ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Vol 10, Issue 10, October 2023

Future Perspectives of Autonomous Driving: Energy Saving, Smart Steering, from Basic Concepts of Autonomous Vehicles to Advancement Beyond Level 5

[1] Jinhong Sun, [2] Hebing Liu, [3] K.W.E. Cheng*, [4] Zhenxin Ye, [5] Zilin Li

[1] [2] [3] [4] [5] Power Electronics Research Centre, Department of EEE, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
Corresponding Author Email: [3] eric-cheng.cheng@polyu.edu.hk

Abstract*— Autonomous driving has emerged as a leading trend in vehicle development, particularly in the realm of electric vehicles (EVs). The controllability offered by EVs employing all-electric systems surpasses that of Internal Combustion Engine (ICE) vehicles. Significant progress has been made in the development of self-driving systems, leveraging advanced technologies such as Lidar, GPS, Radar, Ultrasonic sensors, and image processing. However, there remains a critical need to advance the integration of electric machine systems with autonomous driving capabilities. This paper focuses on the enhancement of dynamic performance through improved steering and power-driving systems in autonomous EVs. In particular, we explore the potential of in-wheel motors and powertrain technologies to deliver high dynamics and energy-efficient operation in autonomous driving scenarios. Additionally, we underscore the importance of addressing the complex energy-power characteristics specific to autonomous driving, as it is crucial for energy conservation and requires further improvement. The future levels l 6 and level 7 autonomous vehicles are discussed.

***Index Terms*—Autonomous vehicles, Energy saving, Smart Steering, Level 6 autonomous vehicle, Level 7 autonomous vehicle.**

I. INTRODUCTION

Autonomous driving vehicles, also known as self-driving vehicles[1], possess the ability to sense and operate in their environment without human intervention. Ideally, these vehicles should possess cognitive capabilities similar to the human brain, enabling them to make decisions beyond what is explicitly coded. In a matter of milliseconds, autonomous driving vehicles must process a comprehensive 360-degree view of their surroundings, comprehend this information, determine their own position, identify potential hazards, and make control decisions.

The advent of fully autonomous driving vehicles has the potential to bring about significant societal changes. They offer opportunities for unlimited individual mobility, particularly benefiting disabled individuals, the elderly, children, and adolescents. Cities can experience an improved quality of life, while the occurrence of traffic accidents and related emissions can be dramatically reduced. The benefits of autonomous driving vehicles can be summarized as:

- Improved Safety: Autonomous vehicles have the potential to significantly reduce the number of accidents caused by human error, as they are designed to operate with enhanced perception and reaction capabilities.
- Increased Efficiency: Autonomous vehicles can optimize driving patterns, leading to smoother traffic flow, reduced congestion, and improved fuel efficiency.
- Enhanced Accessibility: Self-driving cars can provide mobility solutions for individuals who are unable to drive, such as the elderly, disabled, and those without a driver's license.
- Time Savings: Passengers in autonomous vehicles can utilize travel time more productively, engaging in work, leisure activities, or relaxation during the commute.
- Environmental Benefits: Autonomous vehicles have the potential to reduce emissions by optimizing driving routes, minimizing traffic congestion, and facilitating the adoption of electric powertrains.
- Improved Traffic Management: Through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, autonomous vehicles can coordinate with each other and traffic systems, leading to smoother traffic flow and reduced travel times.
- Enhanced Road Capacity: Autonomous vehicles can operate at closer distances and communicate with each other, potentially increasing the capacity of existing road infrastructure.
- Reduced Costs: With the widespread adoption of autonomous vehicles, transportation costs may decrease due to optimized fuel consumption, reduced accidents, and decreased need for parking spaces.
- Improved Quality of Life: The introduction of autonomous vehicles can transform urban environments, reducing noise pollution, freeing up parking spaces for other purposes, and enhancing overall livability.

- Innovation and Economic Growth: The development and deployment of autonomous vehicles can drive technological advancements, create new industries, and generate economic growth through job creation and increased productivity.

The levels of autonomous driving are classified into six categories, ranging from L0 to L5, representing varying degrees of autonomy. Table 1 provides a brief overview of this classification.

Table 1: Six technology levels of autonomous driving vehicles

	Automation Level	Description
L0	No	Conventional vehicle. The driver has full control.
L1	Driver Assistance	The driver performs most of the driving tasks but with support from the technology to assist in driving
L2	Partial	The driver stays alert and the vehicle performs the basic driving function
L3	Conditional	The driver is expected to take over for a certain duration and the self-driving may not perform in some condition
L4	High	Driver/passenger can take over. The vehicle can also perform all the driving tasks
L5	Fully	No human interface. All the tasks are performed by the vehicle

Currently, autonomous driving technology falls under Level 2 - Partial Automation, where the driver must continuously monitor the driving system while having full control over gas, brakes, and steering. Advanced prototypes employ sensors to monitor the vehicle's surroundings, enabling automatic lane following, recognition of speed limit changes, and speed regulation under specific conditions, such as on highways. On separated roads, these vehicles can overtake others and perform evasive maneuvers. In traffic congestions, they can autonomously brake and resume driving within a defined timeframe. However, according to the SAE definition, the driver remains responsible for monitoring the surroundings. To ensure the driver's sustained attention, Level 2 systems require regular contact with the steering wheel. When a vehicle is in Level m3, more control is performed by the vehicle and the driver will have less demand.

Realizing a safe product with a high level of autonomous driving will require significant time and investment. While conventional autonomous vehicle research has primarily focused on driver and sensor-based imaging processing, there is a notable lack of development in electric power systems for autonomous vehicles.

This paper aims to develop a specialized application of autonomous vehicles and power electronics technology. The primary objective is to examine a Level 4 autonomous driving EV, characterized by high automation. In Level 4, the driver, who may assume the role of a passenger, is freed from monitoring traffic and can fully divert attention to other tasks as long as the systems operate correctly. The autonomous driving vehicle assumes complete responsibility for monitoring the surroundings and ensuring fail-safe measures, even in exceptional circumstances or system failures. The power development aspect focuses on the implementation of all-electric power steering and power regeneration systems integrated with the autonomous system. The proposed vehicle will enhance safety through advanced power control, energy management, and motor actuation for the powertrain.

Autonomous driving vehicles represent both an ambitious visionary goal and a highly achievable technological engineering endeavor. The race to introduce the industry's first fully autonomous driving vehicle is intensifying, with significant efforts aimed at overcoming technical challenges and realizing a completely new driving experience that will captivate and delight customers.

II. THE PROPOSED SYSTEM

A. The Basic component

The proposed autonomous driving vehicle system encompasses several key components, including the instruction system, sensor system, GPS, vehicle system, decision system, actuation system, and monitoring system is shown in Fig 1. Each of these components plays a critical role in enabling safe and efficient autonomous driving.

The instruction system serves to define the intended route for the vehicle, while the sensor system utilizes a variety of sensors such as video cameras, radar sensors, Lidar sensors, and ultrasonic sensors to perceive the vehicle's surrounding environment. The GPS system aids in navigation, providing location information for the vehicle. The vehicle system continuously monitors and relays real-time operational status updates. The decision system, powered by advanced AI algorithms, utilizes information from the instruction system, sensor system, GPS, and vehicle system to make informed decisions and control the vehicle accordingly. The actuation system is responsible for executing the decisions made by the decision system, enabling the vehicle to carry out specific maneuvers and actions. Lastly, the monitoring system ensures real-time monitoring of the vehicle's operation, providing vital feedback and oversight.

Together, these interconnected systems form a comprehensive autonomous driving solution, enabling the vehicle to navigate, perceive its environment, make intelligent decisions, execute actions, and continuously monitor its operation.

ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Vol 10, Issue 10, October 2023

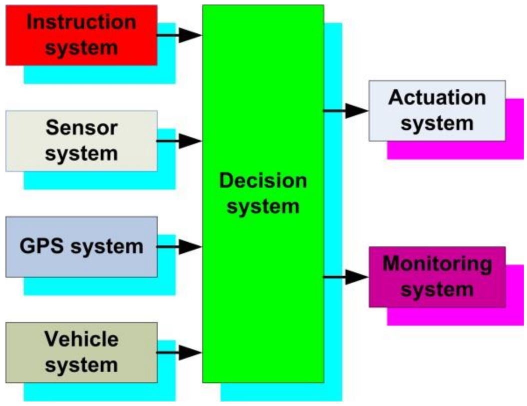


Fig 1 Proposed system structure

B. The architecture

The system encompasses both hardware and software development, working in conjunction to enable the autonomous vehicle's capabilities. Figure 2 provides a descriptive overview of the vehicle. The overall system considers various factors, including environmental conditions, hardware specifications, control parameters, characteristic evaluations, location assessments, and demand conditions. These aspects are taken into account and compared with the planned objectives to make informed decisions regarding the driving tasks. The system's ability to analyze and synthesize this information ensures optimized and safe autonomous driving operations.

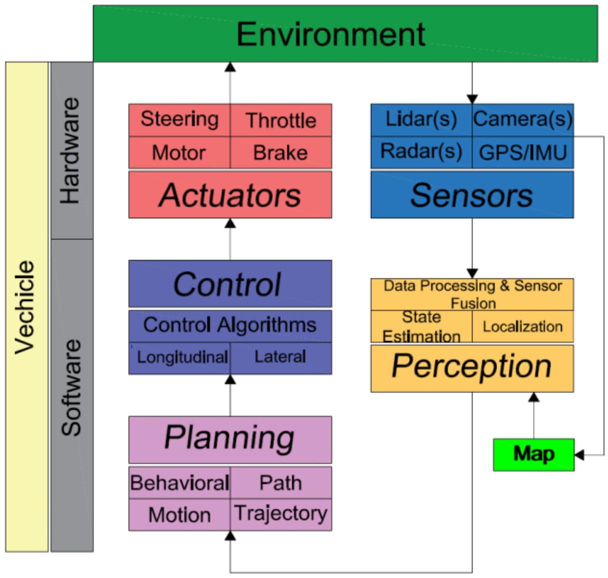


Fig 2 Software and hardware architecture of the proposed autonomous vehicle

III. SENSORS

The sensors to be used in the vehicles are described below:

A. IMU/GPS

The proposed autonomous driving vehicle system incorporates the use of an Inertial Measurement Unit (IMU) and GPS for accurate estimation of the vehicle's 3D orientation, heading, acceleration, and global vehicle states. The IMU provides measurements of acceleration and angular rates, allowing for the estimation of the vehicle's orientation in three-dimensional space. By combining these measurements with GPS data, which provides information on the vehicle's global position, the system can achieve a robust estimation of the vehicle's orientation and position. This integrated approach enables the system to obtain a coarse resolution estimation of the vehicle's 3D orientation, allowing for precise control and navigation in autonomous driving scenarios.

B. LIDAR

The autonomous driving vehicle system incorporates a LIDAR (Light Detection and Ranging) sensor, which plays a crucial role in sensing and mapping the surrounding environment. The LIDAR sensor employs a high number of beams, enabling it to capture a vast amount of data points per second while rotating at a specific rate. This allows for a wide detection range and field of view, crucial for long-range sensing.

Using the continuous stream of LIDAR points, the system creates a localization map that aids in estimating the precise location of the vehicle. By comparing different LIDAR maps, the system can determine the vehicle's movement and track its position accurately. The construction of the localization map utilizes point cloud techniques, which process and analyze the LIDAR data to create a comprehensive representation of the vehicle's surroundings. This detailed localization map provides essential information for navigation, obstacle detection, and overall situational awareness of the autonomous driving system.

C. Camera

The camera system in the autonomous driving vehicle serves as a crucial component for visual perception, enabling the vehicle to perceive and understand its environment. A stereo camera setup is utilized, providing depth estimation capabilities based on images captured from different perspectives. This allows for an accurate perception of distances and spatial relationships. The camera system is designed with high dynamic range and tones, enabling it to capture a wide range of lighting conditions and produce detailed images.

With a wide field of view and high resolution, the camera system captures a comprehensive view of the surroundings, ensuring a detailed representation of the environment. Object detection is performed using advanced algorithms that leverage probability estimation and semantic segmentation techniques. The system is trained to recognize specific objects of interest, enabling it to identify and classify various objects accurately. Additionally, the camera system is capable of counting the number of detected objects, providing valuable information for navigation and situational awareness.

IFERP
connecting engineers... developing research

ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Vol 10, Issue 10, October 2023

Fig 3 The recognition of the camera for autonomous vehicle sensors

IV. SENSORS, DATA PROCESSING AND TESTS

A. Data processing

The data flow and self-driving algorithm can be illustrated in Fig 4. The signal is then processed by the vehicle control unit (VCU) of the vehicle for the vehicle 4-wheel control and associated state analysis.

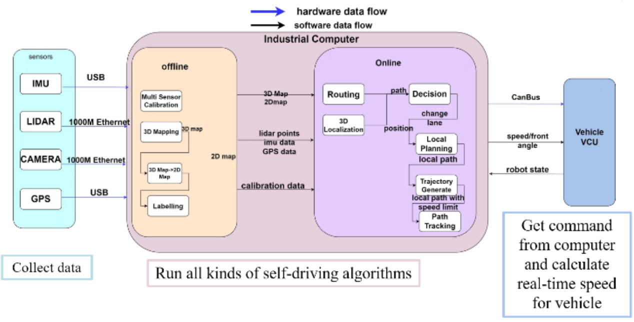


Fig 4: Data flow for the autonomous driving platform

B. Self-driving system

The self-driving architecture is illustrated in Fig 5. The environmental model is to convert the 3D mapping into a necessary 2D model and provide data for the driving control. This requires a process of a large amount of data. The data is then passed to the self-driving controller that provides the perception, decision, local planning and path tracking. Various algorithms needed for unmanned driving in realtime is needed to complete all the calculations and decisions with 100ms or less.

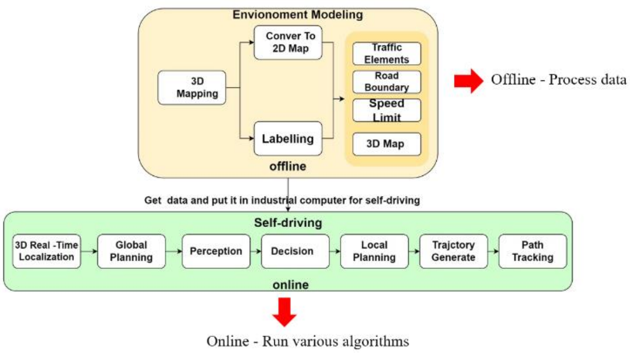


Fig 5 Self-driving system

C. 3-D Mapping algorithm

The framework of the 3-D mapping algorithm is shown in FI 6.

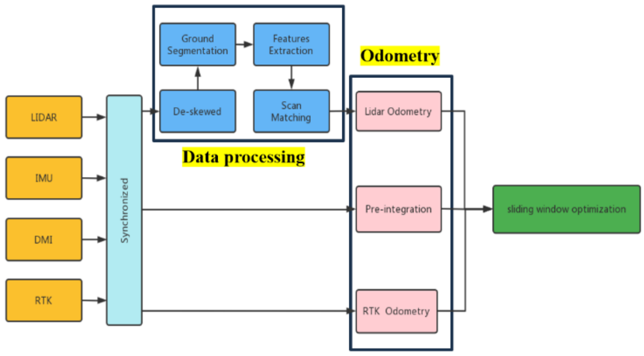


Fig 6: Framework for the mapping algorithm

In the context of 3D mapping, DMI stands for "Direct Mapping Interface" and RTK stands for "Real-Time Kinematic".

The Direct Mapping Interface (DMI) refers to a method or system that allows for direct integration between sensors or devices used for mapping and the mapping software or platform. It provides a streamlined and efficient way to connect and transfer data between different components of the mapping system. The DMI enables real-time data acquisition, processing, and visualization, allowing users to create accurate and up-to-date 3D maps.

Real-time kinematic (RTK) is a technique used in satellite-based positioning systems, such as the Global Navigation Satellite System (GNSS), to enhance the accuracy and precision of positioning data. RTK relies on a base station that provides reference measurements, while a rover receiver device receives signals from multiple satellites. By comparing the measurements from the base station and the rover, the RTK system can correct for errors caused by factors like atmospheric conditions and satellite clock discrepancies, resulting in highly accurate real-time positioning information.

The synchronized unit is to trigger a pulse signal to the sensor to receive a rising edge at the same time. The data processing unit is to conduct the point cloud motion compensation and extract features. The information from Lidar, IMU and GPS are combined for the data processing by the Odometry block. Finally, a sliding window optimization is used to optimize the states with a cost function.

V. PLANNING

The driving path planning is determined by the best planning in moving from A to be and also to avoid any accident [2].

A. Online trajectory planning

Fig 7 illustrates how a cost function is used to plan a driving trajectory. The technique is to minimize the cost that has components of smoothness, energy saving and safety [3].

ISSN (Online) 2394-2320
International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
Vol 10, Issue 10, October 2023

Other cost functions and criteria can also be added for the requirement of certain driving needs.

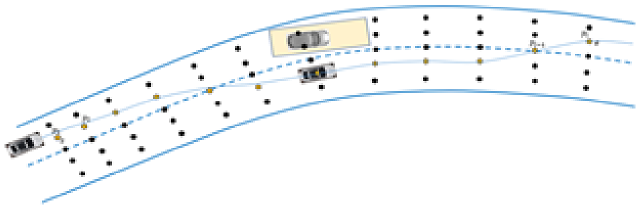


Fig 7: Illustration of the decision on the drive trajectory.

The cost function is shown in Eqn (1) which consists of the conditions of the three components:

$$cost = \underbrace{\sum_{n=1}^{N-1}((p_i - p_{i-1}) - (p_{i+1} - p_i))^2}_{\text{Smooth}} + \underbrace{\sum_{n=1}^{N}(p_i - p_{i-1})^2}_{\text{energy saving}} + \underbrace{\sum_{n=0}^{N}(p_i - r_i)^2}_{\text{Safety}}$$
$$p_i = (x_i, y_i) \quad (1)$$

B. Online decision-making algorithm for obstacle avoidance

The most important task for the city and any driving is to avoid the obstacle. This can be a stationary or a moving object. Fig 8 shows the schematic.

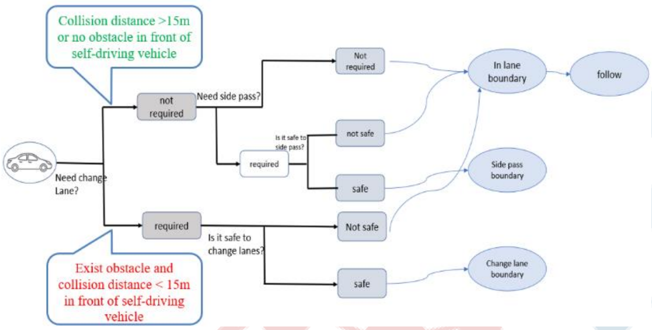


Fig 8: Obstacle avoidance

C. Speed prediction control for obstacle avoidance

Fig 9 shows the mechanism of the vehicle control and how to collide between two vehicles. The intersection of the other vehicle's predicted trajectory and the main vehicle's path is represented in the ST diagram shown above. The speed of the mina vehicle must be calculated as a control so that it can arrive at S2 and also with sufficient time and space gaps with obstacle vehicles.

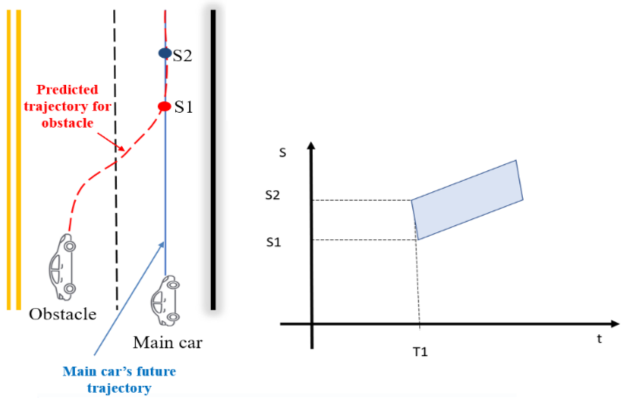
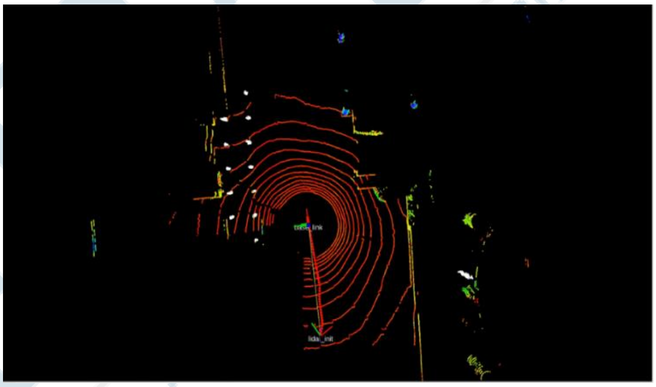


Fig 9 The speed control of the main vehicle

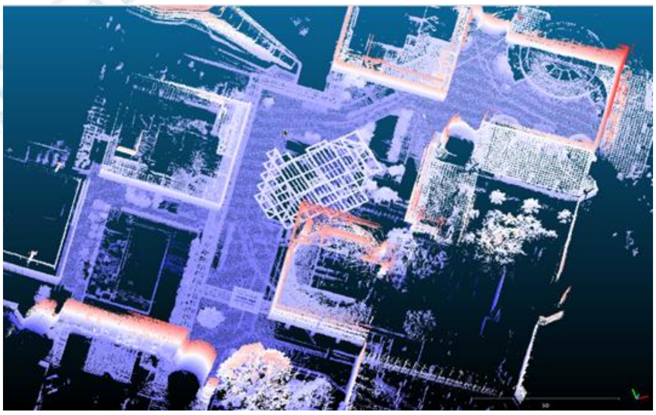
VI. MEASUREMENT

A. 3-D mapping results

3D mapping measurement for autonomous vehicles involves capturing and analyzing detailed spatial information of the surrounding environment. This process utilizes various sensors and technologies to create a comprehensive and accurate representation of the three-dimensional world. These measurements allow the autonomous vehicle's perception system to understand the scene's geometry, identify objects, and estimate their positions in 3D space. By continuously updating and integrating these measurements, autonomous vehicles can navigate safely, detect obstacles, plan optimal paths, and make informed decisions based on their understanding of the surrounding 3D environment. Fig 10 shows the 3D mapping of the main campus road of the university.



(a) The Measurement



(b) 3-D map of the experimental site

Fig 10: The measurement in the University

B. 3D conversion to 2-D map

The conversion from 3D mapping to 2D mapping for autonomous vehicle control involves transforming the rich and detailed three-dimensional representation of the environment into a simplified two-dimensional format. This conversion is necessary to extract relevant information and enable efficient decision-making for autonomous vehicle control. By reducing the mapping data to a 2D representation, the focus shifts to essential elements such as road boundaries,

ISSN (Online) 2394-2320
International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
Vol 10, Issue 10, October 2023

lane markings, and obstacle positions. This streamlined information allows the autonomous vehicle's control system to interpret and react to the environment effectively, facilitating safe and precise navigation. The conversion process involves extracting and projecting relevant information from the 3D map onto a 2D plane, providing the vehicle's control algorithms with the necessary inputs for real-time decision-making and control. The conversion example of the 3-D mapping to 2- map is illustrated in Fig 11.

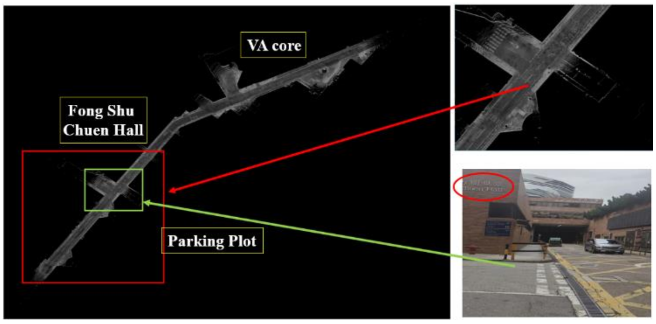


Fig 11: The 3-D to 2D map conversion

VII. DRIVER SIMULATOR AND TESTING

The proposed work is firstly focused on smart steering. The use of smart steering is to use differential speed control instead of the Ackerman steering. A simulation platform is first developed to examine the performance of the different speed controls.

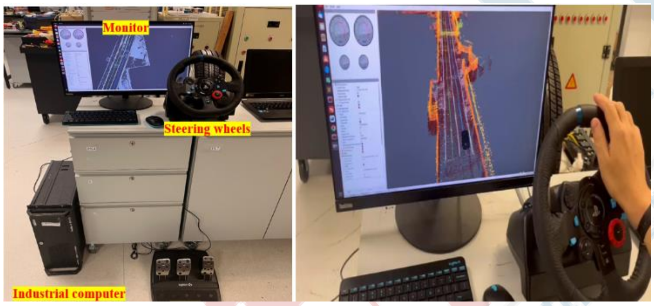


Fig 12 The smart steering test platform

VIII. ENERGY SAVING PLANNING

A. Basic energy saving

The basic energy saving is based on the best plan. The plan is determined by a number of energy consumption conditions. The emerging saving is the key study and the associated energy storage [4] is also a critical design consideration. There are various algorithms that can perform the best plan or the shortest path for energy saving. Fig 13 shows a basic trajectory decision for the energy-saving path. Fig 14 shows an example of how the best path is determined. In this case, an ant colony algorithm together with the energy-saving path is used for the decision-making.

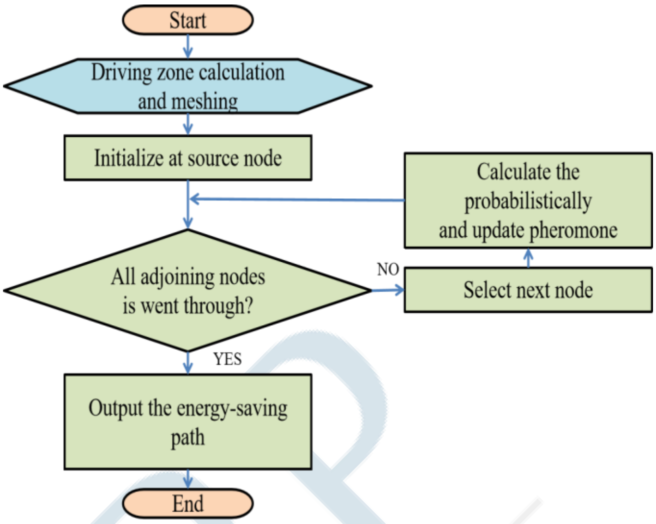
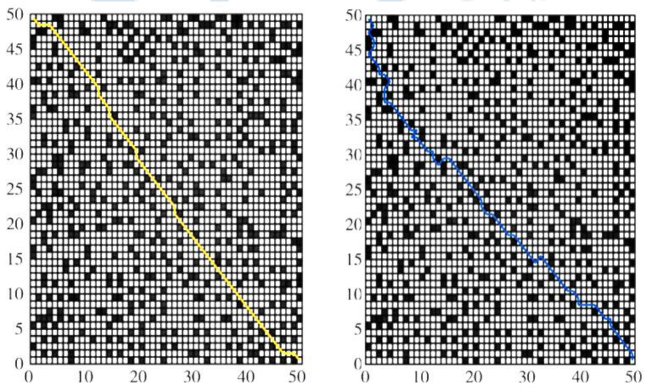


Fig 13 The flowchart of the energy-saving trajectory



(a) Traditional (b) Optimized

Fig 14: Comparison between the trajectory optimization using Ant Colony and differential speed motor control

B. Motor model and control

A schematic of the energy-saving path is shown in Fig 15. The energy saving requires a detailed model of the motor and motor drive models and also the vehicle structure and dynamics. Accurate motor model [5] is important as it is the key energy saving achievement in autonomous vehicles. Even the battery model is needed as it governs energy storage and energy storage efficiency.

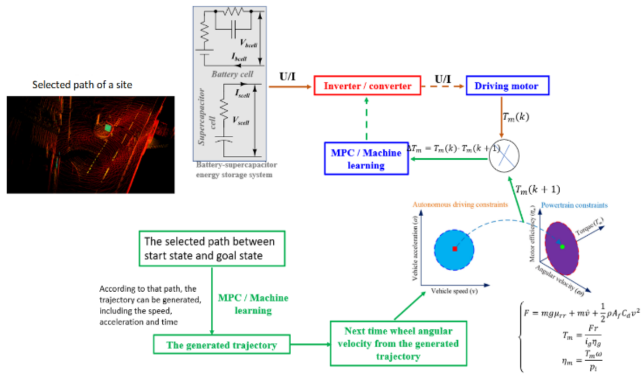


Fig 15 Schematic of the energy-saving program of the autonomous vehicle

IX. FUTURE DEVELOPMENT IN AUTONOMOUS VEHICLES

Level 0 to Level 5 has been well defined. Besides the future autonomous vehicles should have a better perception system [6], the future development of autonomous vehicles will be biased toward high automation, critical environments, and more robotic concepts because of the demand in future environments and AI and robotic systems. Higher energy saving and environmental concerns could be another new and major development. Therefore Levels 6 and 7 are proposed as follows:

A. Level 6

- Extreme Environment: Ability to operate in extreme weather conditions, such as heavy rain, snow, or fog.
- Complex route: Capability to navigate through more complex and dynamic environments, such as construction sites or crowded urban areas.
- Connected Vehicles: Ability to communicate with other vehicles and the surrounding infrastructure in real-time, such as traffic signals or road signs, to optimize traffic flow and safety.
- Advanced environment: Integration of advanced artificial intelligence and machine learning algorithms to enhance decision-making and improve the vehicle's understanding of its environment.
- Vehicle security: Enhanced security features to protect against cyber-attacks and ensure the safety of passengers and other road users.
- Energy saving: Increased sustainability features, such as energy-efficient systems and environmentally friendly materials, to reduce the vehicle's carbon footprint.

B. Level 7

This is a theoretical concept beyond the current state-of-the-art in autonomous vehicle technology. At this level, vehicles would be able to operate completely independently in all driving scenarios, without the need for any human intervention or oversight. Possible features:

- Complete environmental perception: The vehicle would have a sophisticated array of sensors, including cameras, lidar, radar, and other technologies, to accurately detect and analyze its surroundings in real time.
- Comprehensive decision-making capabilities: Level 7 autonomous vehicles would be able to make complex decisions on their own, including route planning, obstacle avoidance, and other critical driving functions.
- Advanced communication capabilities: These vehicles would be able to communicate with other vehicles, infrastructure, and pedestrians to optimize traffic flow and enhance safety.
- Redundant systems: To ensure maximum safety and reliability, Level 7 autonomous vehicles would have multiple backup systems in place, including redundant sensors, computing systems, and power sources.
- Self-diagnostic and self-repair capabilities: These vehicles would be able to detect and diagnose any issues with their systems and take corrective action on their own without human intervention.

X. CONCLUSION

This paper introduces a smart driving and energy-saving program designed for autonomous vehicles. The discussions within provide essential insights into the development of autonomous vehicle design, control, simulation, and experimental setup. The primary focus of this work lies in the advanced development of energy-saving techniques, addressing a crucial aspect that current autonomous vehicles have not fully explored. Future autonomous vehicles are expected to evolve towards extreme condition adaptation, robotic vehicles, energy-saving technologies, infrastructure improvements, and advanced system control. These advancements will pave the way for the realization of Level 6 and 7 autonomous systems, shaping the future of autonomous driving.

Acknowledgement:

This work is supported by the Innovation and Technology Fund, Hong Kong, under Project ITP/047/21AP.

REFERENCES

[1] Azim Eskandarian; Chaoxian Wu; Chuanyang Sun, “Research Advances and Challenges of Autonomous and Connected Ground Vehicles”, IEEE Transactions on Intelligent Transportation Systems, 2021, Vol 22, Issue: 2, pp. 683 - 711.

[2] Pengfei Lin; Manabu Tsukada, “Model Predictive Path-Planning Controller With Potential Function for Emergency Collision Avoidance on Highway Driving”, IEEE Robotics and Automation Letters, 2022, Vol. 7, Issue: 2, pp. 4662 – 4669.

[3] Hebing Liu; Jinhong Sun; Ka Wai Eric Cheng, “A Two-Layer Model Predictive Path-Tracking Control With Curvature Adaptive Method for High-Speed Autonomous Driving”, IEEE Access, 2023, Vol 11, pp. 89228 – 89239.

[4] K.W.E.Cheng, “Storage energy for classical switched mode power converters”, IEE Proceedings-Electric Power Applications, Vol. 150, Issue 4, July 2003, pp. 439-446.

[5] X. D. Xue, K. W. E. Cheng and S. L. Ho, “A Self-Training Numerical Method to Calculate the Magnetic Characteristics for Switched Reluctance Motor Drives”, IEEE Trans on Magnetics, Vol. 40, Issue: 2, 2004, Pp734 – 737.

[6] F. Sauerbeck, S. Huch, F. Fent, P. Karle, D. Kulmer, J. Betz, “Learn to See Fast: Lessons Learned From Autonomous Racing on How to Develop Perception Systems”, IEEE Access, 2023, Vol 11, pp. 44034 – 44050.