The development and application of Taiwan HD Maps for smart mobile mapping technology

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Abstract

The rapid advancement of Intelligent Transport Systems (ITS) has significantly propelled the development of autonomous vehicle technologies in recent years. HD Maps are crucial for autonomous driving technology due to their high accuracy, rich road scene semantic data, real-time traffic conditions, and driving experience information. However, how to produce HD Maps efficiently and meet the accuracy for autonomous vehicles are important challenge. This study proposes related methods to meet the requirement. First one is to publish HD Maps guidelines and standards which are published since 2018, with updated versions scheduled for publication in 2024 and 2025. These documents outline the operating procedures, content format, verification details, and other information to ensure that the final HD Maps maintain consistent accuracy and quality. Second, a semi-automated HD Maps production tool to generate lane lines, stop lines, crosswalks, and other features essential for autonomous vehicle control systems is proposed. This study also defines the procedures and variant detection tools for certified third-party mapping technologies. These tools are designed to improve the efficiency of HD Maps production while reducing costs. Finally, this study creates seamless outdoor and indoor HD Maps in Taiwan which includes closed fields, real roads, and indoor parking lots, supports various application scenarios for autonomous vehicles. This integrated approach not only promotes the advancement of autonomous driving technologies but also drives improvements in mapping methodologies. Establishing a robust HD Maps infrastructure is expected to accelerate the development of fully autonomous vehicles, bringing their widespread deployment closer to reality.

1. INTRODUCTION

The rapid advancement of Intelligent Transport Systems (ITS) has significantly propelled the development of autonomous vehicle technologies in recent years. According to the classification method proposed by the Society of Automotive Engineers (SAE) International, the driving system can be divided into six levels (SAE Level 0 to Level 5) (NHTSA, 2017). As vehicles progress from SAE Level 3 to Levels 4 and 5, control shifts from the driver to the automated system, marking the transition to high and full autonomy. Achieving operational safety at these higher levels requires not only highly accurate positioning but also confirmation that the vehicle remains on the intended route. With advances in computational performance and sensor integration, modern onboard systems now combine technologies such as cameras, Light Detection and Ranging (LiDAR), Global Navigation Satellite Systems (GNSS), Inertial Navigation Systems (INS), and various other perception sensors can be capable of processing complex data streams in real time with high precision. Additionally, High Definition Maps (HD Maps) have emerged as indispensable infrastructure, providing rich, pre-processed environmental information essential for autonomous navigation and decision making.

Unlike traditional two-dimensional electronic maps designed for human drivers, HD Maps deliver detailed three-dimensional spatial data with accurate representations of the physical environment. This level of detail enables autonomous vehicles to respond rapidly to real world conditions and prioritize passenger safety. Consequently, HD Maps have become a fundamental component in both the navigation and development efforts surrounding autonomous vehicle systems. However, producing HD Maps involves considerable costs, influenced by a variety of factors such as required precision, data standards, output formats, production scale, regulatory compliance, and business models. Balancing cost efficiency with the need for accuracy and legal adherence presents a considerable challenge. As illustrated in Figure 1, the cost of map production varies according to the level of vehicle autonomy, shaped by factors including the type of equipment used, operational procedures, and execution time. Strategies for reducing the cost of HD Maps production are as follows (Chiang et al., 2022):

- Standardize HD Maps, including data collection, production, and verification procedures.
- Automate production tools with Artificial Intelligence (AI).
- Develop automated and versatile format converters.
- Implement versatile data collection methods.
- Promote data sharing.

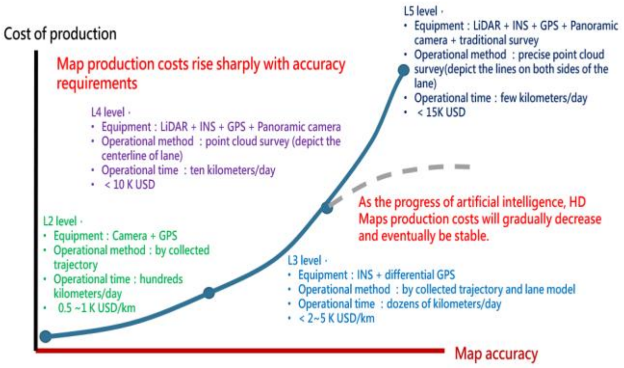

Figure 1. HD Maps production cost curve (Chiang et al., 2022)

2. PROPOSED STRATEGY

2.1 Established HD Maps guidelines and standards

To ensure that HD Maps offer dependable and comprehensive prior knowledge for autonomous vehicles, it is crucial to establish processes for HD Maps operation, data content and format standards, accuracy verification, and quality control for evaluating HD Maps. Additionally, to confirm the soundness and dependability of the proposed specifications, it is necessary for such guidelines to undergo scrutiny by reputable industry authorities. In Taiwan, Taiwan Association of Information and Communication Standards (TAICS) plays a pivotal role in advancing national standards, enhancing regional impact, and aligning local industries with international norms. The proposed HD Maps specifications were subjected to TAICS formal review process, where input from industry professionals and academic experts contributed to refining and improving the documentation. The milestones for HD Maps technical documents are listed in Table 1, with updated versions scheduled for publication in 2024 and 2025.

Technical documents	Language	Version	Time
HD Maps Operation Guidelines	Chinese	v3	2024.12.20
	English	v2	2021.07.30
		v3	Estimated release in the end of 2025
Verification and Validation Guideline for HD Maps	Chinese	v2	2024.12.20
	English	v1	2021.07.30
		v2	Estimated release in the end of 2025
HD Maps Data Content and Format Standards	Chinese	v1.1	2020.06.12
		v2	Estimated release in the end of 2025
	English	v1.1	2021.08.26
		v2	Estimated release in the end of 2025

Table 1. Publication milestones for HD Maps technical documents.

With the support from Taiwan's Ministry of the Interior (MOI), the HD Maps technical guidelines and standards, as listed in Table 1, provide recommended procedures for HD Maps development. These include establishing adaptable data acquisition and mapping workflows, as well as defining validation and verification protocols. Beyond evaluating the specifications for map formats and production methods, considerations must also extend to data collection processes and the specific needs of end users. The scope and steps for establishing HD Maps in Taiwan are presented in Figure 2 (Chiang et al., 2019). Following data acquisition, both point cloud data and vector maps undergo comprehensive verification. Once the accuracy and map attributes meet the required standards, the validated vector maps are converted into a standardized format. Taiwan has adopted an extended version of the OpenDRIVE format as the official HD Maps format serving as a common, intermediate standard for broader application. This enables downstream users, such as HD Maps providers and autonomous vehicle developers, to further convert the standardized maps into other formats tailored to their systems and applications.

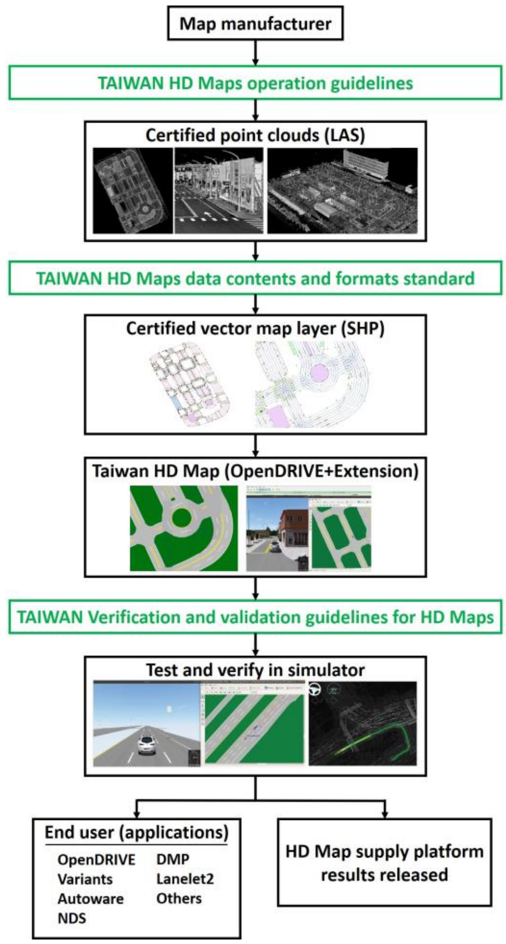

Figure 2. The scope and step of HD Maps in Taiwan (Chiang et al., 2019).

2.2 Semi-automated HD Maps production tool

Due to the high level of detail and precision required, the creation of HD Maps has traditionally been a resource intensive and expensive process. To address this challenge, one cost effective solution is the development of a semi-automated HD Map generation method that leverages advanced mapping tools, deep learning algorithms, and mobile laser scanned point cloud data. This approach aims to enhance efficiency while maintaining mapping accuracy. The workflow for this semi-automated process is illustrated in Figure 3. The process begins with the collection of multi-source data, including imagery, LiDAR derived point cloud data, and synchronized trajectory data from integrated INS/GNSS systems. These datasets are initially labelled using a pre-trained AI model. Following this, a post-labelling phase refines the data, which is then used to train deep learning models. The trained AI system can accurately detect and classify key road infrastructure elements, such as road surface markings, traffic signs, and traffic lights, with potential for further feature expansion. Once feature extraction is complete, the resulting data can be exported into various map formats, including OpenDRIVE and Lanelet2, allowing flexibility for different applications. Figures 4 to Figure 6 demonstrate how road features are extracted through this semi-automated workflow and how the final map outputs appear across multiple supported formats.

This study demonstrates the proposed approach which can be instrumental in streamlining the HD Maps generation process, reducing manual labour, and enhancing efficiency. The assured mapping tool proves to be an effective instrument, particularly when powered by deep learning algorithms and point cloud data geometries, for creating reliable, comprehensive, and application ready HD Maps.

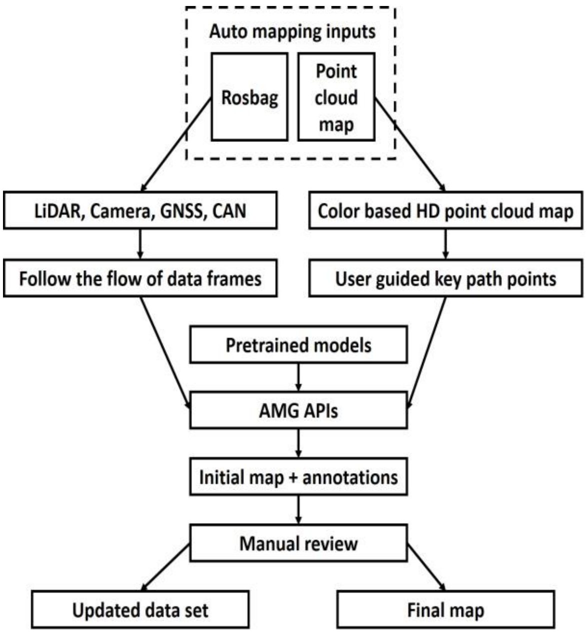

Figure 3. Semi-automated map generation process.

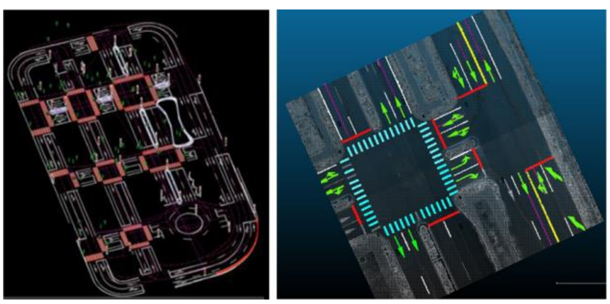

Figure 4. Extraction of road elements (closed area) by semi-automated HD Maps production.

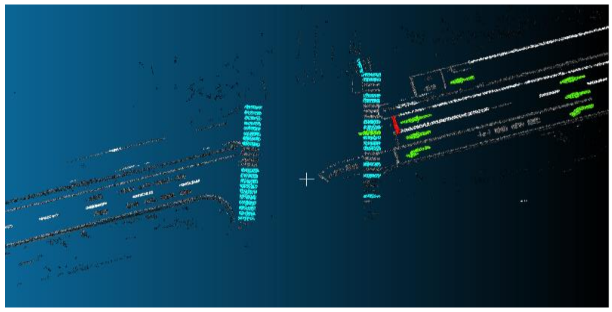

Figure 5. Extraction of road elements (open general road) by using semi-automated HD Maps production.

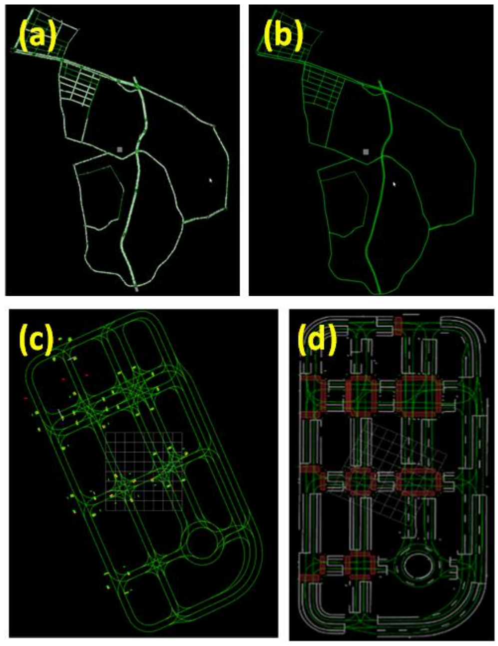

Figure 6. Output map with (a) vector maps (SHP); (b) OpenDRIVE; (c) Lanelet2; (d) KML format.

2.3 Variant detection tools

In addition to employing a semi-automated tool for HD Maps generation, this study also introduces a variant detection system compatible with certified third-party mapping technologies. This alternative mapping method improves the frequency of road data updates and supports real-time collection of road features and infrastructure elements. To ensure accurate detection and classification of objects, the study incorporates extensive testing related to sensor limitations, such as field-of-view constraints, occlusions, and object recognition algorithms. Both image information and point cloud data are utilized, undergoing parallel processing to identify objects and their categories. The outputs from these two data sources are then fused and compared against an existing reference database to identify any discrepancies or changes. Based on the analysis, a determination is made regarding the validity and relevance of any detected variations, and whether they should be flagged or updated in the map. Figure 7 outlines the workflow of the variant detection process, while Figure 8 presents examples of the identified variations and corresponding results.

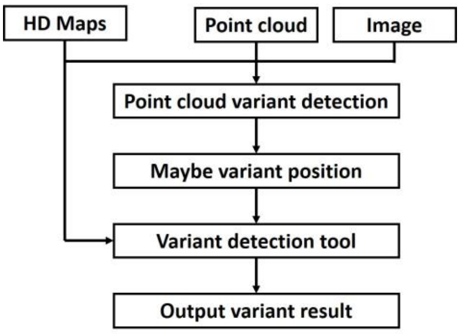

Figure 7. The flowchart of variant detection procedure.

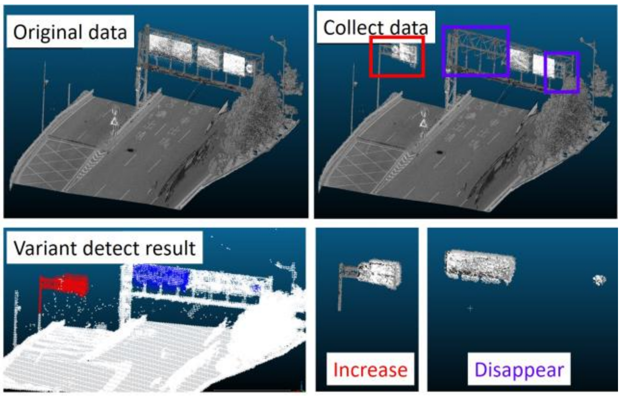

Figure 8. Variant detection result.

2.4 Flexible HD Maps production method

In Taiwan, mapping companies are required to refer to the HD Map guidelines and standards published by TAICS to maintain data quality. However, following these protocols can be both time consuming and resource intensive. To improve the efficiency and coverage of HD Map data collection, this study explores two flexible surveying and mapping approaches.

The first approach focuses on assessing various sources for Ground Control Points (GCP). Depending on the environmental conditions, such as open areas, tunnels, or urban settings, methods like e-GNSS Real Time Kinematic (RTK) positioning and total station measurements are employed. However, in remote locations like mountainous regions or along highways, acquiring GCP can be challenging and costly. To mitigate these limitations, the study proposes using flexible GCP sources. Specifically, aerial orthophotos are used to extract the coordinates of visible features, which serve as reference points for HD Maps creation. This reduces the need for extensive ground surveys, as features visible in aerial imagery can be measured and treated as virtual GCP. These virtual points facilitate aerial triangulation with fewer physical markers. The second approach leverages mobile mapping systems equipped with high precision positioning and orientation tools comparable to those used in autonomous vehicles. Data collection is guided by the virtual GCP mentioned earlier, in combination with Simultaneous Localization And Mapping (SLAM) techniques. Figure 9 illustrates the complete workflow of the flexible surveying and mapping process used in this study. By integrating both physical and virtual GCP, the approach supports the generation of accurate and efficient HD point cloud maps.

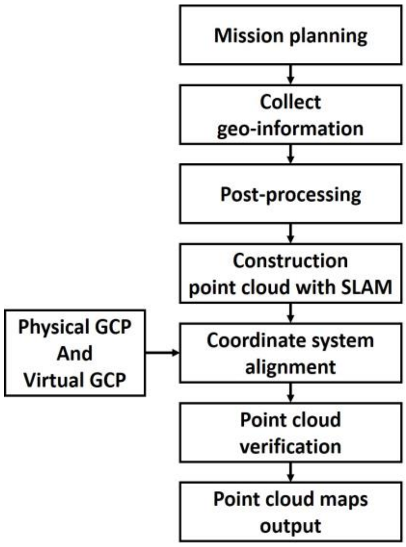

Figure 9. The steps for flexible HD Maps production.

The preliminary results show that the flexible production methods are helpful for formulating and updating the HD Maps guidelines and standards. These experiences will improve the efficiency and integrity of map creation.

3. OUTDOOR AND INDOOR SEAMLESS HD MAPS

Building on the references, this study formulates and releases corresponding HD Maps guidelines and standards to establish a comprehensive surveying and mapping workflow, as illustrated in Figure 10. The procedure encompasses four main stages: operational planning, control surveying, data acquisition, and data processing. During the operational planning phase, detailed specifications are reviewed, including sensor configurations, scanning strategies, GNSS satellite geometry, and the layout of base stations. These parameters help define the scope and methodology for the mapping task. Following this, GCP and scanning data are acquired in accordance with the established plan. Once data collection is complete, various sensor inputs which including LiDAR, INS, GNSS, and others are processed to ensure positional accuracy and completeness. Using the resulting point cloud data, map developers generate vector-based representations of road environments. Final HD Maps outputs are produced in widely supported formats such as OpenDRIVE and Lanelet2, ready for integration into autonomous vehicle systems.

To support the advancement of autonomous vehicle pilot programs, foster research and development in unmanned vehicle technologies, and drive innovation in related industries and services, Taiwan’s MOI oversees the end-to-end process of HD Maps development. This includes data collection, map production, verification, and quality assurance. As illustrated in Figure 11, the entire HD Maps demonstration area has been established under these efforts. The creation and validation of the HD Maps are carried out in accordance with the technical standards and guidelines outlined in Table 1. The resulting HD Maps comprise point cloud data in LAS format, vector maps in SHP format, and are also available in widely adopted formats such as OpenDRIVE and Lanelet2 to ensure compatibility with various autonomous vehicle platforms.

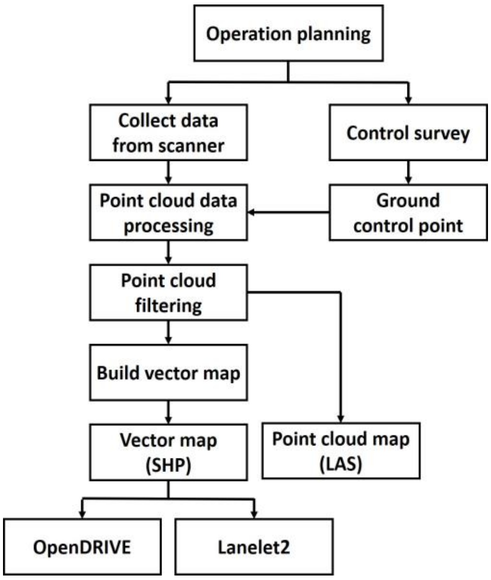

Figure 10. HD Maps surveying and planning procedure.

Figure 11. Taiwan HD Maps demonstration area.

As autonomous vehicle and HD Maps technologies continue to advance rapidly, the development of highway HD Maps has become a critical initiative in Taiwan, aimed at accelerating the deployment of autonomous driving systems. Creating HD Maps for highways enables the delivery of precise, dependable, and real-time positioning information essential for meeting the stringent navigation and localization requirements of autonomous vehicles. Figure 12 displays the HD control point cloud maps created for Taiwan's highway network, which spans approximately 1,000 kilometers. The resulting point cloud data is shown in Figure 13, while Figure 14 illustrates the corresponding vector maps generated using the semi-automated HD Maps production system. Looking ahead, the focus will shift toward fully automating the generation of complete highway vector maps to further streamline the mapping process.

Figure 12. HD control point cloud maps for the highway scenario.

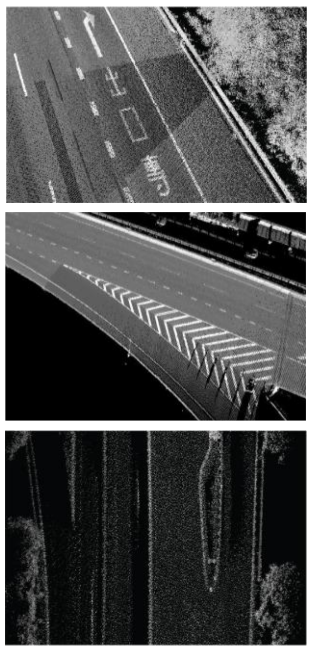

Figure 13. HD control point cloud maps.

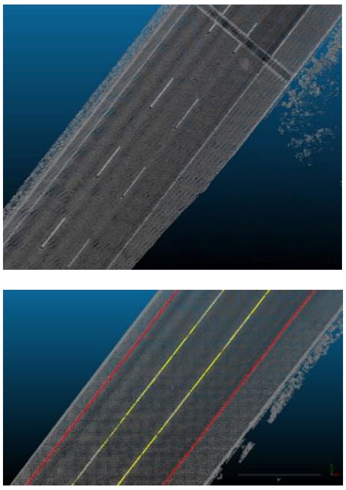

Figure 14. Vector maps for the highway scenario by using semi-automated HD Maps production tool.

With the growing prominence of location-based services, the operational scope of autonomous vehicles is expanding to encompass not only outdoor but also indoor environments. Seamless transition between indoor and outdoor settings is a critical factor to address. While GNSS technology has matured and is widely effective for outdoor positioning, its signals are often obstructed indoors. To enhance positioning accuracy inside buildings, alternative technologies such as Bluetooth Low Energy (BLE), WiFi, Radio Frequency Identification (RFID), Ultra-Wide Band (UWB), infrared, ultrasonic sensors, and computer vision are increasingly utilized. Furthermore, indoor HD Maps offer valuable supplemental data that can improve the safety and navigation capabilities of autonomous vehicles within enclosed spaces. This study presents the development of an indoor HD Maps for the underground parking facility of the Cybersecurity & Smart Technology R&D Building in Taiwan. The map data formats include point cloud data, vector maps, as well as OpenDRIVE and Lanelet2 standards, illustrated in Figure 15. The vector maps detail multiple layers, covering indoor areas, roadways, lane markings, transition zones, ramps, entry and exit points, individual lanes, and restricted zones. Importantly, these indoor maps are designed to integrate smoothly with outdoor HD Maps, as demonstrated in Figure 16. This integration supports the creation of a versatile autonomous vehicle testing environment, combining the Taiwan CAR Lab test track (highlighted by the red boundary, a controlled area), public roads (marked in green), and the interconnected routes bridging indoor and outdoor spaces (indicated by the blue line).

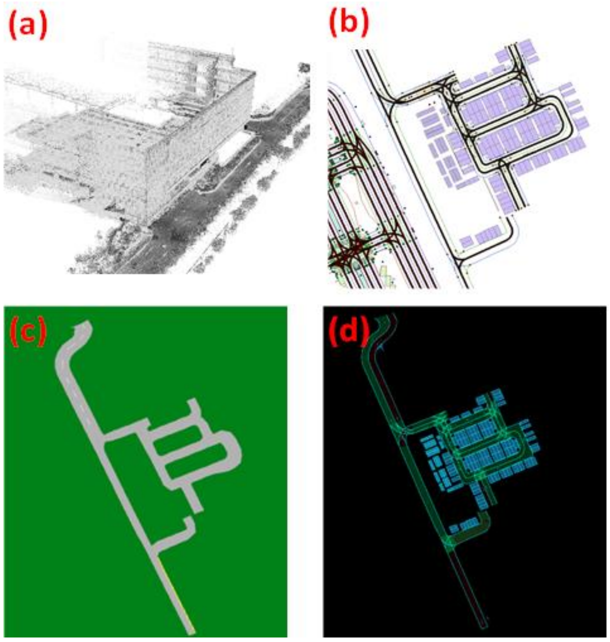

Figure 15. Indoor map with (a) point cloud data (LAS); (b) vector maps (SHP); (c) OpenDRIVE; (d) Lanelet2 format.

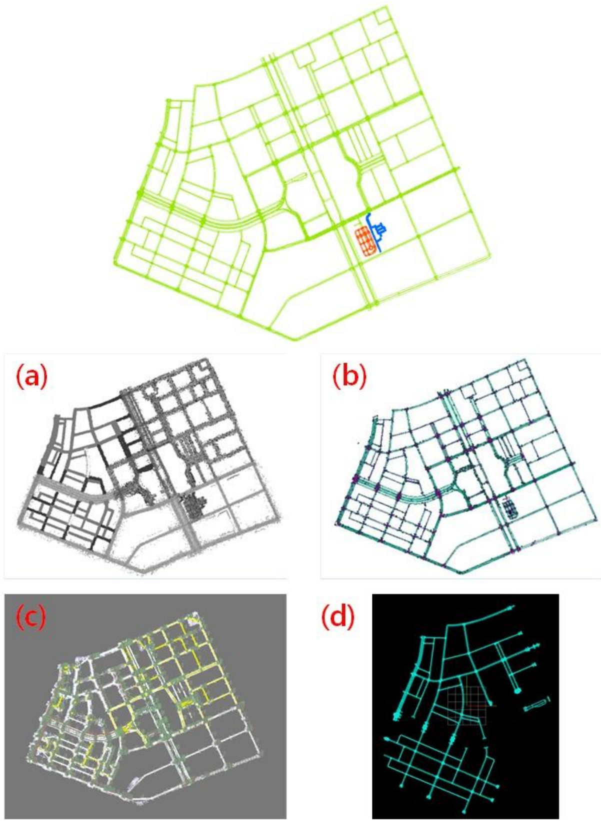

Figure 16. Outdoor and indoor seamless HD Maps with (a) point cloud data (LAS); (b) vector maps (SHP); (c) OpenDRIVE; (d) Lanelet2 format.

4. CONCLUSION

As autonomous vehicle technology advances, HD Maps have become indispensable due to their exceptional accuracy, detailed semantic representation of road environments, real-time traffic updates, and valuable driving experience data. However, the challenge lies in lowering the production costs of HD Maps without compromising quality or regulatory compliance. This study outlines several key strategies to address this issue. Firstly, updated HD Maps guidelines and standards are being developed, with a new edition scheduled for release in 2024. Secondly, the creation of a semi-automated HD Maps generation tool alongside a variant detection system aims to enhance production efficiency while cutting costs. These innovations support the creation of comprehensive HD Maps covering both outdoor and indoor environments across Taiwan. The testing ground encompasses closed test tracks, public roads, and indoor parking facilities, catering to diverse autonomous vehicle scenarios. This integrated approach not only promotes the advancement of autonomous driving technologies but also drives improvements in mapping methodologies. Establishing a robust HD Maps infrastructure is expected to accelerate the development of fully autonomous vehicles, bringing their widespread deployment closer to reality.

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