THE DEVELOPMENT OF INDOOR AND OUTDOOR INTELLIGENT MAPPING TECHNOLOGY

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KEY WORDS: Indoor mapping, High Definition Maps, Mobile mapping technology

ABSTRACT: The development of geospatial and its applications are growing up quickly in recent year. Mobile mapping technology, including multi-sensor integration and multi-platform mapping technology, is used for geospatial data acquisition and various applications such as conventional mapping scenarios, rapid disaster response, smart city, and autonomous vehicle applications. The domestic industry, government, and academia are all committed to the development of autonomous vehicle and High Definition Maps. With the consequential of location-based service, the scene of autonomous vehicle will be not only outdoor, but also indoor. The conversion of indoor and outdoor will be considered. Because of the development of GNSS, the technology of outdoor positioning is maturity. However, the signals of GNSS satellites are blocked in indoor environment. The technology, such as BLE, WiFi, RFID, UWB, infrared, ultrasonic, image vision, can assist increasing the positioning accuracy and achieve indoor application. Besides, the indoor HD Maps also can be considered as assisted information to improve autonomous vehicle safety. In this paper, we review the literature and HD Maps guideline/standard first. Then, the indoor mapping procedure and data format are established referencing these documents. The test field is the underground parking lot of Cybersecurity & Smart Technology R&D Building, Shalun, Tainan, Taiwan. The data format includes point cloud, vector map, OpenDRIVE, and Lanelet2. The layer of vector map that we try to build include indoor area, road, lane line, transition area, ramps, entry/exit, lanes, and forbidden areas. The indoor HD Maps also can be connected with outdoor maps. As shown by preliminary result, we formulate the indoor mapping procedure. The indoor HD Maps are also made successfully by using the procedure. In consideration of there are different kinds of HD Maps scene including Taiwan CAR Lab which is a closed field for testing autonomous vehicle, real road, and indoor parking lot in Shalun, we can combine these outdoor and indoor maps to test autonomous vehicle in composite scene. It is great for helping the development of autonomous and mapping technology in the future.

1. INTRODUCTION

According to Global Navigation Satellite System (GNSS) is well-established, the development of outdoor positioning technology is mature. However, satellite signals are obscured by buildings in indoor environments, additional aided equipment or technologies are required to achieve indoor positioning-related applications. The differences with common indoor positioning technologies, such as Wi-Fi, iBeacon, RFID (Radio Frequency IDentification), UWD (Ultra-Wide Band), and others can be summarized in Table 1.

Table 1. The differences with common indoor positioning technologies (Chiang, 2018).

Technology	Additional infrastructure	Build positioning database	Database creation difficulty	Impact of environmental changes	Positioning error accumulation	Positioning solution mode	Outdoor navigation coordinate system compliance
Wi-Fi	Fewer	Large	High	High	Low	Relative	None
iBeacon	A lot	Small	Low	Medium	Low	Approximate	None
RFID	A lot	Small	Low	Medium	Low	Approximate	None
Image-based	None	Small	High	Medium	Low	Relative	None
UWB	A lot	Small	Low	Medium	Low	Accuracy	None
INS	None	None	None	Low	High	Relative	None
PDR	None	None	None	Low	Medium	Relative	None

As mentioned in Table 1, the indoor positioning technology can be separate with different classification. One of technology is using wireless signal positioning technology represented by Wi-Fi. iBeacon (Bluetooth) and RFID are used Proximity method for single-point approximate positioning. In addition, there are image-based positioning technologies which are referred to do not include direct georeferencing imagery produced by mobile mapping systems. The positioning principle of UWB is similar to that of satellite navigation. Its main features include low power consumption, strong anti-interference ability, strong penetration, and high positioning accuracy. The construction cost of UWB is relatively high. INS (Inertial Navigation System) and PDR (Pedestrian Dead Reckoning) technologies are also listed in Table 1. As shown in the table, each method has its advantages and disadvantages.

In recent years, domestic industry, government and academia have been committed to the development of autonomous vehicles and High Definition Maps (HD Maps) technology. With the evolution of autonomous vehicles technology, self-driving scenarios will gradually extend to indoor environments. The conversion of indoor and outdoor scenes must be considered. The establishment of indoor and outdoor seamless self-driving maps is imperative. At present, our team has released relevant HD map guidelines and standards through TAICS, including "TAICS TR-0010 v2.0-HD Maps operation guidelines v2" (TAICS, 2021) and "TAICS TS-0024 v1.0-HD Maps data contents and formats standard" (TAICS, 2021). Therefore, this study will focus on the feasibility of extending the current HD Maps production procedures and experience to the construction and application of indoor maps.

2. REFERENCE REVIEW

In this study, the reference including the use of indoor graphics to assist self-driving cars in indoor navigation applications, vehicle-mounted indoor navigation technology, and indoor layer connotations, as shown in Table 2. Table 3 shows the combination and analysis of indoor layer content and the information of HD maps standard. Therefore, this study will complete the indoor surveying and mapping operation procedure based on the content of Table 3.

Table 2. Document organization by map construction method.

Map construction method	Document
Build indoor semantic map based on collected point cloud data	Autonomous driving in a multi-level parking structure (Kummerle et al., 2009)
	Real time localization, path planning and motion control for autonomous parking in cluttered environment with narrow passages (Nejad et al., 2012)
	Advanced real-time indoor parking localization based on semi-static objects (Groh et al., 2014)
	Automated valet parking and charging for e-mobility (Schwesinger et al., 2016)
	Map-aided multi-level indoor vehicle positioning (Fritsche et al., 2017)
	Collaborative mapping and autonomous parking for multi-story parking garage (Li et al., 2018)
Construct indoor parking lot semantic map based on image recognition or visual assistance	Parking space recognition for autonomous valet parking using height and salient-line probability maps (Han and Choi, 2015)
	Vision-based semantic mapping and localization for autonomous indoor parking (Huang et al., 2018)
	Indoor navigation for a complex parking building based on computer vision (Jia et al., 2019)
	AVP-SLAM: Semantic visual mapping and localization for autonomous vehicles in the parking lot (Qin et al., 2020)
	Improving positioning accuracy via map matching algorithm for visual–inertial odometer (Meng et al., 2020)
Build indoor environments based on sensors or external devices	U.S. patent application No.14/814,889 (Samyeul, 2016)
	VeMap: Indoor road map construction via smartphone-based vehicle tracking (Gao et al., 2016)
	Underground parking lot navigation system using long-term evolution signal (Shin et al., 2021)
Construct indoor environment based on augmented electronic map or GIS map	Improved vehicle positioning for indoor navigation in parking garages through commercially available maps (Wagner et al., 2010)
	Optimization of map matching algorithms for indoor navigation in shopping malls (Wilk and Karciarz, 2014)

Table 3. Analysis and corresponding of indoor map and HD Maps layers.

Semantic map content	HD Maps standard	Document
Parking space	parkingSpace	Kummerle et al., 2009
Trajectory	LaneCenterLine	
obstacle	obstacle	
Level information	--	
Speed map	Speed	Schwesinger et al., 2016
Parking space	parkingSpace	
Road graph	LaneCenterLine	
Charging bar	object	
intersection	junction	
occupancy grid map	--	Nejad et al., 2012
parking slots	parkingSpace	Groh et al., 2014
wall	building	
Road segments	LaneCenterLine	Fritsche et al., 2017
parking spots	parkingSpace	
Level	--	
ramps	--	
forbidden areas	--	
drivable & non-drivable area	--	Li et al., 2018
Intersection	--	
Central line	LaneCenterLine	
Parking-in & parking-out range	--	
Level-cross node	--	
Parking space	parkingSpace	
Crossroad	junction	
Parking space	parkingSpace	Han and Choi., 2015
Parking slot	parkingSpace	Huang et al., 2018
slot ID	--	
Parking space	parkingSpace	Jia et al., 2019
parking lines	parkingSpace	Qin et al., 2020
lanes	MarkLine	
obstacles	obstacle	
walls	building	
guide signs	MarkLine	
Speed bump	deceleration	
wall	building	Meng et al., 2020
Parking space	parkingSpace	Samyeul, 2016
entry/exit	entry/exit	Gao et al., 2016
Route	LaneCenterLine	
bump	deceleration	
LTE signal map	--	Shin et al., 2021
topology	LaneCenterLine	Wagner et al., 2010
topology	LaneCenterLine	Wilk and Karciarz, 2014

In order to integrity of the surveying and mapping process, the indoor modelling structure have to be evaluated in advance before mapping tasks. Zlatanova et al. (2013) proposed a process architecture including data collection and equipment evaluation, data structure and processing, visualization applications, navigation applications, augmented map applications, and map privacy and copyright. Li et al. (2019) proposed similar concept that it needs to consider about reference coordinate systems, building structures, indoor and outdoor seamless coordinate maps, map visualization, architectural space design, indoor topological relationships, accessible areas, basic indoor equipment, and indoor map formats. The common formats include Indoor OpenStreetMap, OGC IndoorGML, IFC, OGC CityGML, and other. Kummerle et al. (2009) used point cloud data to build a Mobile Laser Scanning (MLS) map of the test field. The map can provide the best path for the starting and ending points among multiple floors, and providing stable observations based on the point cloud to conduct their own vehicle operations. Huang et al. (2018) built an indoor parking lot semantic map based on the image recognition algorithm. The location of the parking space can be identified by CNN (Convolutional Neural Network) network model, and used PVA Net to detect the ID of each parking space. Gao et al. (2016) proposed to produce a map of indoor drivable road sections by fusing information from mobile phone sensors and correcting posture and scale.

Wagner et al. (2010) expanded electronic maps and used the topology map matching algorithm of indoor map matching technology to assist vehicle indoor navigation. The content records information such as road segment connection, lane widths, speed limits, different floor switching conditions, entrance and exit detection, ramp detection, and others to assist the indoor operation of vehicles.

3. EVALUATION OPERATION WITH INDOOR AND OUTDOOR SEAMLESS MAPS

This study considers about the reference as mentioned above and released relevant HD Maps guidelines and standards to construct the surveying and mapping procedures as Figure 1 shown. The procedure includes operation planning, control survey, data collecting, and data processing. The content of description of specifications for sensors, scan planning, GNSS geometric condition, and base station distribution will be checked in operation planning step. Then, ground control point and data of scanner can be measured and collected in accordance with operation planning. After collected data, LiDAR (Light Detection And Range)/INS/GNSS/other sensor data processing will be done. Table 4 shows the indoor vector map layer that this study defined. Map maker will use point cloud to build vector map referenced by the content of Table 4. HD Maps of OpenDRIVE and Lanelet2 format also be built. Finally, these maps production pass simulator autonomous vehicle verification, it will be published for surveying services, research institutes, and autonomous vehicles.

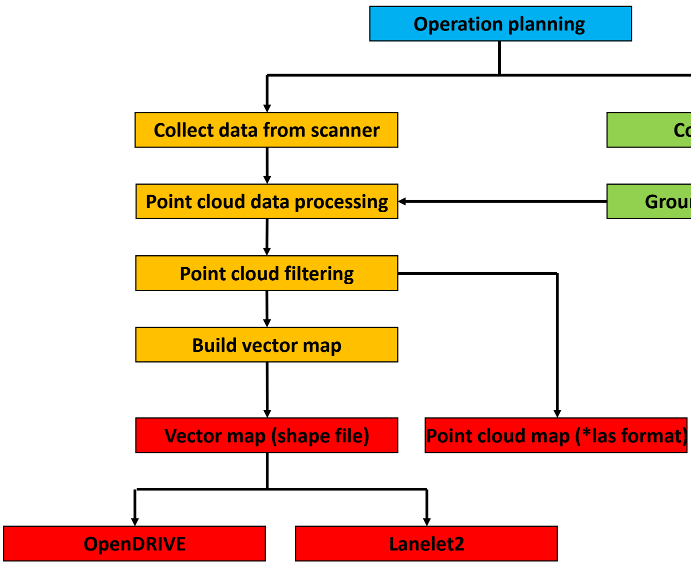

Figure 1. Indoor HD Maps surveying and planning procedure.

Table 4. Defined indoor vector map layer.

Layer		Type	Attribute
Indoor area		Plane	type
Road	Reference Line	Line	id, junction, rule, predecessor, successor, type, startNode, endNode
	Lane Line	Line	id, type, width, startNode, endNode
	Node	Point	id
Lane	Lane Center Line	Line	id, type, width, predecessor, successor, startNode, endNode
	Waypoint	Point	id
	Floor Connection	Point	id, floor
Pedestrian		Plane	type
Transition Area	Transition Area	Plane	type
	Transition Center Line	Line	id, type, width, predecessor, successor, startNode, endNode
Ramp	Ramp	Plane	type
	Ramp Center Line	Line	id, type, width, predecessor, successor, startNode, endNode
Entry/Exit		Point	type
Mark Line	Stop Line	Line	id, width

	Parking	Plane	id, type, access, width, entrancePoint
	Mark Line	Line	id, width
	Mark Area	Plane	id
	Mark Graph	Plane	id, width
Forbidden Area	Pillar	Plane	id, type
	Wall	Plane	id, type

4. RESULT AND DISCUSS

In this study, the surveying and mapping procedures are built. In order to make sure that the procedures may be worked, an actual indoor test area is planning to conduct. The test field is the underground parking lot of Cybersecurity & Smart Technology R&D Building, Shalun, Tainan, Taiwan. Figure 2 to Figure 5 show the HD Maps with different kinds of format results.

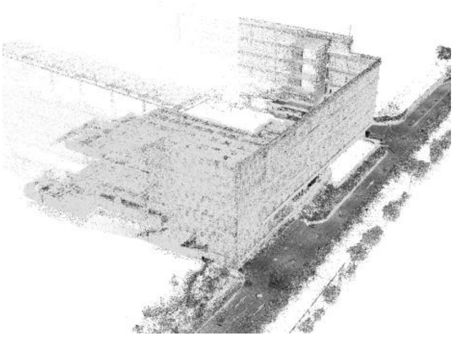

Figure 2. Indoor HD Maps with point cloud (*.las format).

Figure 3. Indoor HD Maps with vector map (shape file format).

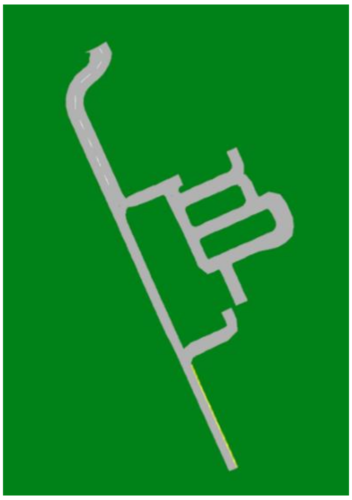

Figure 4. Indoor HD Maps with OpenDRIVE format.

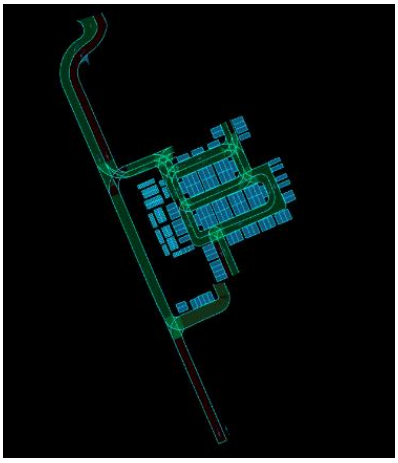

Figure 5. Indoor HD Maps with Lanelet2 format.

As preliminary result shown, the operation procedure of control survey, data collecting, and data processing can be used for making indoor HD Maps. The HD Maps result with point cloud, vector map, OpenDRIVE, and Lanelet2 format are verified and meet the guidelines and standards requirement. The results can be connected indoor and outdoor seamless maps. A multi-functional and various autonomous vehicle testing environment will be established as Figure 6 shown. However, parts of layer such as floor connection, transition area, and entrance are not defined clearly by referring to reference. This study tries to define the position of the layer and continues to collect relevant literature. If there are any clear definitions proposed, HD Maps guidelines and standards will also revise simultaneously in the future.

Figure 6. HD Maps: (Red) Close area; (Green) Open area; (Blue) Indoor area.

5. CONCLUSION

In this paper, we review the literature and HD Maps guideline/standard first. Then, the indoor mapping procedure and data format are established referencing these documents. The procedure includes operation planning, control survey, data collecting, and data processing. In order to make sure that the procedures may be worked, an actual indoor test area is planning to conduct. The test field is the underground parking lot of Cybersecurity & Smart Technology R&D Building, Shalun, Tainan, Taiwan. The data format includes point cloud, vector map, OpenDRIVE, and Lanelet2. The layer of vector map that we try to build include indoor area, road, lane line, transition area, ramps, entry/exit, lanes, and forbidden areas. The indoor HD Maps also can be connected with outdoor maps. As shown by preliminary result, there are different kinds of HD Maps scene including Taiwan CAR Lab which is a closed field for testing autonomous vehicle, real road, and indoor parking lot in Shalun. We can combine these outdoor and indoor maps to test autonomous vehicle in composite scene. It is great for helping the development of autonomous and mapping technology in the future.

ACKNOWLEDGEMENTS

The authors would like to thank the financial support by the Ministry of the Interior (MOI), R.O.C. (Taiwan).

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