The Development of a Self-Driving Bus

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Abstract:- Emerging technologies have led to significant advancements in vehicle technology, particularly in the development and commercialization of autonomous vehicles. Self-driving technology aims to reduce collisions, save energy, and improve traffic conditions, and major car manufacturers and technology companies have invested nearly $80 billion in research and development. Experts predict that by 2030, self-driving cars will be reliable and affordable enough to replace most traditional vehicles. The market for autonomous driving is expected to reach $800 billion by 2035 and $7 trillion by 2050, potentially saving 585,000 lives between 2035 and 2045. The future of mobility will bring significant changes to the environment, with smarter and more connected roads, towns, and cities. Most people will likely experience autonomous driving through privately rented or shared ride vehicles. In response to this trend, governments and industry leaders have proposed self-driving bus solutions. Supported by the government, Taiwanese firms have successfully developed a self-driving bus by integrating automotive parts and systems and using artificial intelligence and deep learning for human-like vision and driving behavior. The self-driving bus has been verified through field tests, and its platform has been commercialized.

Keywords:- *Self-Driving Bus, Autonomous Vehicle, Artificial Intelligence, Innovation.*

I. INTRODUCTION

In recent years, emerging technologies in the fields of information, communication, and automatic control have led to changes in vehicle technology. One of the major changes is the development and commercialization of autonomous vehicle technology. Self-driving technology aims to reduce collisions, save energy and carbon, and improve traffic conditions [1] and is bound to become the mainstream of transportation technology in the future.

In the self-driving era, cars will be more efficient and comfortable to use. In order to realize the vision of autonomous driving and grab business opportunities, the world's major car manufacturers (such as Tesla and Toyota), technology companies (such as Google [2, 3], Apple, and Nvidia), and new companies (such as Uber, Lyft, and Zoox) have invested in research and development. So far, the cumulative investment amount has been nearly 80 billion dollars [1, 4, 5]. In recent years, the Consumer Electronics Show (CES) held in Las Vegas has become the best venue for many companies to explore automotive technology and artificial intelligence. Therefore, experts predict optimistically that by 2030, self-driving cars will be sufficiently reliable, the price will be acceptable to consumers, and they will be good enough to replace most traditional vehicles that require human driving [6]. According to a recent analysis by Lanctot [7], autonomous driving is a huge opportunity, with the market estimated to reach $800 billion by 2035 and $7 trillion by 2050. Due to the reduction in collisions, studies have also predicted that autonomous driving could save an estimated 585,000 lives between 2035 and 2045 [7].

According to Marr [8], the future of mobility will bring significant changes to the environment we live in, with roads, towns, and cities becoming smarter and more connected by up to 25%. These advancements will lead to some of the most exciting changes in mobility, both in the coming year and beyond. For most people, their first experience with autonomous driving is likely to be in a fleet of privately rented or shared ride vehicles, rather than a car they own themselves.

Facing the megatrend, over the past years, national governments and leaders in the automobile industry have proposed the use of self-driving buses. Supported by the government, Taiwanese firms have also initiated the development of self-driving vehicles in general, and self-driving buses in particular. The research has integrated automotive parts and systems, made by both local and global firms, for electric and autonomous vehicles. Artificial intelligence, mimicking human vision and driving behavior, is achieved by way of deep learning from data collected by high-definition (HD) cameras. After continuous training and validation, the vehicle can recognize the planned path and surroundings, allowing for an autonomous driving model. A self-driving bus has been successfully demonstrated in numerous field tests in Taiwan. Meanwhile, derivatives of the self-driving bus platform have been successfully commercialized.

The development of international automatic driving systems and the development of self-driving buses in advanced countries will be reviewed in Section II. Subsequently, the design of a self-driving bus will be introduced in Section III. Results of verifications and field tests of the self-driving bus will be introduced in Section IV. Problems and challenges faced by the self-driving bus will be discussed in Section V. Section VI concludes the work, with suggestions for future development.

II. LITERATURE REVIEW

A. The Development of International Automatic Driving Systems

This section analyzes the current status of self-driving bus development in the world and summarizes the policy planning and demonstrates the operational promotion of autonomous bus development in the United States, Europe, and Asia respectively. Finally, individual development cases are compared and analyzed as an important reference for developing the automatic driving system.

The main reason for the development of autonomous vehicles is that the future of transportation is increasingly facing severe challenges, including safety and efficiency concerns, limited energy resources, the impact of mobile pollution sources on the environment, and changes to the population structure, which have greatly impacted the use of driving vehicles. Moreover, with the revolutionary advances in hardware and software technology, the "Internet of everything" is gradually being popularized, computing power is rapidly increasing, big data is ubiquitous, and artificial intelligence is on the rise, which brings about the technical foundation and ability to develop autonomous driving.

According to the US Department of Transportation, autonomous vehicles can lead to safer roads, more efficient mobility, reduced congestion, improved fuel efficiency, reduced energy consumption, a cleaner environment, better land use, more positive social impacts, a better quality of life, and stronger partnerships. Based on the classification by the US National Highway Traffic Safety Administration (NHTSA) and the Society of Automotive Engineers (SAE), autonomous driving technology can be classified from Level 0 to Level 5. Table 1 classifies each technology, including steering operation, driving environment monitoring, dynamic driving task coping, system capability driving mode, etc. Fully autonomous (Level 5) means fully automated and fully supported by the system.

Table 1 Levels of Driving Automation" Standard for Self-Driving Vehicles

SAE Level	**SAE Name**	**SAE Narrative Defibnation**	**Excution of Steering/Acceleration /Decleration**	**Monitoring of Driving Environment**	**Fallback Performane of Dynamic Driving Task**	**System Capability (Driving Modes)**	**BAST level**	**NTHSA Level**
Human Driver Monitors the Driving Environment								
0	No Automation	The Full Time A Performance by the Human Driver of all Aspects of the Dynamic Dnving Task	Huamn Driver	Huamn Driver	Huamn Driver	N/A	Drive Only	0
1	Driver Assistance	The Driving Mode-Specific Execution by A Driver Assistance System of Either Steering or Acceleration /Deceteration	Human Driver and Systems	Human Driver	Human Driver	Some Dnving Modes	Assisted	1
2	Partial Automation	Part time or driving mode dependent execution by one or more driver assistance systems of both steering and acceleration/deceleration Human driver performs all other aspects of the dynam ic dnving task	System	Human Driver	Human Driver	Some Dnving Modes	Partially Automated	2
Automated driving system ('system') monitors the driving environment								
3	Conditional Automation	dnving mode- specific performance by an automated dnving system of all aspects of the dynamic dnving task - human driver does respond appropriately to a request to intervene	System	System	Human Dnver	Some Driving Modes	Highly Auto Mated	3
4	High Automation	driving mode- specific performance by an automated driving	System	System	System	Some Dnving Modes	Fully Automated	3/4

		system of all aspects of the dynamic driving task - human driver does not respond appropriately to a request to intervene						
5	Full Automa tion	full-time performance by an automated driving system of all aspects of the dynamic driving task under ail roadway and environmental conditions that can be managed by a hum an driver	System	System	System	Some Driving Modes		

Source: [9]

B. Development of Self-Driving Buses in Advanced Countries

➢ *Development of Self-Driving Buses in the United States*

- *Mcity*

Mcity is an autonomous driving system testing base jointly created by the Government of Michigan, the University of Michigan, and several research institutions. It is committed to creating a base that simulates real road conditions and provides an area for the testing and research of unmanned autonomous electric vehicles. It covers an area of 32 acres, including various intersections, signals, curves, roundabouts, and other elements. It's the best place for many teams to test in private.

- *Local Motors*

Local Motors, an American company founded in 2007, originally designed private vehicles for small-scale production and open sourcing. In 2016 Local Motors launched the Olli, an all-electric, fully autonomous self-driving bus. Olli is built by Local Motors, in partnership with IBM's Watson AI which supports the autonomous driving system. Local Motors is an innovative company that has used 3D printing in the past to produce vehicle parts, such as parts for the Olli. Powered by Watson, Olli also has an artificial intelligence system similar to Siri to enhance its ability to serve travelers.

- *Proterra*

Proterra, an American company, is already a leader in providing electric buses in the United States. Proterra electric buses have been used throughout the United States since 2009. Proterra has achieved remarkable results in developing and improving electric bus technologies, breaking records for range on a single charge, energy conversion efficiency, load, climbing, and acceleration performance. In mid-2017, Proterra announced that it would be working on self-driving buses, starting with the initial stages of collecting data and building a Light Detection and Ranging (LiDAR) system. Working with the University of Nevada, Reno, Proterra hopes to test self-driving buses in Las Vegas in the near future. With its established reputation and advanced electric bus technology, Proterra has the potential to create the first self-driving bus in the United States.

➢ *Development of Self-Driving Buses in Europe*

- *Easymile, France*

Easymile is a joint venture between French car brand Ligier and robotics brand Robosoft. Vehicle bodies are built by Ligier, software and backstage functions are provided by Easymile, and the current main model is the EZ10 shuttle. The EZ10 has been tested on the road in many cities around the world, and even put into commercial use. With adaptive programming, the EZ10 can function in many countries, and cities around the world are eager to cooperate with Easymile for testing.

- *German Benz Future Bus*

In addition to developing small vehicles equipped with autonomous driving systems, Benz is also developing self-driving buses. In 2016, a Benz Future Bus successfully drove 20 kilometers from Amsterdam Airport to Haarlem. The Benz Future Bus drove on town roads as well as the Dutch motorway. What made this test different is that the bus was connected to the city's infrastructure, such as traffic lights, so it could exchange information with local authorities. It even has cameras that can scan for potholes and send the data back to the government. In the past, Benz’s “Highway Pilot” automatic bus system was used to assist the basic functions of the bus such as keeping to a fixed speed on the highway. Future Bus’s software, City Pilot, is based on Highway Pilot. As the name implies, this autonomous driving system is designed to be used in cities. There are still drivers in the vehicle, but generally they do not have to intervene. The Future Bus will also be able to stop automatically, with its position accurate to within 10 centimeters.

- *French Navya*

Navya, a famous French self-driving bus company, was founded in 2014. Their fully electric, fully automatic small bus ARMA was launched in 2015. Until recently, France has been one of the most difficult countries in which to trial self-driving vehicles. Navya is one of the very few unmanned self-driving systems that truly reaches the fifth level of autonomous driving. The maximum operating speed of their 15-person small bus can reach 45km/hr, making it the fastest of the unmanned self-driving vehicles.

- *PostAuto Switzerland*

Postauto is a Swiss company owned by Postbus, the Swiss passenger transport company. Postauto began practical testing of self-driving buses in 2016. Testing was based on the ARMA model of the Navya team in France, coordinated with the software systems of Postauto team. It is named the SmartShuttle autonomous bus. Since the second half of 2016, it has been undergoing trials in the Sion area, and has also been sent to other countries and regions for testing. SmartShuttle also conducted a market survey to analyze the public's acceptance of self-driving buses. In Switzerland, 51% of people have no or very few concerns about autonomous driving systems. However, in Sion, after trial operations, the proportion increased to 62%, indicating that after riding experience, the public will not only have a better understanding of the autonomous self-driving system, but also have more confidence in it.

- *Swiss SBB*

SBB, a Swiss Federal Railways company, began piloting self-driving buses in 2017. The SBB tests were conducted within the Zug area. There were two self-driving buses in this trial operation. The self-driving bus system selected by SBB is Olli, developed by Local Motors in the United States, which is coordinated with the data and system of SBB's self-driving research plan. The goal is to put the self-driving bus system into use in 2020.

- *British TRL*

TRL, a British transport laboratory, began testing driverless self-propelled buses in Greenwich in 2017. The team is led by TRL, with participation from a number of universities, local institutions and companies such as Shell. TRL's self-driving bus, called the GATEway Project, has no steering wheel or gas pedal inside, and aims to achieve Level 5 autonomy through self-driving technology. GATEway aims to begin a larger trial operation in 2019.

- *Netherlands*

The Dutch Automated Vehicle Research and Development Demonstration Program (Dutch Automated Vehicle Initiative) is a project organized by TU Delft University of Technology (TU Delft) and the Netherlands Applied Science Research Organization in 2015 (TNO), AutomotiveNL, and other teams to investigate, improve and demonstrate the feasibility of autonomous driving technology for general road use. The project includes verification of technical feasibility, behavioral studies, safety proofing, legal compliance review, and public awareness building. The program uses a variety of vehicles, including Toyota Priuses, to test autonomous driving technology imported from TNO and TU Delft. Testing includes situations such as automatic steering and flow entry. The plan also classifies five levels of autonomous driving, including acceleration and deceleration controls, environmental monitoring, and driving situations that can be controlled by the system.

The project plan of the Dutch automatic vehicle research and development (DAVI) is very wide-ranging, from technical verification and behavior analysis to legal review, and worth further investigation.

C. *Development of self-driving buses in Asia*

- *NTU, Singapore*

Nanyang Technological University in Singapore has been developing driverless bus technology since 2013 and began testing it in multiple locations in 2016. Singapore aims to fully implement self-driving bus technology by 2020. Apart from the mature conditions for technological development, government support is also a key factor. NTU's self-driving electric vehicle, in partnership with Navya, is among the fastest driverless self-driving buses in Asia.

- *ST Kinetics, Singapore*

Another Singaporean company, ST Kinetic, has been contracted by the Land Transport Authority to develop an autonomous bus system. The plan is for three and a half years of testing to be completed by October 2020. Unlike other schemes in development, ST Kinetics plans to produce an autonomous bus that can carry up to 40 people and is expected to reach a top speed of 60 kph. The Land Transport Authority said it would like to develop high-capacity driverless buses in the hope of transporting rush-hour passengers on larger buses in the future. It aims to have the project on the road after 2020. In addition to the 40-seater buses, ST Kinetics has also signed separate contracts with Singapore's Transport Ministry and Sentosa Development Authority to test 20-seater autonomous buses for two years. The project aims to enable tourists in Sentosa to connect to the driverless bus operating system via a smartphone app in the future. The system will determine the route of the driverless bus according to travel needs and monitor it with local closed-circuit television. Self-driving buses with seats for 20 people will travel at speeds of up to 80 kilometers per hour.

- *Hyundai of South Korea*

Hyundai Motor, a major South Korean automaker, is also developing self-driving bus technology in addition to self-driving minibuses. The South Korean Government pushed hard to have self-driving buses in trial operation in 2018 as it hosts the Pyeongchang Winter Olympics, and Hyundai is seen as the company most likely to be selected in time for the games. Hyundai is the leader in the process, with six out of the 12 paper test permits issued by the Korean government. The pilot route will connect Pangyo, known as Korea's Silicon Valley, with Pangyo Station (a 2.5-kilometer distance) and the company complex.

- *Japanese DeNA*

DeNA, a Japanese company, has a self-driving bus system called Robot Shuttle. Robot Shuttle is DeNA's autonomous self-propelled bus model based on the EZ10 of Easymile of France operated with the software of a Japanese team. At present, Robot Shuttle has carried out several tests. Japan aims to provide unmanned self-driving services for the Tokyo Olympic Games in 2020. Robot Shuttle is also expected to provide simple services with fixed routes, such as short shuttle connections.

➢ *Comparisons*

To sum up the above-mentioned cases, statistics for passenger capacity, maximum speed, mileage, test speed, time to market, and other information of various autonomous driving vehicles are presented in the following Table 2, which further remarks about whether there have been actual road tests and the actual outcomes of road environment tests in Asia, as a reference for the site selection of the subsequent test operation environment of this plan. In the future, this plan will further discuss the legal environment of autonomous driving vehicles from domestic and foreign cases, as a reference for our related traffic and vehicle regulations.

Table 2 Comparisons of Solutions for Self Driving Buses

Type	**Capacity (People)**	**Maximum Speed （km/h）**	**Single charge mileage**	**Trial Operations**	**Test Speed （km/h）**	**Road Test in Asia**	**Technology Readiness**	**Time of Introduction**
Proterra Project	N/A	N/A	N/A	No	N/A	No	Low	N/A
Local Motors – Olli	12	40	58km	Yes	19	No	Middle	2019
Navya -ARMA	15	45	5N/A13hr	Seveal	25	Yes	High	2018
Easymile –EZ10	12	40	14hr	Seveal	20	Yes	High	2017
Benz – Future Bus	N/A	70	N/A	One	70	No	Low	N/A
TRL –GATEway	3	25	N/A	One	16	No	Middle	2019
Postautos – SmartShuttle	11	45	130km	One	20	No	High	2018
SBB –Olli	10	40	58km	One	N/A	No	Middle	2020
DeNA – Robot Shuttle	12	40	14hr	One	10	Yes	High	2020
Hyundai Project	12	N/A	N/A	One	30	Yes	Low	2019
NTU -ARMA	15	45	130km	One	25	Yes	High	2020
ST Kinetics Project	40	60	30N/A50km	No	N/A	Yes	Low	2020

Remark: N/A means not available.

III. DESIGN OF THE SELF-DRIVING BUS

In this section, details regarding the automatic driving system and vehicle sensing equipment, including the automatic driving system, positioning navigation point tracking, environment awareness, autopilot deep learning method, and infrastructure and operation planning will be introduced. When fully loaded, the maximum speed of the vehicle is 28 km/h, the climbing force is more than 20%, endurance is more than 100 km, and the charging time is about 10-12 hours. The performance of the vehicle is sufficient for at least six hours of daily operation at the test site. Vehicle specifications are detailed in Table 3 below.

Table 3 Specification of the Self-Driving Bus

Item	**Contents**
Length × width × height	4,800×1,500×1,965 mm^3
Seat number	8
wheelbase	2,580 mm
Empty weight	1200 kg
Top speed (full load)	28 km/h
Climbing force (full load)	20%
Motor	7.5KW/72V AC Motor
Battery capacity	14 kwh
Cruising endurance	≥100 km
Brake system	Double circuit hydraulic brake; front disk and back drum

A. *Automatic Driving System*

The project uses Nvidia DRIVE™ PX, an open artificially intelligent vehicle computing platform that instantly understands the vehicle's surroundings, accurately locates the vehicle on HD maps, and plans a safe route. Combined with deep learning, sensor fusion, and surround vision, the architecture can be expanded to support various settings. Through an integrated architecture, deep neural networks can be trained on data center systems before being deployed on vehicles.

Nvidia is the only existing chip manufacturer with the highest mastery of artificial intelligence technology. From the bottom of the computing module to the top of the neural network training the application has complete hardware and software support. According to Nvidia (2018), DRIVE PX "merges data from multiple cameras, radar, and ultrasonic sensors, allowing the algorithm to accurately interpret the full 360-degree environment around the vehicle, presenting the most complete picture possible, including static and dynamic objects. Using deep neural networks to detect and classify objects greatly improves the accuracy of the sensor data after fusion."

The autonomous driving of vehicles in this project is mainly achieved through an artificial intelligence control system and deep learning core technology. The artificial intelligence control is completed by positioning and navigation (global planning) and environment awareness (local planning), which are described below.

B. *Positioning Navigation Point Tracking*

The first step is positioning and navigation. This plan uses an Inertial Measurement Unit (IMU)-enhanced GPS combined with high-precision maps (HD maps) to conduct accurate positioning and overall path planning through map assets and positioning components. The first step of automatic driving is completed, which determines the general direction of the vehicle path planning and follows the path.

The waypoint tracking module is the driving route planned by the navigation system according to the starting and ending points and the pre-established static map, as well as the general direction of the traveling route. During driving, dynamic obstacle avoidance is carried out by the local planner, which integrates various sensor information to reconstruct the dynamic obstacle scene.

The main work of waypoint tracking is to enable vehicles to locate their location in real-time to confirm whether they are still on the planned path. This project adopts the IMU-enhanced GPS combined with high-precision maps for real-time positioning and real-time pathing, precise positioning, and path planning.

C. Environment Awareness

The second step is environmental awareness, that is, the real-time route adjustment and micro-amplitude-change decisions made by the identification of objects and lane judgment while the vehicle is running. This part is controlled by AI and depends on the information provided by sensors. However, this plan incorporates different sensors, including a camera (image), radar, and LiDAR to judge the target and lane, and integrated sensor feedback information for regional end path planning (lane selection, obstacle avoidance, etc.).

The perception model can be divided into two key functions, namely target identification and driveable space identification. The core logic of the perception model is to identify the target and driveable space through continuous operation so that the autonomous vehicle can understand the driveable area and obstacles to avoid to make correct route selections. The proposed sensors are a combination of image, radar echo, and optical radar sensors to make up for the shortcomings of each sensor and greatly improve the sensing accuracy.

Image recognition using a photographic lens can simultaneously target identifiable objects in view and determine a specific object’s possible behavior after tracking it, but it is difficult to reach sufficient accuracy to judge the distance and actual size of the object.

At this time, the radar is used to judge the distance and size of the object, and the radar can also track the direction of the object, and this information can also be fed back to the imaging system to assist in tracking the object.

The vehicles in the scheme are equipped with an obstacle detection system using optical sweep sensors that can detect obstacles up to 7 cm wide at a range of 40 to 100 metres and use fail-safe detection to scan the area in front of the vehicle. The obstacle detection system plugs directly into the low-level motion controller and interrupts navigational tasks. Obstacle detection can distinguish between actual detection targets and "ghost" detection targets, such as rain, snow, or falling leaves.

The sensor has a wide aperture and four layers of scanning, a scanning base (vehicle scanning path), and an extended body. Both body sections are divided into cells and each cell is scanned several times per second to determine the presence of a target probability factor. Based on the calculated probability of the target’s reaction, it is converted into an adaptive velocity curve. The vehicle will slow down when an obstacle is detected and stop if necessary. The following Table 4 lists the sensing equipment used in the project.

D. Deep Learning Method For Autopilot

Automated driving requires continuous deep learning to accumulate experience of various scenes, learn to cope with different scenarios, and establish a Deep Neural Networks (DNNs) model, that is, gradually reduce the dependence of the system on human intervention, thereby upgrading the level of automation.

Table 4 Devices Adopted by the Self-Driving Bus

Device	**Brand/Model**	**Application**
Camera-A	Whetron WS CAMERA-100	Image Recognition
Camera-B	Sekonix AR0231-SF3322/AR0231-SF3323	Auxiliary Image Identification
Sonic sensor (plus 1 ECU)	Whetron IRC-APA-12S-000	Detection of objects and obstacles
Touch screen	GeChic On-Lap1002	Vehicle equipment operation and setting
GPS	Xsens (MTi-G-710-2A8G4) MTi-G-710-GPS/AHRS RS232, USB	Positioning and navigation
Lidar	Velodyne VLP-16	Object and obstacle detection

The process of deep learning in an autonomous vehicle involves implementing various deep neural networks to sense and understand the environment, locate the vehicle on a high-resolution map, predict the behavior and location of other objects, calculate vehicle dynamics, and plan safe driving paths. The project introduces Nvidia's newly announced DX-2 deep learning server system. Through integrated architecture and enhanced computing power, deep neural networks can be trained in a central data center. Then it can be deployed on the vehicle, reducing the neural network training time in the data center from several months to several days.

During the process, data such as information from the controller area network (CAN), surrounding image data, and distance traveled must be collected, and the data processed (interpreting and labeling). The inference testing phase is based on the inference center training, and the model can be validated (refer Figure 1).

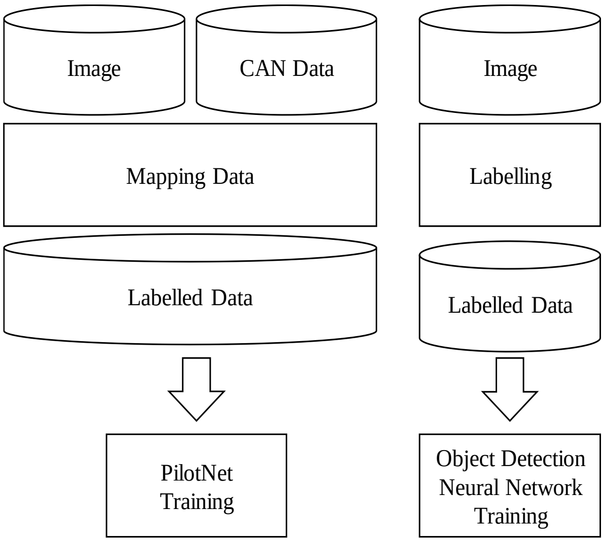

Fig 1 Deep Learning Process of DNNs

E. Infrastructure and Operation Planning

➢ *High Precision Maps*

HD maps contain high-precision coordinates, accurate road markers, road signs, the number of lanes, and include mapping layers information such as vertical slope, curvature, roll, and surrounding objects. Activity layers can be updated with real-time traffic conditions, weather, obstacles, etc.

3D video geographic information system (GIS) technology is used in high-precision map production. This technology is derived from CV (Camera Vector) technology, which combines continuous images into one and forms a real stereo space. It can be fully integrated with 2D layers of the ArcGIS and GIS databases to achieve real-time interactive applications. At the same time, with LiDAR point cloud information, three-dimensional high-precision maps can be constructed.

The generation process of a high-precision map is to first integrate the topographic map and electronic map of 1/1000 along each operation route of the autonomous vehicles in the area of field test. The results serve as the basic map. An image acquisition vehicle (with 2 high-level 64-128 LiDAR and more than 4 cameras) is used for measurement along the route, and the 3D Video GIS technology is employed. Combined with the three-dimensional circumnavigation GIS map (LiDAR point cloud), the survey results are finally integrated based on the Image Mobile Mapping System (IMMS), and the measurement accuracy is mainly based on a three-dimensional image map of at least 10cm resolution. After manual editing, deindexing, and image blur processing, a three-dimensional high-precision map can be constructed (the integration result of the image, point cloud, and two-dimensional high-precision electronic map). The information contains dynamic and static data. The dynamic data consists of a real-time road condition layer and a traffic event layer, while the static data includes data an update layer, traffic facility layer, lane layer, and road layer.

High-precision images can be obtained by the above method. The data processing technology and POS trajectory calculation require automatic image tone correction, automatic ground dead angle compensation of the ring landscape image, GNSS satellite signal processing, POS trajectory calculation, and CV image (Camera Vector) fusion. In this way, it can improve the efficiency of signal calculation against the high-rise shelter and multipath effect, and also greatly reduce the need for ground control point layouts to achieve the required accuracy, and provide unmanned vehicle navigation, obstacle avoidance, stopping, and other AI learning references.

IV. FIELD EXPERIMENTS AND RESULTS

Field tests of the self-driving buses were initiated in February, 2017, in Taoyuan Exposition, Taiwan. During the test ride, we planned to survey passenger satisfaction by questionnaires. 1,242 questionnaires were collected before the ride, and 1,223 questionnaires were collected after the ride. The error was less than 2.83% at a 95% confidence level. According to the answers, passengers were given 4 points for being very satisfied, 3 points for being satisfied, 2 points for being average, 1 point for being dissatisfied, and 0 points for being very dissatisfied. In terms of the level of satisfaction with safety, comfort, and overall service, the actual satisfaction with self-driving cars is higher than the expectation before riding. In terms of specifics, 78% of passengers think "ride stability" is an important factor before riding, and 28% of passengers suggest that "ride stability" should be further improved after riding.

In July 2018, four medium-sized buses and two shuttles were produced as prototypes and tested in Lihpao Amusement Park, Taichung, Taiwan. They served on three routes connecting the parking lot, a hotel, the amusement park, and a racing track.

After that, a field test in Taoyuan MRT stations started in September, 2019. A 6-meter autonomous driving bus offered regular passenger service within the train depot and traveled over 5,000 km. A traffic light was installed to test vehicle-to-infrastructure synchronization. In February, 2020, 6-meter and 4-meter prototypes passed 45 scenarios in the national AV testing circuit, certified by TÜV Rheinland [10].

Starting in May 2020, two autonomous driving buses could be called at all bus stops along the 8.3 km bus lane in downtown Taipei at off-peak hours. Roadside units were developed and installed at major road intersections for comprehensive safety assessment. A 5G private network and an operation and control center were established. Traffic light status is calibrated and integrated with the system. The total mileage exceeds 2,000 km, and over 3,000 people have been onboard [10].

Then, in February, 2021, a 6-meter autonomous driving bus was put to service in a residential area, on the open road with mixed traffic flow, including scooters. Seven roadside units were installed. The AV travels more than 3,000 km and takes over 1,000 passengers. Recently, the smart golf cart fleet was first successfully commercially deployed in May 2022. The golf carts give golfers the safety, privacy, and freedom to take control of their pace of play. Real-time information about vehicle statuses can be accessed by the golf course owner or operator via administrative systems [10].

V. DISCUSSION

The design of the self-driving bus has been verified as successful through the road tests. Meanwhile, the platform of the self-driving bus has successfully been implemented in various categories of self-driving buses. However, problems faced in the field tests merit further discussion and investigations.

A. End-to-end deep learning

In terms of technology, as the driving location is constantly changing and there is no fixed scene to be used as a reference, the LiDAR cannot be used for Simultaneous Localization and Mapping (also known as SLAM), and GPS combined with high-precision map cannot be used to realize positioning and navigation. In addition, the vehicle dynamic control algorithm was not perfect at that time, and it was difficult to accurately control the steering. In order to make the vehicle run automatically, the plan decided to adopt "end-to-end deep learning".

"End-to-end deep learning" means that, given the input and output data, a deep neural network can be trained to "automatically learn" how to go from one location to another without having to manually establish an end-to-end processing process. This project uses the neural network PilotNet built by Nvidia. The input data is the actual road image and the output data is the steering control data of human drivers. The trained PilotNet model can judge how to control the vehicle according to the new input images.

The fascinating thing about deep learning is that models surprise, sometimes learning more than expected. Because we train the model based on human driving behavior in real road conditions, the model may learn more than the intended goal. For example, after the program ended, the vehicles moved to a new location for the test. Not only did they recognize the white lane markings and follow them without any advance work, but they also recognized the parking lanes and parked in them. They also slightly avoided pedestrians, which means they could draw parallels.

However, relying solely on the results of deep learning has its drawbacks. When the amount of data is not diverse enough, the model cannot really exert its power. For example, the "road" defined in this plan is white lane markings, so the model only recognizes white lines; If there is no white line to refer to, it will fail, but an actual road may contain no markings, different road materials, and so on. This is the limitation of the deep learning model.

In the approach to artificial intelligence, rule-based decision models and deep learning models both excel, and the transition from the former to the latter should be a gradual process, much like the human concept of learning new things – advanced learners use their knowledge to figure out how new situations and formulate rules within that framework; the younger generation will use textbooks to get started. After accumulating enough basic knowledge, they will naturally find that there are too many things that textbooks cannot cover, so they begin to read extensively, collect a lot of information, and finally learn from one another. On the other hand, if starting from scratch means taking in a lot of information aimlessly, humans will have no control over what they learn.

B. Obstacle Avoidance and Detour Functions

At that time, this plan did not achieve the function of object avoidance and rerouting. During the Nongbo operation, the vehicle made a decision to stop after detecting obstacles, and only continued to drive after the obstacles were cleared. The decision-making process to make a detour is quite complicated. It is necessary to first detect obstacles in front of the predetermined route, then judge all alternative routes that can be taken (map information, traffic rules, etc., must be checked at the same time), and then judge whether there are obstacles on each alternative path, so as to select the most appropriate alternative path and control vehicle steering and speed. Machine learning alone is far from enough, requiring a high degree of integration of positioning, navigation, perception, decision-making and other modules. These are the key items of follow-up research and development for the implementation team of this plan.

C. Future Development Proposals and Demonstrations on the Open Road

The operation field of the project is a closed area, and there are still many challenges to be overcome in future operations on actual roads with mixed traffic flow. Closed areas may replicate all the static elements of a real road, such as roads, markers, signals, etc., but they still lack the most difficult pedestrians and vehicles. In other words, if a self-driving car is to operate on the open road, it must be able to deal with people and cars first.

After this plan was completed, the team continued to develop the autonomous driving system (refer Table 2), gradually building full autonomous driving capabilities to enable vehicles to achieve SAE Level 4 and even Level 5 on the open road. Many of the projects in the above architecture could and should have been validated first in closed or simulated fields. For example, localization, decision module partial functions (lane following, bypass), vehicle control, as well as some basic perception and corresponding decisions can also be tested in closed areas. The experience of testing in closed areas can be used as a basis for application on open roads.

As for how to deal with the complex mixed traffic flow, especially locomotives, it is still necessary to identify locomotives visually through deep learning artificial intelligence, and then try to explore the behavior pattern of locomotives in simulators. Through thousands of simulations and models, real-world data will continue to accumulate. There are no shortcuts to this learning process. In addition, the speed of system identification is limited due to the limitations of the computing power of the vehicle computing platform (or rather, platforms with high computing power are highly expensive and do not have commercial competitiveness). Over time, as performance improves and prices fall, devices will become more capable of instantly identifying large numbers of moving objects at high speeds.

In addition, Vehicle to Everything (V2X) technology can be used to assist autonomous vehicles to cope with people and vehicle dynamics on the road. The installation of V2X devices at intersections with heavy traffic and complex vehicular and human behavior should help autonomous vehicles detect the movement of vehicles in blind spots, out of sight, and coming from the side. The content of V2X is extensive and diverse. However, for autonomous vehicles, if roadside Infrastructure to Vehicle (I2V) communication can be realized and cameras, radars and other devices on the roadside can sense people and vehicles and then instantly transmit that data to the computing platforms of autonomous vehicles, the safety of self-driving cars in mixed traffic flow will be improved.

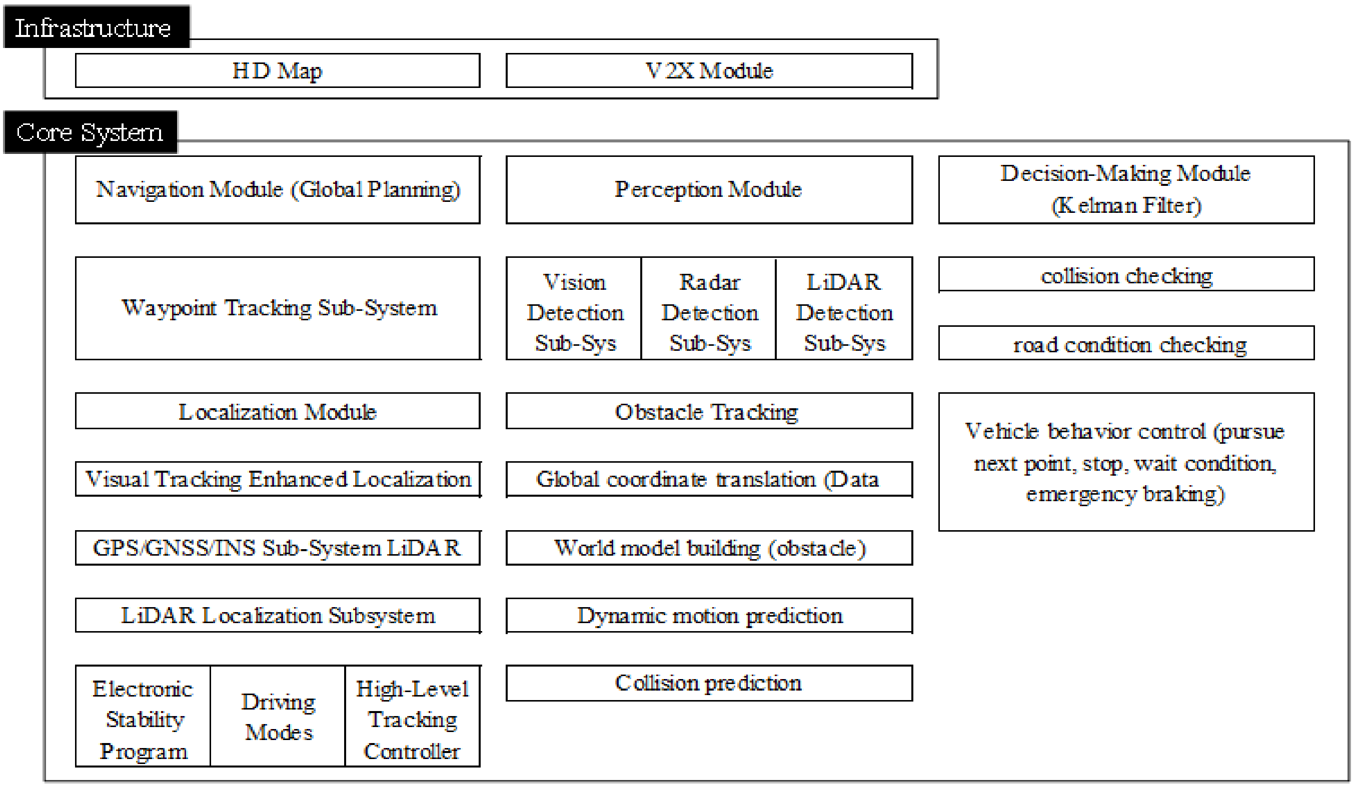

Fig 2 Autonomous Driving System Development Project

VI. CONCLUSIONS

The development and commercialization of autonomous vehicles have been accelerated by emerging technologies. Almost $80 billion has been invested in self-driving technology to reduce collisions, save energy, and improve traffic conditions. In response to this trend, governments and industry leaders have proposed self-driving buses. With government support, Taiwanese firms have developed self-driving buses that integrate automotive parts and systems and use artificial intelligence and deep learning for human-like driving behavior.

In the future, the Government should grasp the momentum of the global development of self-driving cars, integrate relevant ministerial resources, improve the testing environment and regulations, build an autonomous vehicle platform, and discuss with relevant industry, education, and research institutions the application of self-driving cars in parks and rural connections, public transport station connections and other services.

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