles, including sensor technology, artificial intelligence, and navigation systems. Overall, this paper provides a comprehensive insight into autonomous vehicles and how they could change the way we get around in the future.

The paper by Rus, Leba, Risteiu, and Marcus (2023) [5] aims to investigate the development of intelligent electric vehicles that possess the potential for transformation into autonomous counterparts. A crucial aspect of this research involves the formulation of a robust and intuitive mathematical model, which serves as the foundation for a dedicated cruise control system designed for small electric vehicles. The proposed control system is intended for deployment in both outdoor and indoor industrial environments, in alignment with the principles of sustainable development. To achieve this objective, the researchers engaged in extensive simulations and mathematical modeling of a small electric vehicle. The primary focus of the modeling process encompassed the dynamic behavior of the vehicle and its core components. These components comprise the powertrain, suspension system, tires, and the human driver. The powertrain model intricately incorporated the electrical and mechanical characteristics of the electric motor, the behavior of the controller, and the state of charge of the battery. Additionally, the suspension system model accounted for the unique attributes of dampers, springs, and the vehicle's mass and moment of inertia. On the other hand, the tire model encompassed essential features such as tire-road contact, lateral and longitudinal forces, and slip angle. Furthermore, the driver model captured the inputs from the accelerator and brake pedals, as well as the steering wheel. The various component models were meticulously combined in a comprehensive simulation framework to facilitate the examination of the small electric vehicle's dynamic behavior under diverse operating conditions. Moreover, this integrated simulation environment served as an effective platform for rigorous testing of various control algorithms. Among the control algorithms studied were those pertaining to regenerative braking systems, energy management, and battery charging. The researchers relied on the powerful MATLAB Simulink software platform to implement the numerous vehicle component models and conduct the control algorithm assessments. MATLAB Simulink provides a versatile and user-friendly block-based modeling environment, which is ideally suited for this type of complex system modeling. Moreover, the software's support for real-time hardware-in-the-loop simulation enabled the researchers to execute the control algorithms on a real-time platform. As a result, they could send inputs to the physical vehicle components and receive outputs, facilitating the evaluation and validation of the control strategies in a real-world context.

In summary, the investigation undertaken by Rus, Leba, Risteiu, and Marcus (2023) [5] constitutes a significant advancement in the development of intelligent electric vehicles that can eventually transition into fully autonomous entities. The establishment of a reliable mathematical model and the utilization of the MATLAB Simulink software platform have been pivotal in simulating and testing control algorithms critical to the performance and autonomy of these vehicles. By embracing these technological advancements, the automotive industry moves closer to realizing a greener, safer, and more efficient future for sustainable transportation. This provides the ability to test control algorithms in a real environment to verify their performance and ensure that they meet the desired specifications. The literature review reveals that there is a wide variety of research related to the development of electric vehicles, especially regarding the extension of their autonomy, energy efficiency and the implementation of advanced control systems [6, 7]. Based on the developed mathematical model [5], the researchers demonstrated its use for sizing electric motors for various types of electric vehicles, including off-road vehicles such as the electric buggy and electric ATV [8].

Using the mathematical model as an inverse model, they were able to determine the minimum moment required for the vehicles to climb slopes of varying degrees. These results allowed the appropriate selection of electric motors for the vehicles in question, thus ensuring the reliable and efficient operation of the propulsion systems. The study emphasizes the importance of continued research in the field of electric vehicles, especially for the development and implementation of autonomous driving algorithms. Advances in this area promise to bring significant improvements in the efficiency, safety and performance of electric vehicles. The integration of advanced technologies, such as artificial intelligence, into electric vehicles will make them more intelligent, autonomous and easy to use, contributing to sustainable development and reducing the impact on the environment [9].

The study by Rus and Leba (2023) [10] provides a succinct but insightful exploration of the progress made in the development of an intelligent electric vehicle with autonomous driving capabilities. This revolutionary vehicle demonstrates outstanding adaptability, seamlessly integrating into the next-generation concepts of Smart Grid and Smart City, also contributing as a prosumer element in electricity supply networks. The research provides a brief but informative outline of the complicated process involved in creating a small electric vehicle, which is achieved by converting a thermal engine into a highly efficient electric motor. Additionally, the study highlights the successful incorporation of state-of-the-art communication systems based on the LoRa network, improving vehicle connectivity and data exchange capabilities. In particular, the integration of LiDAR sensors adds a remarkable dimension to the vehicle's functionality, enabling precise mapping of specific areas of interest. Furthermore, the research introduces a future concept for establishing an innovative power supply system. Combining cutting-edge technologies, innovative design concepts and sustainability principles, this study presents the potential for significant advances in the field of intelligent electric vehicles, thus contributing to a more efficient and environmentally conscious future of transport. A noteworthy aspect is that this vehicle's environmental impact is genuinely 100% non-polluting, as its batteries are entirely powered by renewable energy sources [10].

Within our university, there are several achievements regarding the development of autonomous electric vehicles, one such outstanding example is the prototype of a mini autonomous electric vehicle made on the functional platform of a Buggy-type vehicle, an innovation that promises to revolutionize the way we move in the urban environment as well as on off-road terrain. This prototype represents a compact and intelligent version of an electric vehicle, designed to offer an efficient and environmentally friendly transport solution. It is proposed to equip it with advanced technologies, such as sensors, video cameras and artificial intelligence algorithms, which allow it to navigate autonomously through traffic, without requiring human intervention. The mini autonomous electric vehicle is designed to meet urban mobility needs, with small dimensions that allow it to easily slip through dense traffic and park in small spaces.

Thus, it becomes a practical and efficient option for traveling short distances, such as the daily commute to work or shopping. Another remarkable aspect of this prototype is its exclusive use of electricity. The vehicle is equipped with an advanced electric propulsion system based on a BLDC brushless motor, powered by a high-performance battery. This sustainable approach not only reduces carbon emissions and the noise produced by vehicles with conventional engines, but also provides a smooth driving experience, without unpleasant vibrations or noises. Also, this mini autonomous electric vehicle comes with a modern and intuitive interface that allows users to access different functions of the vehicle, turning it into a viable solution for public and shared transportation. In the future, through a mobile application, users can request the vehicle, check availability and even monitor the route and status of the vehicle in real time.

The prototype of this mini autonomous electric vehicle represents an important step in the direction of smart and sustainable mobility. The integration of autonomous technology in electric vehicles opens new horizons for urban transport, increasing the safety, efficiency and comfort of passengers, while reducing the negative impact on the environment [5].

2. IMPLEMENTED METHODS AND SYSTEMS

This work presents two system prototypes that are the basis of the construction of a mini autonomous electric vehicle. The first system prototype is a hardware type developed to manage the direction of travel of the mini autonomous electric vehicle, while the second system is a software type that allowed the creation of a dashboard for this type of vehicle. Regarding the development of the autonomous steering hardware prototype, in the first stage, a system was created using a control algorithm in a closed loop with the help of sensors that can be used to determine the position of the vehicle's wheels in relation to the steering wheel's position (Figure 1). This is just a concept; at this stage of research, it has not been realized from a hardware point of view.

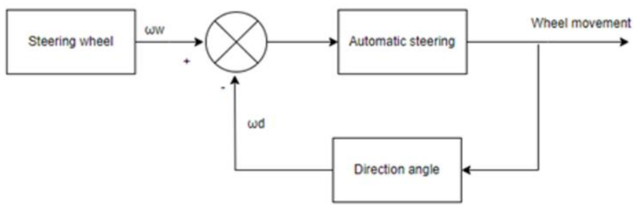

Fig.1. System block diagram

The vehicle's physical steering wheel can be replaced with a trajectory function whose output values can control the direction change system via a microcontroller. To do this, a Raspberry Pi-type development board, a Lidar sensor, a speed sensor, a temperature sensor, a touchscreen and a voltage and current sensor were used, so that a dashboard for this type of vehicle was created. In Figure 2 shows the connection of the Lidar sensor to the Raspberry Pi development board which was also connected to the touchscreen.

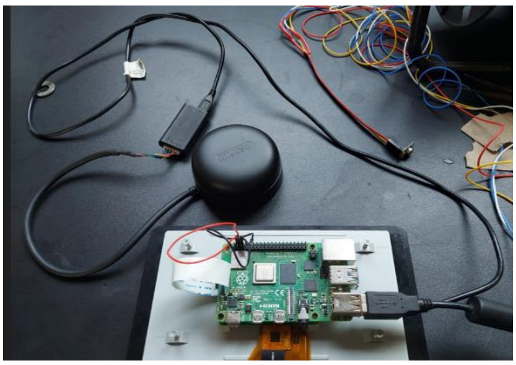

Fig.2. Hardware connections

This dashboard has the ability to display various essential vehicle data, including engine temperature, battery terminal voltage, battery capacity and current consumption, allowing drivers and technicians to monitor vehicle performance in real time. In the initial stage, the development environment was set up, ensuring that there was Python installed on the working system and the necessary libraries were included to program the GUI using Qt. To design the interface, QtDesigner was used, thus allowing the development of an ergonomic and intuitive design for users. Our dashboard features a set of information panels, each providing essential vehicle data (Figure 3).

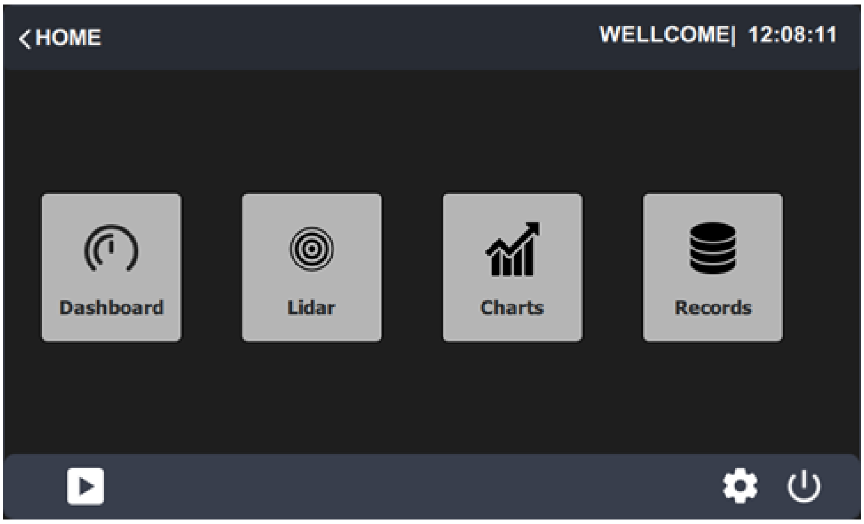

Fig.3. Main dashboard screen

The main panel displays data related to engine temperature, battery terminal voltage, battery capacity and current consumed (Figure 4 and Figure 5).

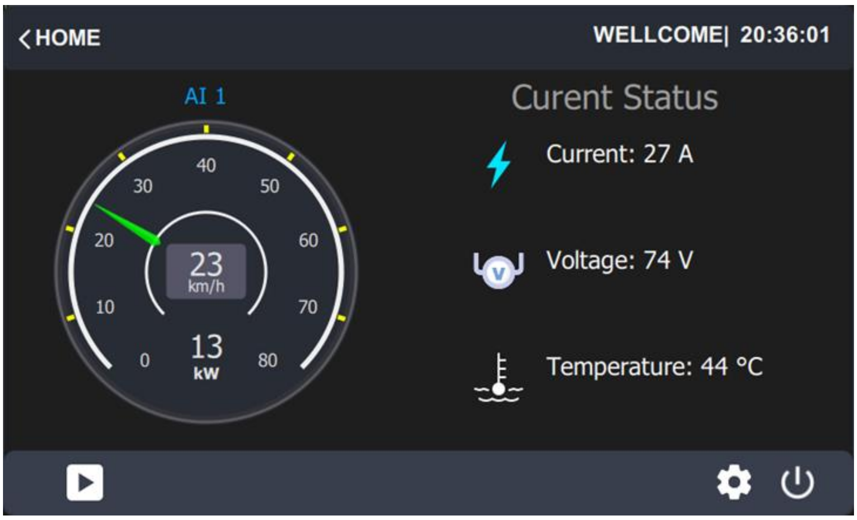

Fig.4. Screen for viewing speed, battery voltage, current consumed and engine temperature

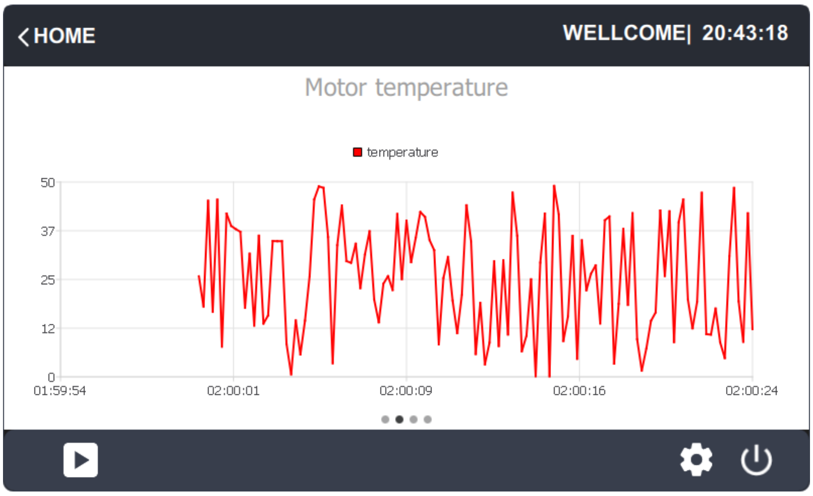

Fig.5. Graphic representation of the engine temperature evolution

This critical information is updated in real time, allowing users to monitor the condition of the vehicle throughout its life. An innovative element of this dashboard is the integration with the Lidar sensor. This sensor plays a crucial role in creating an efficient and safe autonomous navigation system. Through the Lidar sensor, the dashboard can retrieve relevant data about the vehicle's environment and provide a graphic representation of the route followed by it (Figure 6).

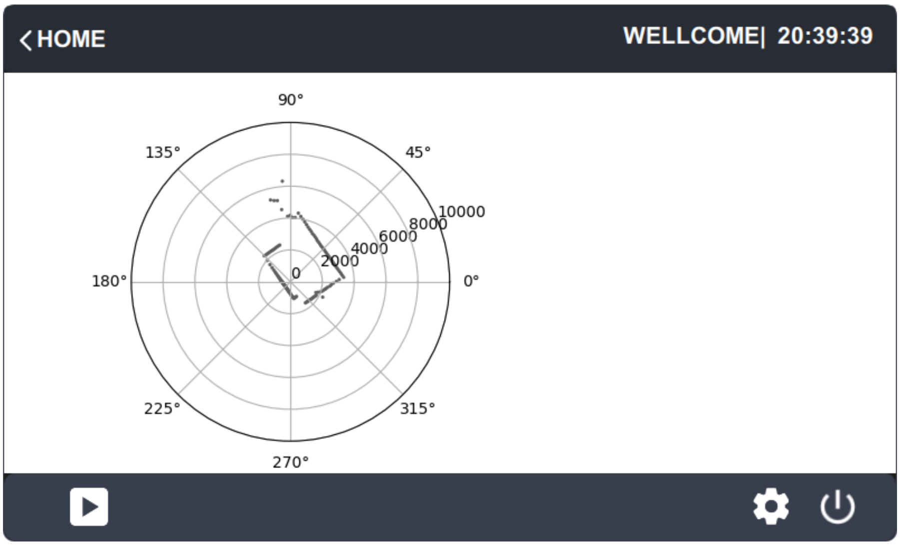

Fig.6. The map generated using the Lidar sensor

Through this route map, users can observe in real time how the vehicle plans its movements and adapts to different traffic situations. This advanced functionality significantly improves user confidence and safety in self-driving systems.

3. RESULTS AND DISCUSSION

Until now, the hardware structure of the entire system has been successfully implemented and relatively good results have been obtained in a simulation of the entire autonomous driving algorithm made in Matlab Simulink. The algorithm is structured into 9 main design and simulation steps as follows. Making a map of the physical space where the electric vehicle will follow a route, this being done with the Lidar sensor, as can be seen in Figure 7.

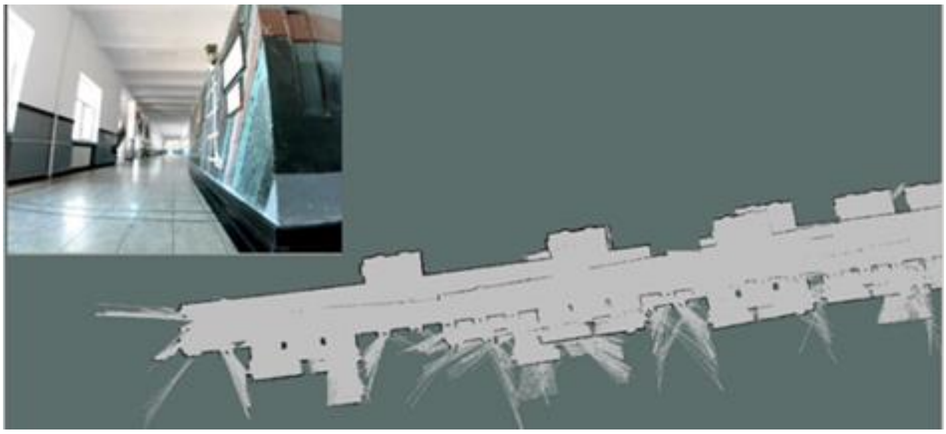

Fig.7. Map resulting from the use of the system based on the LiDAR sensor [11]

Then based on a part of the map of the studied premises, a simple algorithm was implemented in the Matlab Simulink simulation environment that generated the trajectory of the autonomous electric vehicle in the form of a sequence of coordinate points (x, y) in the plane. The generated trajectory is shown in Figure 8 [11].

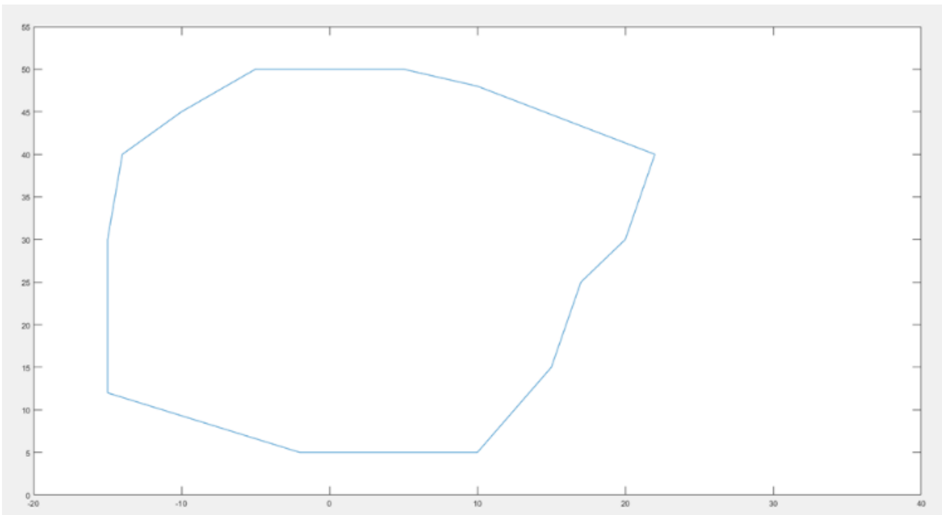

Fig.8. The map generated using the Lidar sensor

The entire process of driving an autonomous electric vehicle was thought to follow the following steps: checking the position of the electric vehicle in relation to the trajectory, reading the position of the electric vehicle with the help of a localization system, orienting the electric vehicle to the desired trajectory, imposing the necessary position on the proposed trajectory, determining the direction angle of the electric vehicle, actuating the servomotor coupled to the steering as well as the drive motor and last but not least avoiding obstacles.

In order to simplify the simulation model made in Matlab, it was considered that when encountering an unforeseen obstacle while traveling an imposed route, the electric vehicle will stop. In the first sequences of the realized Matlab program, the number of points on the imposed trajectory represented in a 2D plane (16 points) were defined, then the x,y pairs related to each point and the starting point of the electric vehicle were defined. The speed of the electric vehicle was considered to be 3 m/s, approximately 10 km/h. With the help of a minimum algorithm, the closest point on the imposed trajectory and the distance from the initial position of the electric vehicle were determined. The angle α was determined, which represents the angle of movement of the electric vehicle's steering wheel required to reach a certain point on the imposed route, as well as the time required to move from one point to another on the defined trajectory. The simulation results for an imposed route represented in Figure 9 are satisfactory and can be taken into account when implementing an autonomous navigation system on an electric vehicle [11].

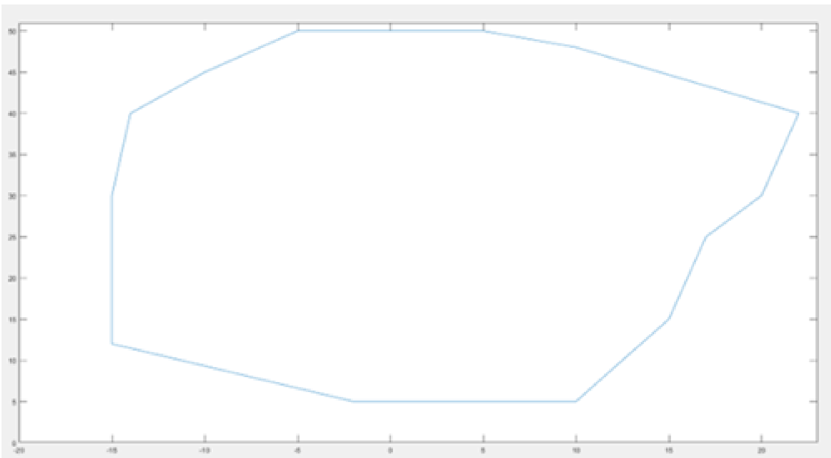

Fig.9. Navigation route imposed

Figure 10 shows the graph of the change in angle α for each pair of points separately, as well as the graph showing the time required to travel a distance between two points on the imposed trajectory. It is thus possible to carefully analyze the evolution of angle α according to each distinct point on the trajectory, highlighting the differences between its values for various pairs of points. The graph reveals how the angle α varies depending on the route taken, allowing a deeper understanding of the vehicle's behavior on the predetermined trajectory. In addition to this aspect, the time required to cover the distances between the points on the trajectory can also be seen in the graph. This graph shows the relationship between the distance traveled and the time required to perform this operation, providing an insight into the vehicle's performance on the required route. By combining these two aspects, a comprehensive approach is proposed to evaluate the behavior and performance of the autonomous electric vehicle on the set trajectory. Thus, possible deficiencies or optimizations that can be brought to the control system and the navigation algorithm can be identified to ensure a more precise, safe and efficient movement. These results make significant contributions to the field of autonomous vehicles, where a good understanding of the interaction between angle α and travel time between trajectory points is crucial for optimizing the autonomous driving experience.

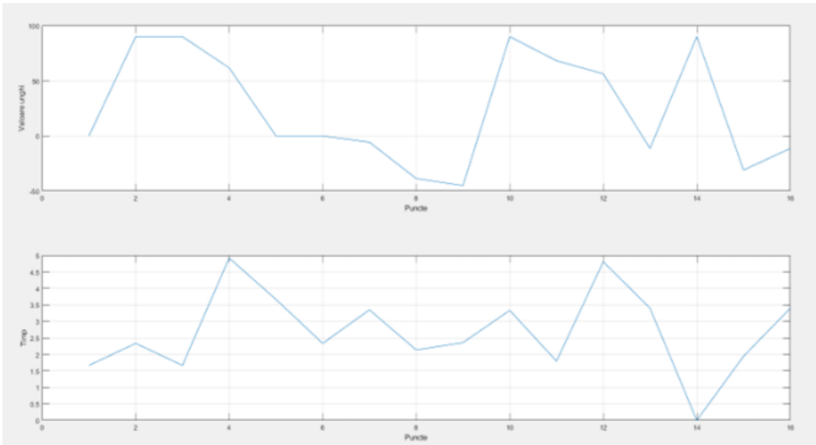

Fig.10. Graph of angle α and graph of travel time distance between two points

In Figure 11, we present the simulation system that plays a crucial role in our study. This system actually acquires the steering angle from the workspace, where it is meticulously calculated based on the desired trajectory. Afterwards, this calculated steering angle is skillfully translated into the precise direction of the vehicle's wheels. The integration of this simulation system marks an essential step in our research, as it allows us to analyze and optimize the steering behavior of the vehicle in relation to the desired trajectory. By accurately translating the calculated steering angle into actual wheel movements, we can assess the vehicle's ability to follow the intended path and make the necessary adjustments to improve its overall performance. This simple simulation system is an indispensable tool in our quest to develop and refine cutting-edge self-driving capabilities for the smart electric vehicle.

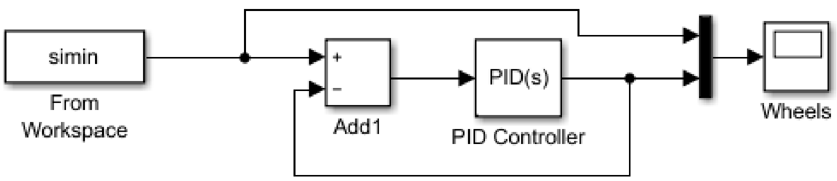

Fig.11. Simulation diagram for steering system

In Figure 12, we illustrate a vital aspect of our research, where the comparison between calculated and actual steering angles is shown. The blue curve represents the steering angle values meticulously calculated based on the imposed trajectory, while the red curve describes the real-time steering movements of the vehicle's wheels. This representation allows us to closely observe the alignment between the desired steering angles and the actual response of the vehicle during operation. Analyzing this data enables us to obtain valuable information about the accuracy and effectiveness of our steering control system.

Discrepancies or variations between calculated and actual steering angles can provide critical feedback for further refinement and optimization of our self-driving capabilities. By striving to minimize the gaps between the two curves, we aim to increase the precision and reliability of the vehicle's direction, consequently improving its ability to faithfully follow the imposed trajectory.

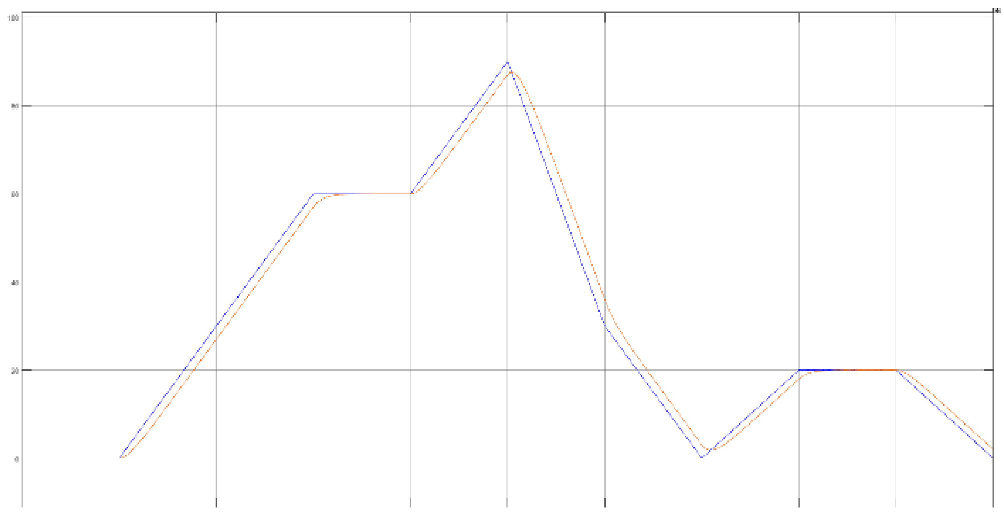

Fig.12. Steering simulation results

Figure 13 and Figure 14 show the difference between the imposed trajectory and the trajectory achieved by the autonomous electric vehicle if its starting point is inside the imposed trajectory and if the initial position is outside the imposed trajectory. Satisfactory results are observed even if the two curves do not overlap perfectly, the algorithm presenting some errors, something that can be improved by choosing more points to define the imposed trajectory. The curve of the trajectory made on the basis of the trajectory imposed using this algorithm is then superimposed over a certain area on the map of the studied space obtained with the help of the system based on LiDAR mapping and after it is established that the simulated route falls perfectly over the mapped area considering also a certain safety zone in relation to its proximities (the safety space in the industrial environment is usually considered 10%), the algorithm can be implemented in the software structure of the system thus obtaining an autonomous driving system.

Fig.13. The result of the simulation of the autonomous driving algorithm for the case where the initial position of the vehicle is inside the imposed trajectory [11]

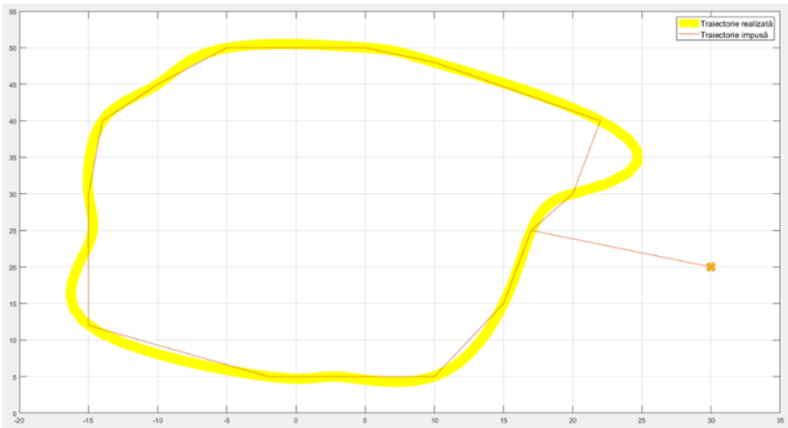

Fig14. The result of the simulation of the autonomous driving algorithm for the case where the initial position of the vehicle is outside the imposed trajectory [11]

Undoubtedly, the algorithm used in our study presents some errors when it comes to accurately achieving an imposed trajectory. However, it is important to note that despite these challenges, the algorithm remains a valuable asset that can be effectively integrated into the functional system of an electric vehicle. This integration is made possible by incorporating a sophisticated communication and location system along with a state-of-the-art LiDAR mapping system [12, 13]. As a result of this comprehensive integration, we successfully transform the electric vehicle into an autonomous entity.

The use of this algorithm in the functional system of our electric vehicle represents a significant step in this stage of research and development [14]. It lays the foundation for a fully autonomous electric vehicle that can navigate any type of environment with far above average precision and safety. Although some errors persist, they serve as valuable learning opportunities to refine and optimize the algorithm. Continuous improvement, guided by real-world data and feedback, is essential to enhance vehicle autonomy and ensure smooth tracking of the imposed trajectory. With the convergence of advanced communication, localization and mapping technologies, we can achieve an autonomous electric vehicle. The culmination of these efforts will ultimately lead to greener, safer and more efficient transport, revolutionizing the way we travel and shaping a sustainable future for generations to come [15].

4. CONCLUSIONS

This paper stands out for its dual focus on developing a precise steering control system, enhanced by a suite of sensors and a closed-loop algorithm, and a sophisticated software algorithm for autonomous navigation, underpinned by Matlab Simulink simulations and Lidar sensor data for environmental mapping. The cornerstone of this research is the hardware prototype, which employs a microcontroller and Lidar sensor to achieve exact steering control, crucial for the vehicle's precise maneuvering. This system's flexibility and modularity are highlighted, allowing for upgrades and adaptations as technology progresses. The integration of an interactive dashboard that displays vital performance metrics such as motor temperature, battery voltage, and current consumption in real-time further exemplifies the hardware's role in enhancing vehicle monitoring and safety. Parallelly, the software component's innovation lies in its algorithm for autonomous navigation. The algorithm, validated through simulations, utilizes Lidar-generated maps and defined coordinates to navigate the vehicle autonomously within a predefined trajectory, showcasing adaptability to environmental changes. The research illustrates the algorithm's capability to guide the vehicle efficiently, marking a significant step towards autonomous indoor mobility. The paper's findings contribute significantly to the field by demonstrating the successful integration of hardware and software systems for autonomous electric vehicles. It underscores the importance of a harmonized approach to vehicle design, where steering systems, navigation algorithms, and real-time monitoring coalesce to create a vehicle capable of intelligent autonomous operation in indoor environments. This research's implications extend beyond academic interest, offering insights into practical applications for autonomous electric vehicles in industrial, commercial, and residential settings. It lays a foundation for future advancements in autonomous mobility, emphasizing the need for continuous innovation in hardware and software development. The study serves as a testament to the potential of integrated technologies in transforming transportation, making strides towards safer, more efficient, and environmentally friendly autonomous vehicles.

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