Alternative GCP Sources for Accurate HD Map Production

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KEY WORDS: High Definition Maps Guideline, Standard, UAS, SLAM, Ground Control Point

ABSTRACT:

In Taiwan, map companies have to referenced the HD Maps guideline and standard which published in TAICS, Taiwan to make ensure the quality of data. The procedure costs lots of times and resources. In order to increase the capability and mileage of HD Maps, this study try to use diverse surveying method and different kinds of sources for ground control points to produce the maps. The test field is National expressway No.8 in Taiwan. With different ground control points sources issue, we measure the features as ground control points and check points from UAS orthophoto. The preliminary results show that the absolute accuracy is suitable the requirement of HD Maps guidelines. With the diverse surveying method topic, we use sensor data from autonomous vehicle and SLAM algorithms to make HD Maps. The preliminary map results can be used as a base map to accomplish the concept of ground control point cloud. It can be used as ground control point to establishment, update, and overlay other point cloud data. On the other hand, these point clouds can be provided for application of SAE Level 3 autonomous vehicle to achieve the positioning accuracy of where in lane (0.5 meter). The flexible producing methods are helpful for formulating and renewing our HD Maps guideline and standard. These experiences will improve the efficiency and integrity for making map.

INTRODUCTION

In response to the development of autonomous vehicle and the requirement of HD Maps (High-Definition Maps), the car company in advanced countries as The United States of America, Europe, Japan have invested in the research for self-driving maps. Many countries consider about expressway or highway as high priority because the complexity of facilities with highway is lower than urban roads. The main contents of highway are lane lines, signs, signals, barriers, delineators. Besides, the field of highway is open sky so that the GNSS (Global Navigation Satellite System) signal is good. The cost and difficulty of making HD Maps is lower than urban city.

In Taiwan, map companies have to referenced HD Maps operation guidelines, Verification and validation guidelines for HD Maps, and HD Maps data contents and formats standard which published in TAICS (Taiwan Association of Information and Communication Standards), Taiwan to make ensure the quality of data. These HD Maps guideline and standard explain how to make and verify the data clearly. The operation guideline shows the mobile mapping system process including task planning, field reconnaissance, system test, system alignment, trusted sources, data post-processing, accuracy check, and map production and report writing for HD Maps. The verification and validation guideline present the checklist including operation planning, control survey, operation results, point cloud data, and vector layer. The data contents and formats standard clearly specify the content and encoding formats for the data of HD Maps in Taiwan.

Due to the high surveying and mapping costs of HD Maps in Taiwan, it is important for bending the curve of HD Maps production. The strategy for reducing the cost of HD Maps production includes standardize HD Maps, standardize the procedure of data collection, production, and verification, automated verification procedure, automated production tools based on AI (Artificial Intelligent), automated and versatile format converter, versatile collecting method, data sharing, and infrastructural production system. In this study, we try to use diverse surveying method and different kinds of sources for ground control points to produce the maps. This method is hoped to be established HD Maps successfully. The guideline and standard can be revised if the accuracy meets the specification. These flexible production methods will help improving the quantitative of HD Maps.

SPECIFICATION OF HD MAPS GUIDELINE AND STANDARD

With the support of Taiwan’s Ministry of the Interior (MOI), the related technical guideline and HD Maps format standard, recommendation of steps for producing HD maps, establishment of flexible data acquisition and mapping services, and stipulation of verification procedures are proposed since 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. Various publication milestones for HD Maps technical documents are listed in Table 1.

In this study, the ground control point parts can be referenced by HD Maps Operation Guidelines and Verification and Validation Guideline for HD Maps. Table 2 shows the recommendation on grades and specifications of inertial measurement unit and density of matched auxiliary ground control points. The control points should be local natural objects, artificial structures (such as the corner of road sign stripe) or man-made targets, with cm level accuracy. The

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spacing should be adjusted according to the grade of the adopted integrated GNSS/INS (Inertial Navigation System) positioning and orientation system, satellite positioning signal quality, surveying environment and execution feasibility. Satellite signal quality determination criteria can be established according to the standard data conversion format of RINEX v3.03 (6). The surveying methods includes e-GNSS real-time kinematic positioning system, post-processing positioning, and total stations. The accuracy requirement of ground control points shall have the absolute two-dimensional of less than 10 cm and the absolute three-dimensional accuracy of less than 15 cm (TAICS, 2021).

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
Operation and verification guidelines for HD Maps updating- Permanent static data v1	2021.10.21	Chinese
Standard for autonomous vehicle HD Maps auxiliary and events data	2022.12.29	Chinese

Table 1. Publication milestones for HD Maps technical documents.

Specifications	Stability drift	Recommended density of auxiliary ground control points
Navigation grade	Gyroscope drift: 0.001-0.01 degree/hour Accelerometer: 50-100 μg	Every 500 m
High tactical grade	Gyroscope drift: 0.1-1 degree/hour Accelerometer: 10-300 μg	Every 300 m
Medium tactical grade	Gyroscope drift: 1-10 degree/hour Accelerometer: 300-1000 μg	Every 100 m
Other grades	Gyroscope drift: > 1 degree/hour Accelerometer: > 2 mg	Every 30 m

Table 2. Recommendation on grades and specifications of inertial measurement unit and density of matched auxiliary ground control points (TAICS, 2021).

METHODOLOGY

In this study, there are two flexible surveying and mapping methods proposed. First one is to evaluate the use of different sources of control points. The mainly methods are using e-GNSS real-time kinematic positioning system and total stations which depend on the environment, for example open sky, tunnel, or urban area. However, it may be difficult or need to increasing the cost to survey ground control points in mountain area or highway. The idea of flexible ground control points sources is proposed. We use the aerial orthophotos and measure the coordinates of features as ground control points for HD Maps. In this way, we can use fewer physical ground control points to do the aerial triangulation with aerial images. Then, we can measure any features to get the coordinates which we name it as virtual ground control points.

Second part is about using MMS (Mobile Mapping Systems) with autonomous vehicle level positioning and orientation systems to collect data. The ground control points and algorithms are virtual ground control points as mentioned above and SLAM (Simultaneous Localization And Mapping). Figure 1 shows the procedure of flexible surveying and mapping methods in this study. We try to use both physical and virtual ground control points to make HD point cloud maps.

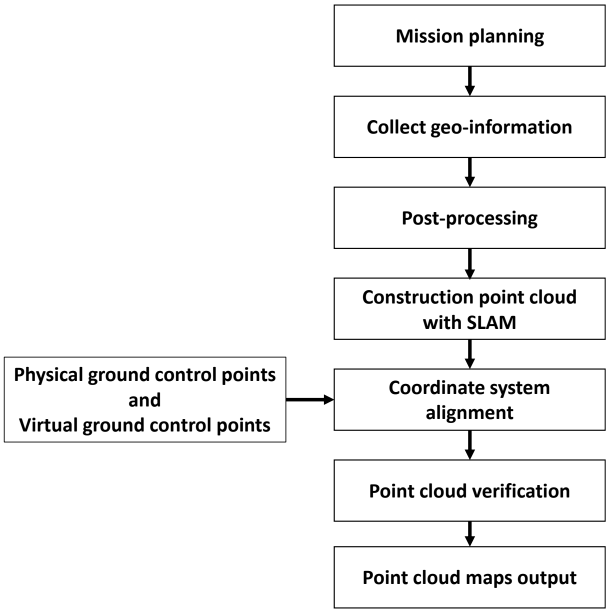


Figure 1. The steps for flexible HD maps production.

RESULTS AND DISCUSSION

4.1 Different sources of control points

In this study, the test field is National expressway No.8 in Taiwan. National expressway No.8 is viaduct form so that the ground control points can be separate to on the viaduct and below the viaduct. Figure 2 to Figure 5 show the distribution of ground control points. The triangle with yellow color are the ground control points which are on the viaduct (on the expressway). The amount are 15 points. The triangle with white color are the ground control points which are under the viaduct (on the road). The amount are 64 points.

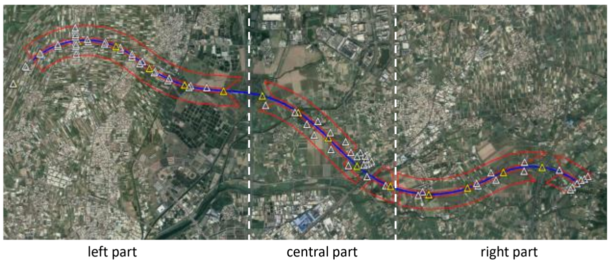


Figure 2. Distribution of ground control points.

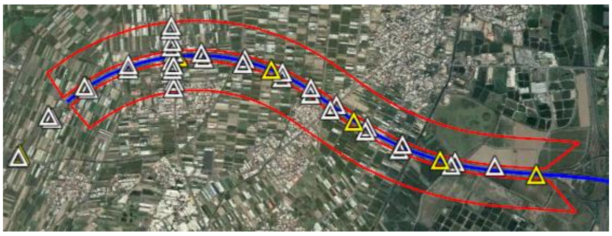


Figure 3. Distribution of ground control points (left part).

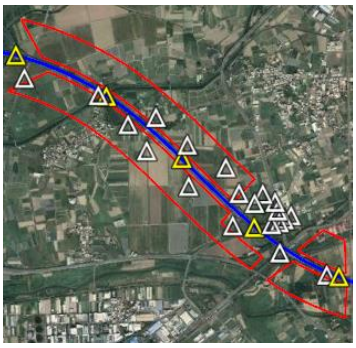


Figure 4. Distribution of ground control points (central part).

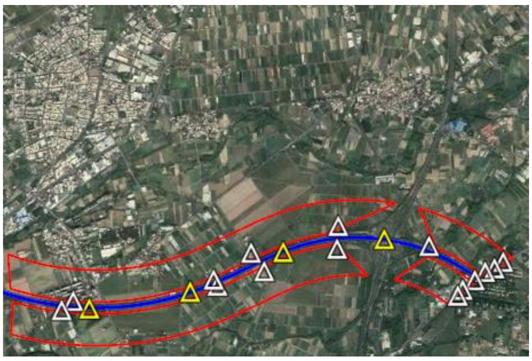
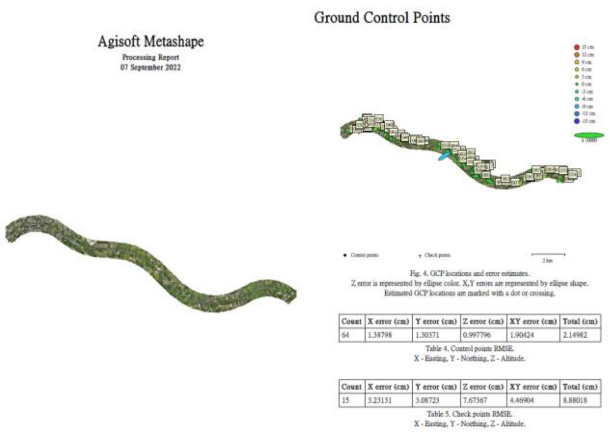


Figure 5. Distribution of ground control points (right part).

Figure 6 and Figure 7 show the ground control points surveying by e-GNSS. The ground control points on the road are used for UAV photography and aerial triangulation data processing. Then, we can measure the coordinates of triangle with yellow color from orthophoto and evaluate its accuracy. The red area in Figure 2 is the photography range by UAV (Unmanned Aerial Vehicle). After finishing aerial triangulation data processing, we can get the UAV orthophoto to measure any feature for its coordinate. Figure 8 shows the report of aerial triangulation. Figure 9 and Figure 10 show the orthophoto result.

Figure 6. Ground control points surveying by e-GNSS (on the road, white triangle).

Figure 7. Ground control points surveying by e-GNSS (on the expressway, yellow triangle).



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Ground Control Points

Control points   Check points   2 km

Fig. 4. GCP locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated GCP locations are marked with a dot or crossing.

Count	X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total (cm)
64	1.38798	1.30371	0.997796	1.90424	2.14982

Table 4. Control points RMSE.
X - Easting, Y - Northing, Z - Altitude.

Count	X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total (cm)
15	3.23131	3.08723	7.67367	4.46904	8.88018

Table 5. Check points RMSE.
X - Easting, Y - Northing, Z - Altitude.

Figure 8. Report of aerial triangulation.

Figure 9. UAV orthophoto result.

Figure 10. UAV orthophoto result (part).

In order to evaluate the accuracy of virtual ground control point, the coordinates of triangle with yellow color from orthophoto are measured. Figure 11 shows the result of measuring ground control point from orthophoto. Table 3 shows the accuracy by comparison coordinates of virtual and physical ground control points. The preliminary results show that the two-dimensional and three-dimensional accuracy of virtual ground control points are less than 10 cm and 15 cm. The results meet the requirement of guideline. The virtual ground control points can be used for HD Maps.

Figure 11. Measuring ground control point from orthophoto.

Point	Accuracy (cm)				
	X	Y	Z	2D	3D
E002	-2.3	-1.4	-1.5	2.7	3.1
E003	-0.2	2.8	0.9	2.8	2.9
E004	-0.7	-0.6	-12.0	0.9	12.1
E005	6.5	4.7	-8.5	8.0	11.6
E006	0.6	1.1	-13.8	1.2	13.9
E007	-0.9	0.4	-13.8	0.9	13.8
E008	-1.3	-1.4	-9.0	2.0	9.2
W001	-6.0	0.0	7.6	6.0	9.7
W002	2.4	1.6	3.1	2.9	4.3
W003	-0.6	-0.7	2.0	0.9	2.2
W004	3.0	-2.1	-1.5	3.7	4.0
W005	-1.0	3.7	1.7	3.8	4.2
W006	2.8	-6.8	-8.4	7.4	11.2
W007	0.2	3.3	5.6	3.3	6.5
W008	6.8	5.4	4.8	8.7	9.9

Table 3. Accuracy by comparison coordinates of virtual and physical ground control points.

Next, the amount of ground control points which are on the road will be decrease to evaluated the minimum number of points that can achieve the best benefits. Table 4 shows the accuracy by comparison coordinates of virtual and physical ground control points with different number of ground control points (on the road, white triangle). The preliminary results show that the accuracy still achieve requirement of guideline when the amount of ground control points (on the road, white triangle) are 34 points, as every 430 m per point. If the amount is 24 points, the three-dimensional accuracy of point W008 is not less than 15 cm.

In addition, the z-axis accuracy is not ideal in this test. The possible reasons include three part: (1) The influence of camera interior orientation parameter calibration; (2) The location of ground control point (on the road, white triangle) for aerial triangulation data processing are with similar elevations, and the measured points (virtual ground control points) are all located on the viaduct; (3) The flight trajectory is parallel along the direction of National expressway No.8, and there is no vertical direction data. This test is limited by the actual environment and can only conduct aerial photography missions in this way. If conditions permit in the future, the aerial photography missions need to be carefully evaluated during planning.

Number of ground control point (on the road, white triangle)	Accuracy (cm)				
	X	Y	Z	2D	3D
64	3.2	3.1	7.7	4.5	8.9
54	3.0	3.1	8.4	4.3	9.4
44	2.9	3.1	8.4	4.3	9.4
34	2.9	3.4	8.8	4.5	9.9
24*	3.1	4.0	11.1	5.1	12.2

* 3D accuracy of point W008 > 15 cm

Table 4. Accuracy by comparison coordinates of virtual and physical ground control points with different number of ground control points (on the road).

In this study, we also compare the cost by traditional control surveying and measuring the orthophoto method. When we survey on expressway or highway in Taiwan, it is necessary to apply for a traffic maintenance planning. The cost with traditional surveying method including the amount of ground control points (on the expressway) and number of days on expressway is around NTD 60,000. The cost with measuring the orthophoto method including the amount of ground control points (on the road), UAV flight, and photography data processing is around NTD 139,000.

Due to the small range and evaluating feasibility of different ground control points sources purpose, this test use rotorcraft to collect data. The cost is relatively high. There are some suggestions when you try to use measuring the orthophoto method in the future. (1) When the field area is large and long, it is recommended to use a fixed-wing UAV equipped with a measurement camera, for aerial photography. The altitude is higher and the GSD (Ground Sample Distance) remains unchanged. It will collect larger area data with same time. (2) The rotorcraft can be used for small area or the task of adding fewer ground control points. It can reduce the cost of flight effectively. (3) The past UAV or airplane images also can be used to measure the coordinates of feature if the accuracy meets the requirement of guidelines. It also can decrease the cost.

4.2 Diverse surveying method

Second part is about using MMS with autonomous vehicle level positioning and orientation systems to collect data. Figure 12 and Table 5 shows the appearance and specifications of sensors and vehicle. The test field is also in National expressway No.8. The blue line in Figure 2 shows the trajectory of MMS.

Figure 12. Appearance of sensors and vehicle

Equipment	Specification
LiDAR	Velodyne HDL-64E
Laser class	Class 1 - eye safe
Range	120 m
Points generated	Max. 1,300,000 pt/sec
Distance accuracy	< 2 cm
Rotation rate	5-15 Hz
Position and Orientation System	iNAT-RQH
Constellation	GPS, GLONASS, GALILEO
Frequency	L1, L2
Accelerometer bias instability	10 μg
Gyroscope bias instability	0.02 deg/hr
Accelerometer scale error	100 ppm
Gyroscope scale error	5 ppm

Table 5. Specifications of sensors and vehicle.

This study uses MMS to collect data. The ground control points are virtual ground control points as mentioned in section 4.1. Data processing use SLAM technology. Figure 13 and Figure 14 show the HD point cloud maps results. The hue transition from red to blue corresponds to the change from high to low terrain. The preliminary result shows that the HD point cloud maps meet the requirement of the guidelines. The density of point cloud is 400 to 600 points per square meter and the relative accuracy is less than 10 cm.

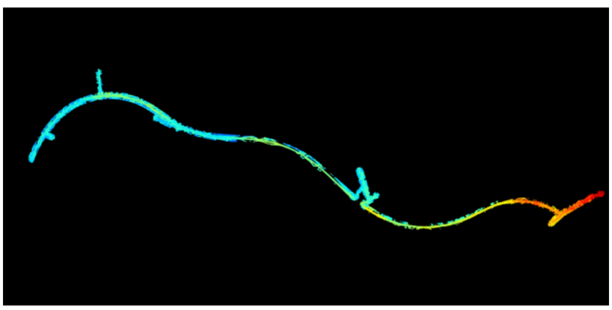

Figure 13. HD point cloud maps results.

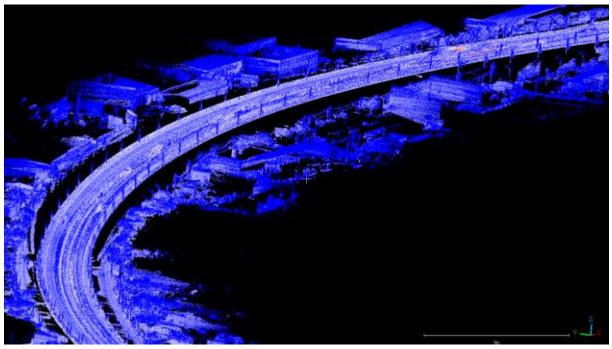

Figure 14. HD point cloud maps results (part).

For promotion of policy, the construction of HD point cloud maps can refer as the reference to revise the guidelines. For application issue, HD point cloud maps can be used as a base map to accomplish the concept of ground control point cloud. The ground control point cloud can be considered as ground control point so that the new collecting point cloud can match to the ground control point cloud by using NDT (Normal Distribution Transform). The point cloud will be modified and fit to the coordinate system of real world. It also can implement the establishment, updating, and increasing density of point cloud. On the other hand, integrated multi-sensor and HD point cloud maps can provide SAE level 3 navigation of autonomous vehicle service. The positioning accuracy can achieve “where in lane” level.

CONCLUSION

In response to the development of autonomous vehicle and the requirement of HD Maps (High-Definition Maps), the car company in advanced countries as The United States of America, Europe, Japan have invested in the research for self-driving maps. Many countries consider about expressway or highway as high priority because the complexity of facilities, cost, difficulty of highway is lower than urban roads. In Taiwan, map companies have to referenced the HD Maps guideline and standard which published in TAICS, Taiwan to make ensure the quality of data. The procedure costs lots of times and resources. In order to increase the capability and mileage of HD Maps, this study try to use diverse surveying method and different kinds of sources for ground control points to produce the maps. The preliminary results show that the two-dimensional and three-dimensional accuracy of virtual ground control points are less than 10 cm and 15 cm. The results meet the requirement of guideline. The virtual ground control points can be used for HD Maps. Considering the best benefits, every 430 m per ground control point is needed for aerial triangulation so that the two-dimensional and three-dimensional accuracy of virtual ground control points can achieve less than 10 cm and 15 cm in this study. With the diverse surveying method topic, we use MMS, SLAM algorithms, and virtual ground control points to make HD Maps. The preliminary map results can be used as a base map to accomplish the concept of ground control point cloud. It can be used as ground control point to establishment, update, and overlay other point cloud data. On the other hand, these point clouds can be provided for application of SAE Level 3 autonomous vehicle to achieve the positioning accuracy of where in lane (0.5 meter). The flexible producing methods are helpful for formulating and renewing our HD Maps guideline and standard. These experiences will improve the efficiency and integrity for making map.

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