Establishment of HD Maps Verification and Validation Procedure with OpenDRIVE and Autoware (Lanelet2) Formats

Kai-Wei Chiang [1], Meng-Lun Tsai [1, *], Sean Lin [1], Yen-En Huang [1], Jhih-Cing Zeng [1], Yi-Feng Chang [1], Jou-An Chen [1], Yung-Chieh Huang [2], Chin-Sung Yang [1], Jyh-Ching Juang [3], Chi-Kuei Wang [1], Ching-Fu Lin [3], Jeffrey Lee [4], Hatem Darweesh [5], Pei-Ling Li [6]

[1] Department of Geomatics, National Cheng Kung University, Taiwan - kwchiang@geomatics.ncku.edu.tw, taurusbryant@geomatics.ncku.edu.tw, seanlin151@gmail.com, f64061020@gs.ncku.edu.tw, cing850831@geomatics.ncku.edu.tw, f64066185@gs.ncku.edu.tw, rouan.cc@gmail.com, struts@geomatics.ncku.edu.tw, chikuei@mail.ncku.edu.tw
[2] XIANG CHENG ELECTRONIC CO., LTD., Taiwan - yongjie989@gmail.com
[3] Department of Electrical Engineering, National Cheng Kung University, Taiwan - juang@mail.ncku.edu.tw, lin4080@gmail.com
[4] MSC Software Taiwan, Taiwan - jeffrey.lee@mscsoftware.com
[5] Graduate School of Informatics, Nagoya University, Japan - hatem.darweesh@gmail.com
[6] Department of Resources Engineering, National Cheng Kung University, Taiwan - pointlpl@geomatics.ncku.edu.tw

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ABSTRACT:

Mobile mapping technologies, for example multi-sensor integration and multi-platform mapping technology, have developed and improved over recent decades, various applications such as conventional mapping scenarios, rapid disaster response, smart city, and autonomous vehicle application arise synchronously. Especially, autonomous driving vehicles have made enormous progress. High-definition (HD) maps are key for autonomous driving because of their high accuracy and rich information of road scenes. However, how to make sure that HD maps are suitable for autonomous vehicle requirement is an important topic. The HD maps guidelines and standards in Taiwan are released since 2018 and mainly focus on point cloud and shape file format. In this paper, a procedure for the verification and validation of HD maps for OpenDRIVE and Autoware (Lanelet2) is proposed. It discusses about the verification strategies, suggestion review item, recommendation tools, and process. As shown by our preliminary results, the proposed process can conform not only in closed area but also public road. These issues can help reducing HD maps production costs. When the foundation of HD maps accomplishes, the autonomous driving techniques can naturally complement. The vision of full automation vehicle will come true rapidly in the future.

1. INTRODUCTION

With the development of Intelligent Transport Systems (ITS), autonomous driving vehicles, or self-driving cars, have made enormous progress 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 (Level 0 to Level 5) (NHTSA, 2017). The vehicle transit from human drivers to autonomous driving from Level 3 to Level 5. Level 3 called conditional automation means that the driver is a necessity, but is not required to monitor the environment. The driver must still be involved at any time in case of emergency. Level 4 called high automation is a fully automated driving category under certain conditions. Level 5 called full automation has fully automated driving category and the best car communication system for communication between vehicles.

In order to achieve Level 4 or higher functional safety, obtaining the precise position information of the vehicle and driving on the correct road is most important for autonomous vehicles. With the advances in computing and sensor technologies, onboard systems, the integrated system of cameras, Light Detection And Ranging (LiDAR), Global Navigation Satellite System (GNSS), Inertial Navigation System (INS), and other perception sensors, can deal with a large amount of data and achieve real-time process continuously and accurately. Furthermore, the maps with navigation information for autonomous vehicles, called High-Definition (HD) maps, also can provide reliable and robust prior information on the environment. These systems and maps are essential for the operation of autonomous driving technology and fully autonomous.

HD maps comparing with conventional two-dimensional (2D) electronic maps which is used for navigation based on human visual can provide three-dimensional (3D) navigation information with true scales in the real world. According to the prior information by HD maps, autonomous vehicle can make decisions immediately to ensure passenger safety. Moreover, HD maps are also sufficiently detailed, with planar and vertical accuracy of 20 and 30 centimeter, respectively, in 3D space (Farrell et al., 2016). It is necessary to realize the navigation and research and development of autonomous vehicles through HD maps at present time.

2. ESTABLISHED HD MAPS GUIDELINES AND STANDARDS

With the support of Taiwan's Ministry of the Interior (MOI), the related technical guidelines and HD maps format standards, recommendation of steps for producing HD maps, establishment of flexible data acquisition and mapping services, and stipulation of verification procedures are proposed since 2019.

* Corresponding author

In addition to an evaluation of the HD maps format standards and the map production method, data collection and end-user requirements must also be considered. The scope of HD maps established in Taiwan is presented in Figure 1 (Chiang et al., 2019). After data collection, all the point clouds and vector maps are already verified. If the map accuracy and attributes are assessed, these certified vector maps will be converted to the standard format. OpenDRIVE with extension format are selected as the Taiwan HD maps format and regarded as unified and intermediate maps; end users such as map makers or autonomous vehicle companies can convert these maps into other supported map formats based on their needs.

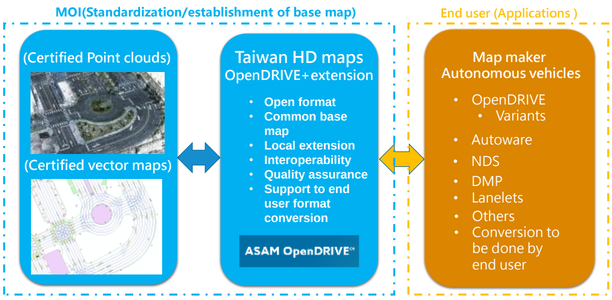

Figure 1. Scope of HD maps in Taiwan (Chiang et al., 2019).

In order to ensure that HD maps can provide reliable and robust prior information to autonomous vehicle, processes for HD maps operation, data contents and formats standard designed, accuracy verification and quality control for evaluating HD maps are required. Furthermore, to verify the integrity and reliability of the proposed guidelines and standards, they must be reviewed by credible industry organizations. Taiwan Association of Information and Communication Standards (TAICS) is an industry organization in Taiwan with the objective of promoting the implementation of domestic industry standards to expand regional influence and bridge local industry and global standards. The proposed guidelines and standards were reviewed through the formal procedure of TAICS and were optimized by incorporating suggestions from experts and scholars. Various publication milestones for HD maps technical documents are listed in Table 1.

Technical documents	Time	Language
HD Maps Operation Guidelines v1	2018.12.26	Chinese
HD Maps Operation Guidelines v2	2019.10.17	Chinese
	2021.07.30	English
Verification and Validation Guideline for HD Maps	2020.06.05	Chinese
	2021.07.30	English
HD Maps Data Content and Format Standards v1	2020.03.16	Chinese
HD Maps Data Content and Format Standards v1.1	2020.06.12	Chinese
	2021.08.26	English

Table 1. Publication milestones for HD maps technical documents.

3. PROPOSED VERIFICATION AND VALIDATION STRATEGY

The steps for producing HD static maps production shown as Figure 2 is conducted in accordance with the guidelines and standards for professional MMS (Mobile Mapping System) described in previous sections. In order to complete the verification processing for end user, it is essential to establish the verification methods for different kinds of map format. Most of Taiwanese autonomous driving platforms currently apply HD maps from Autoware developed by Tier 4 Company in Japan or OpenDRIVE format. Therefore, we propose the recommended software and procedures for verifying HD maps of OpenDRIVE and Autoware (Lanelet2) format.

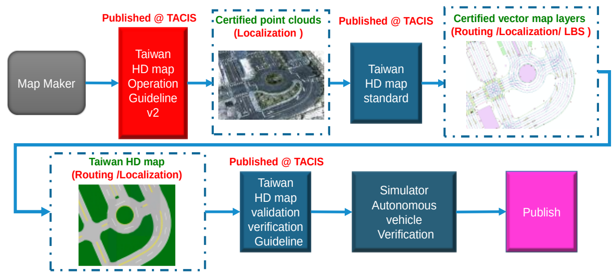

Figure 2. The steps for HD maps production (Chiang et al., 2019).

3.1 OpenDRIVE

Many autonomous vehicle manufacturers use this format as its base map, because the publicity of OpenDRIVE is open data format and regarded as unified and intermediate maps. The main content of OpenDRIVE define the relevant content of lanes, lane markings, facilities, and traffic signs through XML schema, so that there is a common standard for different vehicle manufacturers. Figure 3 shows the architecture of OpenDRIVE format.

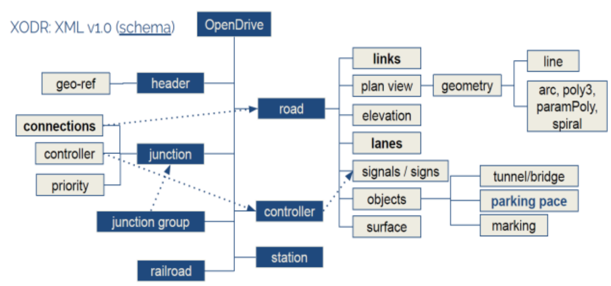

Figure 3. Architecture of OpenDRIVE format (cited by https://www.asam.net/standards/detail/opendrive/).

In this study, VTD is chosen for verifying the OpenDRIVE format. VTD is a vehicle simulator that enables the creation, configuration, presentation, and evaluation of virtual environments for road- and rail-based simulations. VTD can generate 3D content to the simulation of complex traffic scenarios, and even simulate either simplified or physically driven sensors (von Neumann-Cosel et al., 2009). The maps with OpenDRIVE format can be loaded into simulator to guarantee the stability of simulated driving tests and correctness of the map connection. Following presents the method of verification and validation for OpenDRIVE.

First step is loading the generate OpenDRIVE format data into VTD. If there is not any error message, the information of VTD return “Import of OpenDRIVE data. Done.” (Figure 4). After loading data correctly, the road centerline, left lane, and right lane setting also have to review (Figure 5). Then, VTD can generate 3D visualization graphics to verify the road smoothness and road marking displaying (Figure 6 to Figure 8).

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Reviewer can make sure each road through 3D visualization windows. Final is about the definition of lane direct link and simulation of autonomous driving. According to OpenDRIVE document, predecessor and successor element are defined for linkage of each roads and junctions. A successor of a given road is an element connected to the end of its reference line. A predecessor of a given road is an element connected to the start of its reference line. For junctions, different attribute sets shall be used for the predecessor and successor elements (Figure 9 and Figure 10) (VIRES Simulationstechnologie GmbH, 2019).

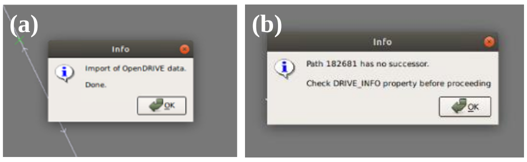

Figure 4. Checking OpenDRIVE format: (a) correct; (b) incorrect.

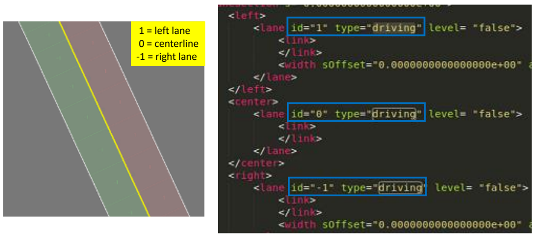

Figure 5. Reviewing the centerline, left lane and right lane setting.

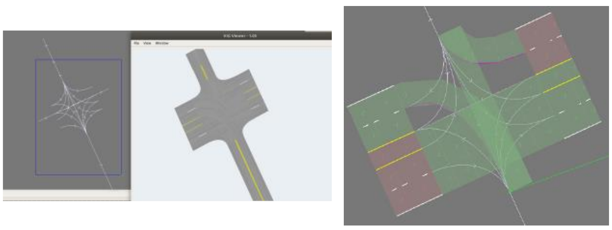

Figure 6. Connection of road and junction reviewing.

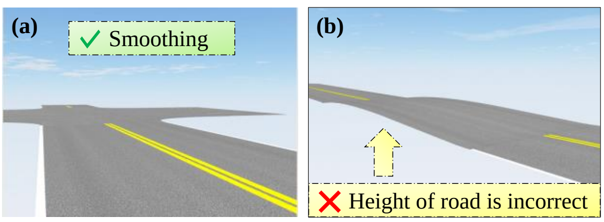

Figure 7. Road smoothness of 3D visualization.

Figure 8. Road marking displaying of 3D visualization.

Figure 9. Correct example about the linkage of road and junction.

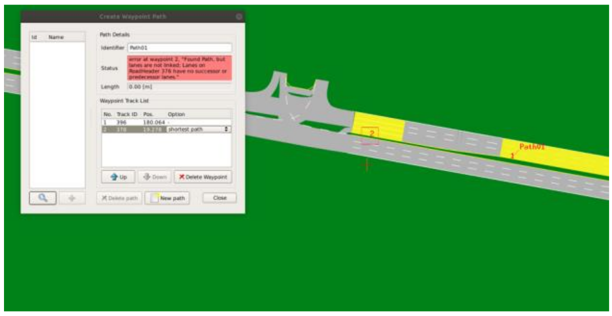

Figure 10. Error message about the empty of successor or predecessor.

After above checking item finished, the review of automated driving simulation will be performed. The examination method also includes all roads, lanes, and junctions. The vehicle has to drive smoothly on the planned path. If the vehicle is driving on off-road for example traffic island, weaving in and out of traffic, and other unreasonable driving path, the verification result will be failed.

3.2 Autoware (Lanelet2)

Autoware is the all-in-one open source software for autonomous vehicle hosted under Autoware Foundation. Autoware format can be applied to autonomous vehicle application and converted to other HD maps formats. The operating architecture of Autoware format presents as Figure 11. Based on different version of ROS, there are two versions of Autoware formats. The Autoware.AI is based on ROS 1 and the Autoware.Auto as the next generation successor of the former one is based on ROS 2. The improvement of Autoware.Auto compared to Autoware.AI are modern software engineering, improved system architecture, and module design. Autoware.Auto uses the Lanelet2 format to define geometric and semantic information of lanes in the environment (cited by https://www.autoware.org/autoware). The base element of Lanelet2 format presents in Figure 12 and the official Lanelet2 documentation presents the detailed information about the format. Hence, this study will propose the step of verifying the Lanelet2 format.

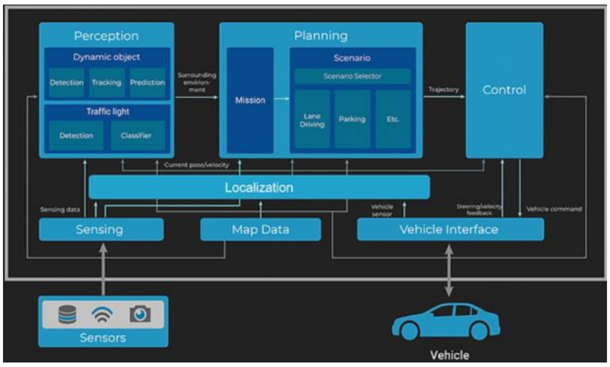

Figure 11. Operating architecture of Autoware format (cited by https://www.autoware.org/autoware).

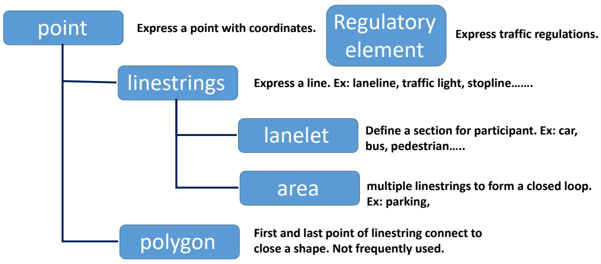

Figure 12. Base element of Autoware (Lanelet2) format.

First, the Autoware Lanelet2 extension package is used for checking format. If there is not any error message, the information returns "finished validation." (Figure 13 and Figure 14). Then, Autoware.ai is used to review the geometric accuracy. After loading point clouds and Lanelet2 vector maps, this step will make sure that these two data are coincident or not (Figure 15 to Figure 17). After format correctness finished, Vector map builder is chosen for logic checking. Vector Map Builder is a tool for quickly creating a vector map for Autoware that is compatible to Lanelet2 format. According to the function of Vector Map Builder, it also can be used to ensure road and junction connection correct or not (Figure 18 to Figure 20). Finally, Autoware Universe is used for simulating that the vehicle can drive smoothly on the planned path or not. The simulator can setup the start and goal point and add some NPC pedestrian and car that the simulation scenario is similar to reality world (Figure 21).

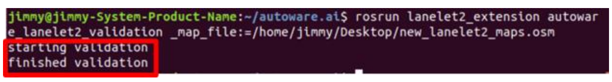

Figure 13. Checking Autoware (Lanelet2) format: correct.

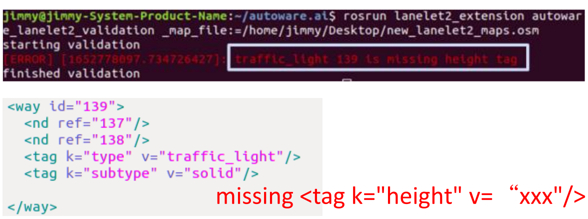

Figure 14. Checking Autoware (Lanelet2) format: incorrect.

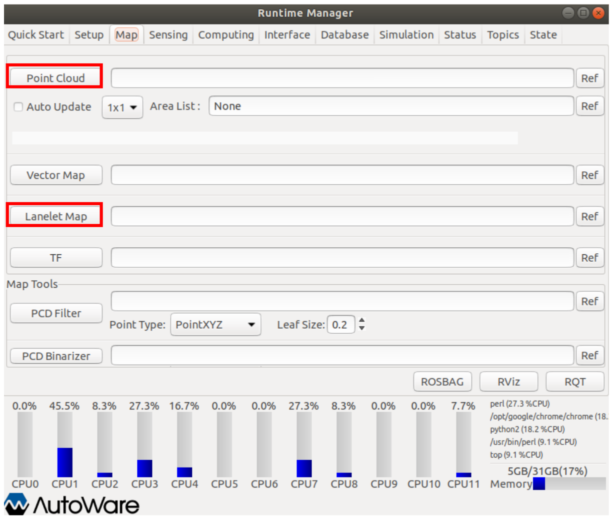

Figure 15. The interface of Autoware.ai.

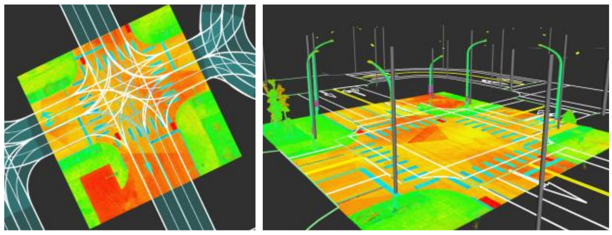

Figure 16. Fitting point clouds and vector maps.

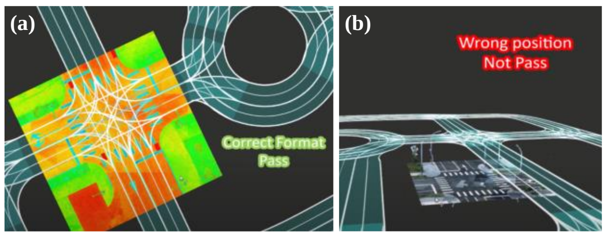

Figure 17. Reviewing point clouds coincident with Lanelet2 vector maps: (a) pass; (b)failed.

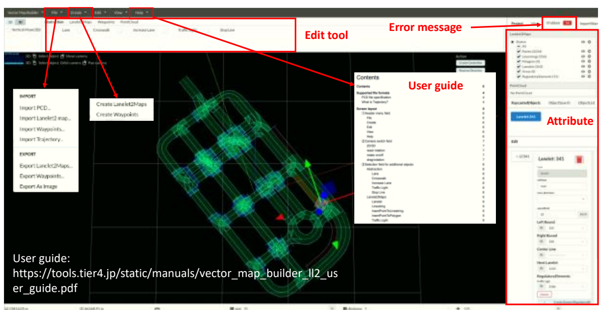

Figure 18. The interface of Vector Map Builder.

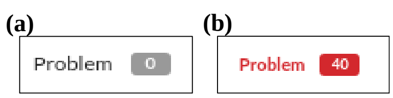

Figure 19. Reviewing the connection: (a) pass; (b)failed.

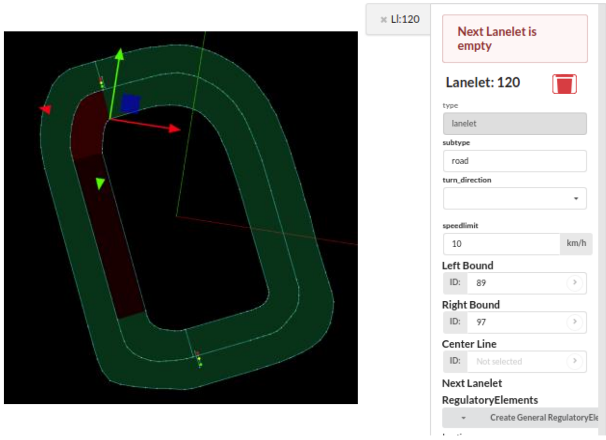

Figure 20. The example about explanation of incorrect connection part.

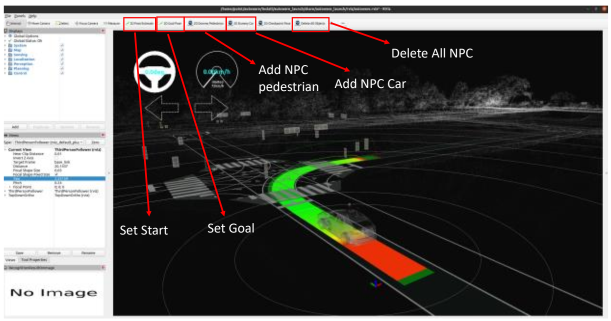

Figure 21. The interface of Autoware Universe.

4. RESULTS AND DISCUSSION

In order to ensure the processing of verification for OpenDRIVE and Autoware (Lanelet2) format data, the Taiwan CAR Lab is chosen as the test field. Taiwan CAR Lab as illustrated in Figure 22 is the first test field constructed in Taiwan for research on autonomous vehicles. It provides a closed space so that the HD maps data will be pure and undisturbed by other external influence. It is a suitable simulation environment.

Figure 22. Road scenarios in Taiwan CAR Lab.

Figure 23 to Figure 27 illustrate the process of verifying test field HD maps with OpenDRIVE format. The results show that the proposed verification and validation process can assist to ensure the correctness and completeness of OpenDRIVE format data.

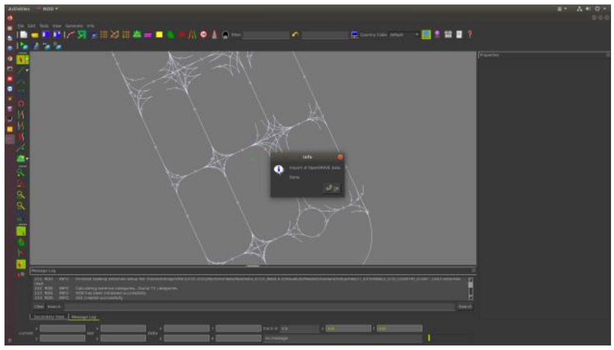

Figure 23. Verification of format correctness with OpenDRIVE.

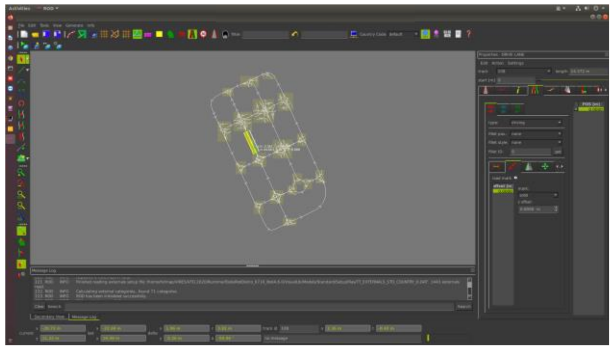

Figure 24. Verification of connection of road and junction (3D stereo visualization) with OpenDRIVE.

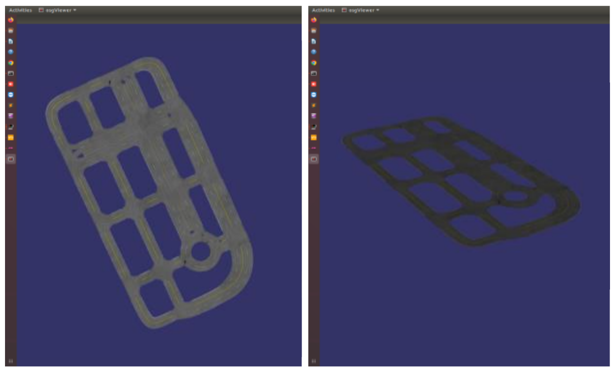

Figure 25. Verification of road smoothness and road marking displaying (3D stereo visualization) with OpenDRIVE.

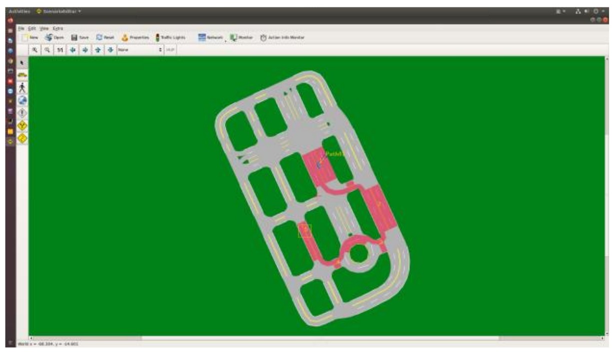

Figure 26. Verification of logic checking with OpenDRIVE.

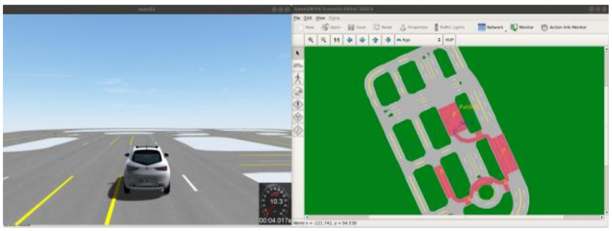

Figure 27. Verification of automated driving simulation with OpenDRIVE.

Figure 28 to Figure 32 illustrate the process of verifying test field HD maps with Lanelet2 format. The results also show that the proposed verification and validation process can assist to ensure the correctness and completeness of Autoware (Lanelet2) format data.

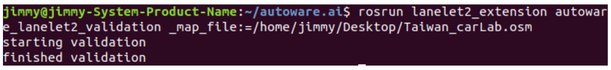

Figure 28. Verification of format correctness with Autoware (Lanelet2).

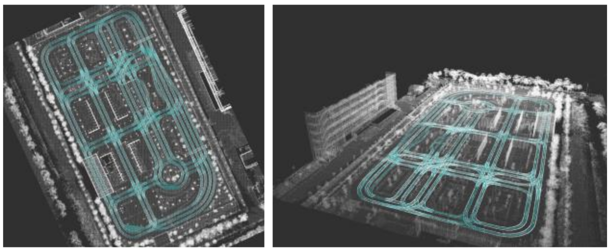

Figure 29. Verification of Fitting point clouds and vector maps (format correctness) with Autoware (Lanelet2).

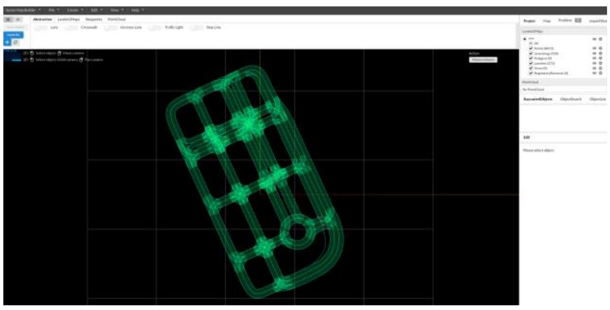

Figure 30. Verification of Logic checking with Autoware (Lanelet2).

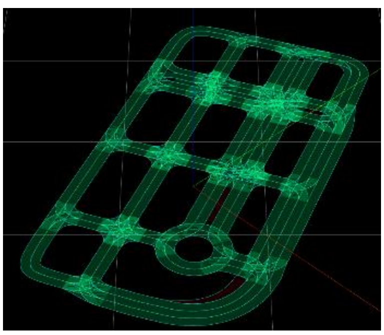

Figure 31. Verification of 3D stereo visualization with Autoware (Lanelet2).

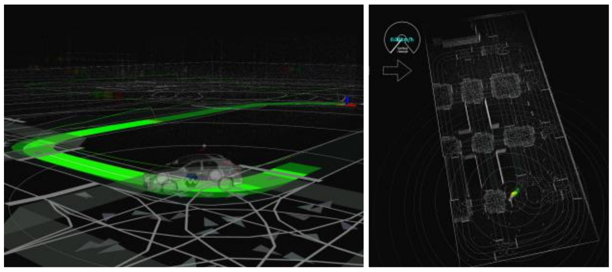

Figure 32. Verification of automated driving simulation with Autoware (Lanelet2).

Further, the verification for OpenDRIVE format data in public road is also be implemented. The total mileage of verifying HD maps is about 180 kilometer over the regions in Taiwan presented in Figure 33. As shown by our preliminary results, the proposed process can conform not only in closed area but also public road.

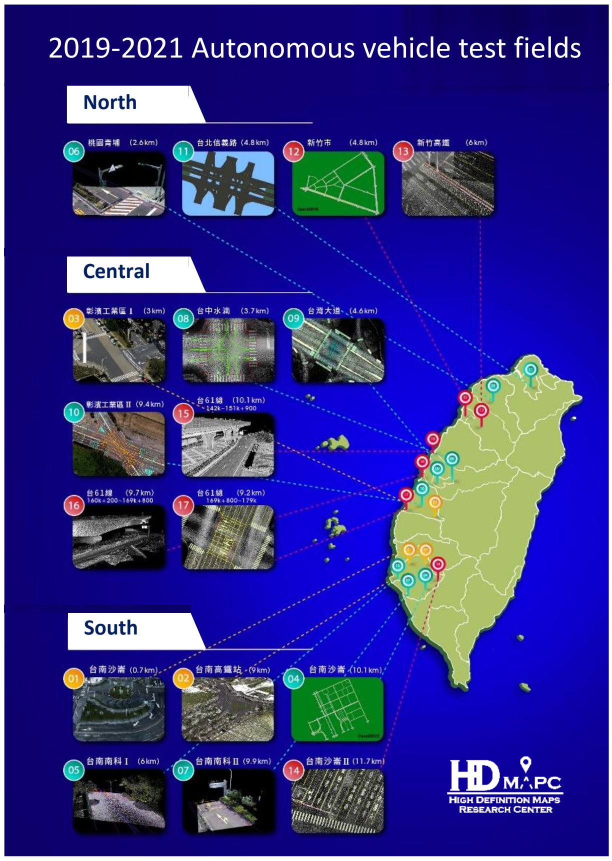

Figure 33. Verification of public road with OpenDRIVE in Taiwan.

5. CONCLUSION

With advances in autonomous driving technologies and the evolution of the automotive industry, autonomous vehicles will become a reality. HD maps as a key component in autonomous vehicle development, how to make sure the accuracy, correctness, and completeness is important. With the support of the MOI and academic institutions, we proposed the verification and validation strategies, suggestion review item, recommendation tools, and process to ensure that HD maps with OpenDRIVE and Autoware (Lanelet2) format agrees with the requirements. As preliminary results shown, the proposed process can conform not only in closed area but also public road. According to the results mentioned above, we can update and renew the HD maps guidelines and standards. The proposed verification strategies also can help reducing HD maps production costs. When the foundation of HD maps accomplishes, the autonomous driving techniques can naturally complement. The vision of full automation vehicle will come true rapidly in the future.

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