GNSS Determination of Road Elevation Information Required for 3D Pipeline Reduction

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ABSTRACT

In the process of 3D pipeline data, the original field measured pipeline burial depth needs to be worked with road elevation information, usually provided by Digital Elevation Model (DEM), in order to obtain the absolute pipeline height. formation system. This study uses Global Navigation Satellite System (GNSS) data recording and Post Processing Kinematic (PPK) method to compute the time series coordinates along the road, as based on vehicle platform. According to the average performance of the test roads, the GNSS data missing rate is about 6%, the success rate, obtaining a fixed solution of PPK, is about 97%, and the plane and vertical precision of coordinates are about 2 cm and 4 cm, respectively. When the Artificial Neural Network (ANN) is applied to complement the coordinates of missing points, the elevation information can still conform to a fitting error of less than 4 cm. The accuracy of the GNSS determinations, checked by precise leveling, is better than 10 cm, which is superior to the road elevation information with an estimated error of about 60 cm, as provided by the 5 m grid DEM normally used in Taiwan's 3D pipeline system.

Keywords: Global Navigation Satellite System (GNSS), Post Processing Kinematic (PPK), 3D pipeline system, road elevation information

3D 管線歸算所需道路高程資訊之 GNSS 測算研究

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摘　　要

在 3D 管線資料建置過程中，原始量測之管線深度資料，便需配合使用由數值高程模型(DEM)所提供之道路高程資訊，以取得管線高程值。本研究採車載 GNSS 資料與後處理動態定位(PPK)模式，進行道路資料解算。由測試道路之表現可知，GNSS 漏測率約為 6%，PPK 取得固定解的成功率約為 97%，坐標成果的平面與高程內部精度分別約為 2 cm 與 4 cm。當運用類神經網路(ANN)進行缺漏點坐標增補，其高程仍可符合小於 4 cm 誤差。透過精密水準進行檢核可知，GNSS 外部精度優於 10cm，可優於我國 3D 管線系統慣採 5 米網格 DEM 所提供約 60cm 誤差之道路高程資訊。

關鍵詞：全球導航衛星系統、後處理動態定位、三維管線系統、道路高程資訊

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I. INTRODUCTION

With the rapid development of geographic information system (GIS) and the gradual formation of 3D data standards, map services have expanded towards the direction of multi-dimensional integration. Therefore, 3D geospatial information has been incorporated into national construction planning, which includes building a 3D map platform and its auxiliary application module (see Fig. 1) using public pipeline information to facilitate its 3D integration and application.

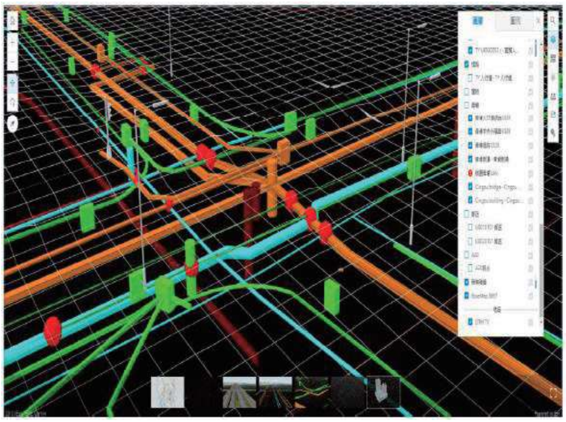

Fig. 1. 3D pipeline information system

In measurements related to the correctness of pipeline data, in accordance with the national specifications, when measuring the plane and vertical coordinates of existing pipelines, manholes, and facilities, the positioning accuracy must be better than 20 cm, in order that all kinds of pipeline can be properly drawn with digital maps on a same coordinate datum, such as TWD97 in Taiwan.

However, in the implementation process, it is found that when the existing 2D pipeline data is transferred to a 3D pipeline, the following phenomenon may occur due to insufficient correctness:

(1) The pipeline attribute, as submitted by the pipeline company, is missing; for example, the buried depth of the starting point and end point of the pipeline is not filled in, thus, only the default value can be displayed on the 3D platform, which results in incorrect joint displays for the 3D pipeline (see Fig. 2);

(2) The height of the pipeline is obtained through the reduction of the road elevation and the buried depth of the pipeline. When the road elevation is not well-measured on-site, and the DEM of a 20 m or 5 m grid is used, the underground pipeline may be misplaced or the manhole cover may not fit the road due to the lack of details in the DEM (see Fig. 3).

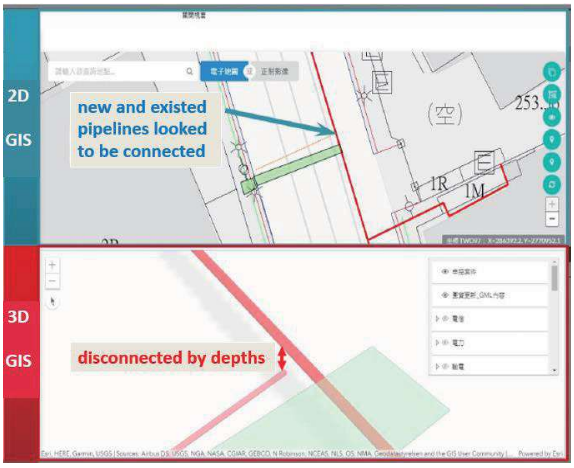

Fig. 2. Pipeline joints displayed differently on 2D and 3D platforms

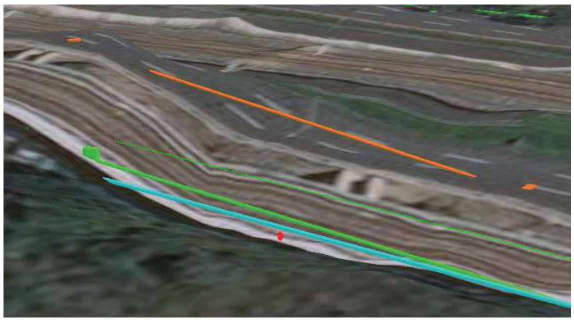

Fig. 3. The lack of details in DEM leads to the unreasonable display of underground pipeline standing out the road

Regarding the abovementioned Point 2, there are confidential restrictions on the use of existing high quality of DEMs based on the 1 m grid DEM, as measured by airborne LiDAR. Although the 5 m grid DEM obtained by aerial photogrammetry can be widely used, its error may be larger than 50 cm. Considering the manhole and pipeline data with 20 cm accuracy, as obtained by surveying, it may have deficiencies in the application on the 3D pipeline system, as shown in Fig. 3.

Therefore, it is beneficial to improve the data quality of 3D pipeline systems for road elevation information if a rapid, applicable, inexpensive and accurate method can be developed. In recent years, GNSS satellite positioning technology has achieved success due to the advantages of convenient operation and standardized computation [1][2][3]. It may become a major technology for rapid road elevation measurement [4][5]. However, in a road environment dominated by metropolitan areas, buildings and other structures on both sides of the road may obscure many GNSS signals, and result in the deterioration of satellite geometry, which may lead to the loss of satellite positioning precision, or even lead to the omission of positioning results [6][7].

This study used the GNSS satellite systems, including GPS, GLONASS, BeiDou, Galileo, and QZSS, to collect observations with low and medium speed driving vehicles in different street areas, and then, the PPK method was adopted to form a fast measurement tool for road elevation information. In addition, artificial intelligence or auxiliary information can be used to complement the missing coordinate data along the roads [8-13]. In order to test the data observed in different trials, the GNSS positioning results were checked against the precise leveling, and another type of results carried out by low-altitude UAV 3D model measuring was also included in the comparison of the road elevation information. In brief, the technical topics discussed in this study included the causes of errors in underground pipeline height reduction, the applicable performance of GNSS kinematic positioning in street areas, the effectiveness of the missing data completion method, and the external accuracy check of road elevation information, in order to ensure that GNSS results can be effectively provided for the construction of the 3D pipeline system.

II. HEIGHT REDUCTION ERRORS OF UNDERGROUND PIPELINE

In the process of 3D visualization of underground pipeline information, various forms of geo-spatial data may be used, which are including (1) basic terrestrial data, such as a basic topographic map, high-resolution aerial survey images, DEM, and ground building models; (2) underground thematic data, such as underground pipelines, ancillary facilities, and structures (e.g. integrated pipe trench, common pipelines, underground shopping malls, or underground tunnels). Among them, DEM categorized in the basic terrestrial data can provide the 3D terrain data needed for visual presentation. However, in the process of building a 3D pipeline system, if the DEM is not detailed enough, pipeline dislocation will occur after terrain data interpolation processing in the GIS system, as shown in Fig. 3.

In addition, the height of the underground pipeline in the database is obtained by a relative mode, which is calculated by deducting the pipeline buried depth from the road elevation information. In other words, the pipeline height, playing a role on presenting the vertical position of the underground pipeline in the 3D pipeline system, is closely related to the road elevation information and the pipeline buried depth. Therefore, initiating an observing method that can obtain sufficient elevation information on the road can improve the spatial presentation quality of the 3D pipeline system.

In accordance with the data standard for public pipelines, the vertical position of 3D pipelines, as recorded in a relative mode at the time of data construction, should be converted into an absolute mode. The spatial relative relationship is shown in Fig. 4, and the data reduction function used in the conversion process is shown in Eq. (1).

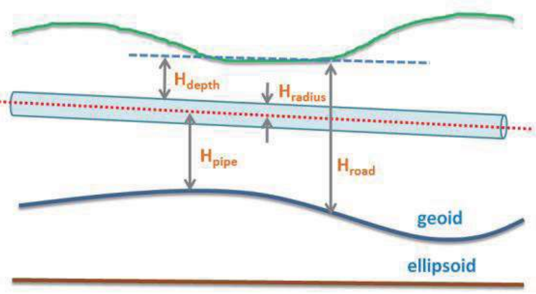

Fig. 4. Spatial correspondence between road elevation and pipeline buried depth

$$H_{pipe} = H_{road} - H_{depth} - H_{radius} \quad (1)$$

where, H_{pipe} is the height of the underground pipeline, which is obtained by deducting the road elevation (H_{road}) from the buried depth referred to the top of the pipe (H_{depth}) and half of the pipe diameter (H_{radius}).

It is a fact that the road elevation information is highly unlikely to be measured in the field work. Therefore, the road elevation required in the reduction process can only use the DEM model with insufficient details, which may lead to large reduction errors in the pipeline heights.

This study classified the problems caused by the pipeline height reduction error in the 3D pipeline system into two types: one is the spatial dislocation of the underground pipeline; the other is that the manhole cover does not fit the road. The simulated values, as shown in Fig. 5, are taken as an example; if the elevation information changes from the correct 120 m to the incorrect 120.5 m at the right end of the road, under the condition that the whole section of the underground pipeline top is buried at the same depth of 1.2 m, then the pipeline height of the left section will be the correct 118.8 m (i.e. 120-1.2 m). However, the pipeline height of the right section will be incorrect at 119.3 m (i.e. 120.5-1.2 m), which will lead to spatial dislocation. As shown in Fig. 6 for another case, when the height of two manhole covers on the road is 120 m, the manhole cover on the left can correctly fit the road at 120 m, but the manhole cover on the right will be raised to 120.5 m due to the wrong road elevation information, and the manhole cover will be 0.5 m under the road, which is an unreasonable position.

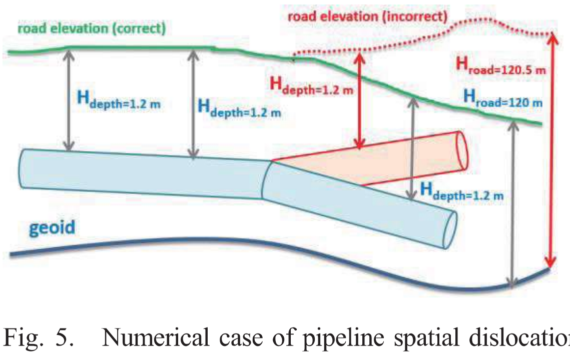

Fig. 5. Numerical case of pipeline spatial dislocation caused by incorrect road elevation information (red section on the right)

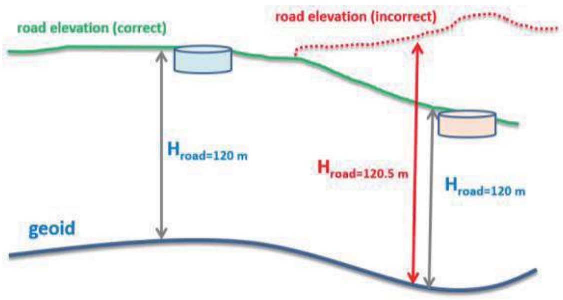

Fig. 6. Numerical case of incorrect road elevation information (red section on the right) resulting in manhole cover not fitting the road

III. GNSS DETERMINATION METHOD

If the 3D coordinates of the spatial positions of various pipelines can be provided by ground measuring, the pipeline height reduction errors, as based on DEM data, can be avoided in GIS. However, in fact, as the existing pipeline has been buried under the ground for a long time, and its height is not easily detected, the reduction method using ground elevation and pipeline buried depth must be adopted. Thus, in order to make the 3D pipelines appear in reasonable spatial positions, this study explored a ground measuring method to effectively obtain high-quality road elevation information.

A set of onboard GNSS receiver was used as the main sensing device, which was expected to overcome the signal obstructed problem in the road environment through the observations of multi-system navigation satellites, and obtain a large amount of the elevation data on the path through the PPK mode. In addition, when ANN is introduced to complement the missing points, complete and high-precision road elevation information can be built. The related operational structure is shown in Fig. 7. GNSS satellite observations, as recorded on moving vehicles, are used to obtain high-precision road elevation information along the driving route through positioning data processing, and then, the 3D pipeline height reduction is applied. The spatial relationship of the related measurements is shown in Fig. 8.

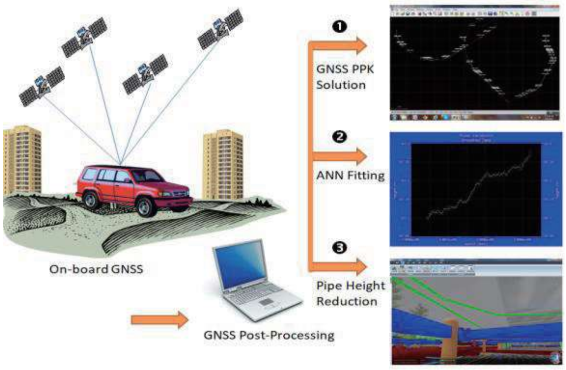

Fig. 7. The operational framework designed in this study

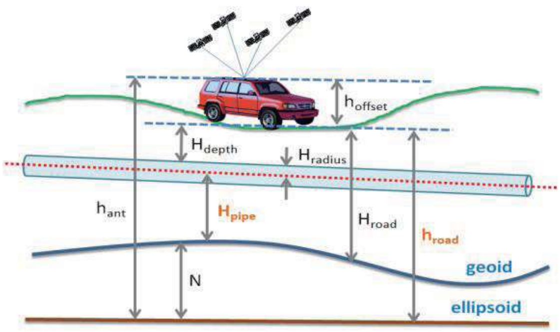

Fig. 8. Spatial relationship of underground pipeline height measured by on-board GNSS

According to Fig. 8, the original heighting value (h_{ant}) calculated by GNSS PPK is the vertical coordinate based on the ellipsoid. After deducting the GNSS antenna height (h_{offset}), the ellipsoid height (h_{road}) of each measuring point along the road can be established, and then, the geoid undulation (N) can be applied for deduction. The H_{road} can be defined under the orthometric height system, and the relationship is, as follows:

$$H_{road} = h_{road} - N = (h_{ant} - h_{offset}) - N \quad (2)$$

Eq. (1) can then be used to calculate the underground pipeline height (H_{pipe}), as required by the 3D pipeline system, and based on the attribute data in the pipeline database, including the pipeline buried depth (H_{depth}) and pipe radius (H_{radius}).

In the process of establishing the basic ellipsoid height (h_{road}) of each measuring point along the road, the on-board GNSS receiver recorded all satellite observations, and then, employed the PPK mode to determine the solutions. As the GNSS kinematic positioning mode does not need to collect observations for a long period of time at the same point, there may be not very accurate; however, it can be suitable for a large number of positioning needs regarding road elevation information.

In addition, according to the PPK positioning mode, at least one base station at appropriate distance should be set up at known coordinate point, and the carrier phase observables should be simultaneously recorded by the rover. However, since there was no need to carry on real-time positioning, there was no need to equip wireless communication. The GNSS observations, as received by the base station and the rover, were downloaded to a computer after the campaign was complete, and each epoch of coordinate of the rover were calculated by the post-processing method.

In terms of the quality assessment of road elevation information, as detected by an on-board moving vehicle using the PPK operation mode, the availability and accuracy of positioning results need to be discussed. The assessment indicators used are, as follows:

(1) The success rate is represented by the ratio (SR), obtained by the number of integer ambiguity fixed solutions diving the number of all GNSS observations; the higher the SR value, the higher the availability of GNSS data.

(2) Internal precision is represented by the average standard deviation ($\overline{\sigma}$) of the fixed solutions obtained by GNSS PPK; the smaller the $\overline{\sigma}$ value, the smaller the distribution of positioning errors.

(3) External accuracy is represented by the root mean square (RMS) of the height difference between the two points, as obtained by GNSS PPK solutions minus the precise leveling measurement; the smaller the RMS value, the smaller the deviation between the GNSS heighting results and high precision of leveling check data.

IV. TESTS AND ANALYSIS

The test site of this study was located in Zhongli District of Taoyuan. The GNSS observations and check data were collected from three different types of roads with different signal obstructed environments, and the PPK mode was used to process the GNSS observations and evaluate the results. NovAtel ProPak 6 GNSS receivers were used in the base station and vehicle-based rover. Data processing in the PPK mode was performed using Waypoint GrafNav 8.90 software [14].

4.1 Pre-test

In order to understand the difference of the PPK results using different GNSS combined observations, in January 2020, an unknown station was set up next to a road with around 60% open sky, and the baseline length between the unknown station and the base station installed in the open space on the roof was about 250 m. The satellite observation data was collected by static mode for 2 hours with one second data interval.

The static observation data were treated as kinematic data to solve with the PPK model. The errors in the plane (2D) and vertical (h) components of this set of coordinate solutions, as obtained by using GNSS observations and their success rates, are shown in Table 1.

Table 1. Evaluation of pre-test results using different combinations of GNSS data

Observation combination	$\overline{\sigma}$ (cm)		SR (%)
	2D	h	
GPS+GLONASS	9.9	16.7	59.9
GPS+GLONASS+QZSS	5.9	15.0	97.8
GPS+GLONASS+BDS	1.8	4.0	99.6
GPS+GLONASS+Galileo +BDS+QZSS	1.4	3.6	100

According to the evaluation results in Table 1, the error and the success rate in the PPK coordinate solutions using the traditional GPS+GLONASS observations collected on the roadside were poor, but when the BDS or QZSS observation was added, the positioning precision and success rate were significantly improved due to more satellites received. When a full set of GNSS observations were included in the solution, the precision in the plane component was increased to 1.4 cm, and the vertical component was 3.6 cm. In addition, as the ambiguity fixed solution has a 100% success rate, it can be regarded as a better method to conduct kinematic positioning for road elevation information.

4.2 Road Tests

During the road tests, the GNSS base station was located at the same point as pre-test, and the three roads, coded with A, B, and C, were about 0.5 km, 1.5 km, and 7.2 km from the base station, respectively. The test roads have 2 lanes, 4 lanes, and 6 lanes in two directions, with average open-sky ratio of about 40%, 60%, and 80%, respectively. However, it was noted that a section of the widest road C was located under a highly obstructed MRT elevated rail.

The average speed of moving vehicles was controlled by 20-30 km/hr [15], and the data sampling rate was set to be 1 Hz, which is equivalent to the road sampling density at about 5-8 m, or roughly equals to the 5 m grid of DEM. After conducting observation of the on-board GNSS, including GPS, GLONASS, Galileo, BDS and QZSS, in January 2020, the relevant performance indicators can be evaluated, as obtained from the street.

After calculating about 800 epochs of GNSS data for each of the three test roads, the available data number and elevation profile for each path are shown in Fig. 9, Fig. 10, and Fig. 11. In addition, the GNSS observation data recorded along the three test roads were examined to evaluate the data missing rate, as well as the precision and availability, as listed in Table 2.

Table 2. Evaluation of GNSS data and PPK results of three test roads

Road	Missing rate (%)	$\overline{\sigma}$ (cm)		SR (%)
		2D	h	
A	9.0	3.2	6.0	93.4
B	0.3	0.9	1.8	99.7
C	7.1	1.5	2.9	97.4
Mean	5.5	1.9	3.6	96.8

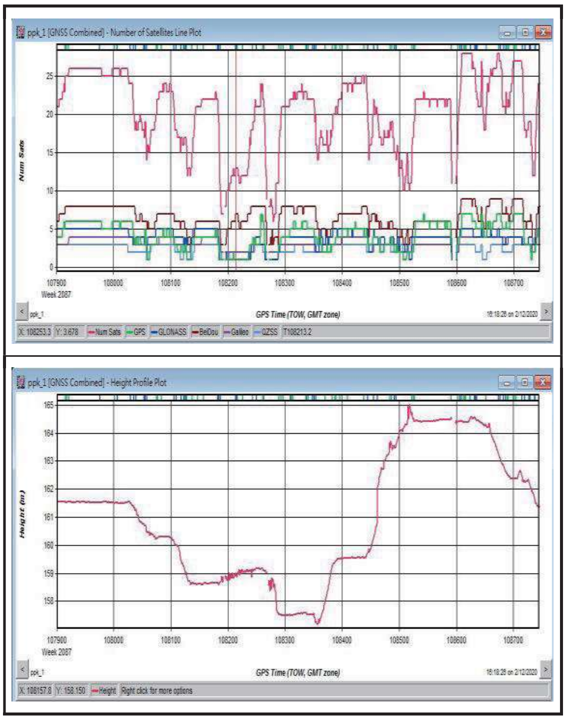

Fig. 9. Satellites received (upper) and elevation profile solved by PPK (lower) for Road A

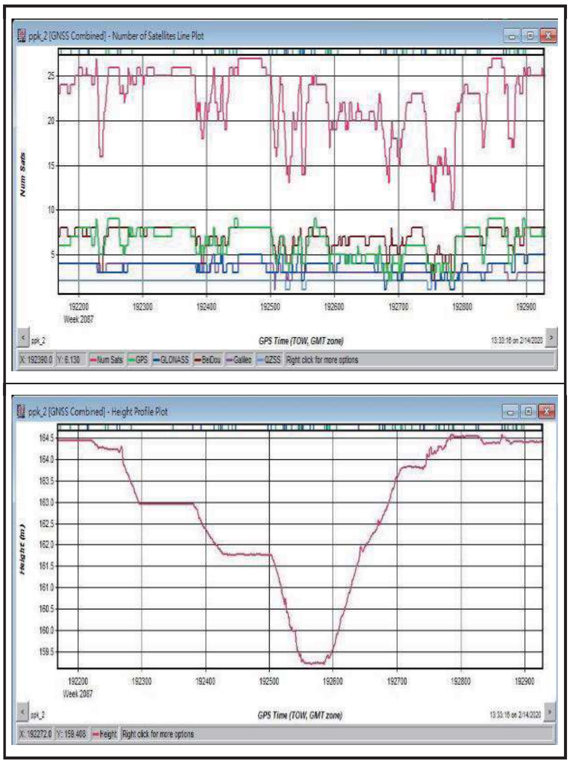

Fig. 10. Satellites received (upper) and elevation profile solved by PPK (lower) for Road B

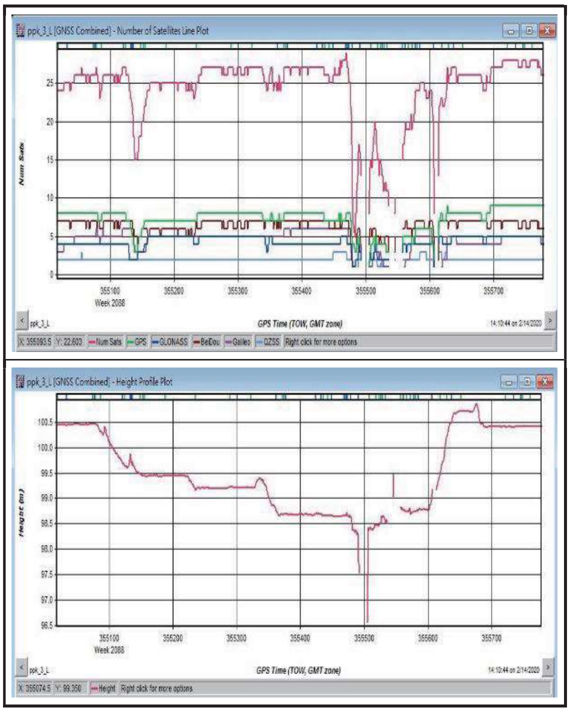

Fig. 11. Satellites received (upper) and elevation profile solved by PPK (lower) for Road C

Based on the GNSS kinematic data received from the three test roads, the following performance characteristics were provided from the PPK-based results:

(1) Due to a section of MRT overpass on the path of Road C, the number of satellites received, the data missing rate, the success rate, and the internal precision were all affected and degraded.

(2) Based on the over-all evaluations, the average data missing rate was about 6%, the success rate of PPK solution was about 97%, and the internal precision of coordinate was better than 2 cm and 4 cm in plane and vertical component, respectively.

(3) The GNSS data missing rate is correlated with the success rate and the internal precision of the positioning results. In other words, the obstacles to GNSS observation, as caused by the road environment, have a strong impact on data integrity, the success rate of ambiguity resolution, and the coordinate precision.

4.3 Coordinate Completion for Missing Points

As GNSS observations are affected by road environments, the road elevation information obtained by PPK may not be complete. Thus, in order to improve the integrity of the GNSS solutions, ANN were adopted to complement the missing coordinates for the road points that may be missed or rejected due to poor data quality.

The ANN method is a learning algorithm derived from the imitation of human thinking patterns, which can achieve automatic prediction through the learning process [16] [17]. The neural network used in the operation is composed of a large number of processing components of neurons (or nodes), where each processing element (X_1, X_2, …, X_n) is called a link, and each is connected to a weighted value (W_{1j}, W_{2j}, …, W_{nj}) [18]. The output value (Y_j) is the result of weighting the input value and function conversion. The function is, as follows:

$$Y_j = f(\sum_{i=1}^{n} W_{ij} X_i - b_j) \quad (3)$$

where W_{ij} is the connection weight between nodes i and j between layers, and b_j is the threshold value of node j.

The multilayer node model and error Back Propagation (BP) are mature ANN application methods, which can transform the input-output problem of a group of samples into a nonlinear optimization problem, and determine the related regularities in a large amount of data. The learning rule of the BP neural network mainly focuses on the function of the network learning error and weight of the network link, and it should continuously minimize the error and adjust the weight until the overall error is lower than the fixed threshold value.

The MATLAB tool was used to calculate the BP-based ANN, the training samples were adopted by ambiguity fixed solutions of the three sets of PPK test results. The optimal number of hidden layers and predicted missing coordinates were automatically calculated by the program, including training samples, test samples, and verification samples, after the coordinate data were divided into N, E, and h components. The points with authentic positioning coordinates in the sample data can also be compared with their predicted values to obtain the estimated RMS error (see Table 3), which can be used to evaluate the effect of the ANN operation.

Table 3. RMS error after coordinate completion with ANN for the missing points

Road	Completion (pts)	N (cm)	E (cm)	H (cm)
A	65	174.1	154.1	5.6
B	2	126.2	184.1	4.6
C	54	167.5	171.9	2.1
Mean	40	230.7 (2D)		4.1

According to the results in Table 3, after the ANN method was used to complement the PPK solutions of the three test roads with the coordinates of the missing points (see Fig. 12, Fig. 13, and Fig. 14), the estimation error was 231 cm in the plane component. However, the RMS error of the vertical component was effectively estimated to be only about 4 cm by using ANN. The reason for the large plane error is that the 2D alignment of the test road had no geometric regulations in general, which led to higher estimation errors. However, due to the requirement of flatness for the road, the road elevation information normally had continuous and smooth characteristics and, hence, it provided better elevation estimation results.

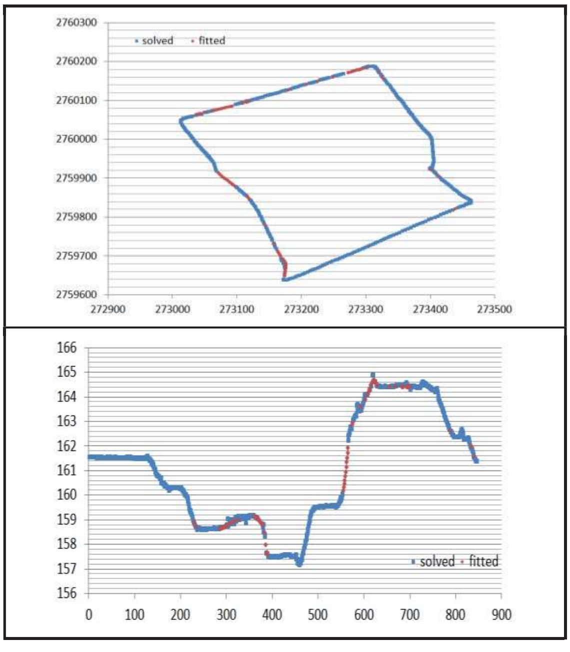

Fig. 12. Plane track (upper) and elevation profile (lower) of ANN data completion for Road A

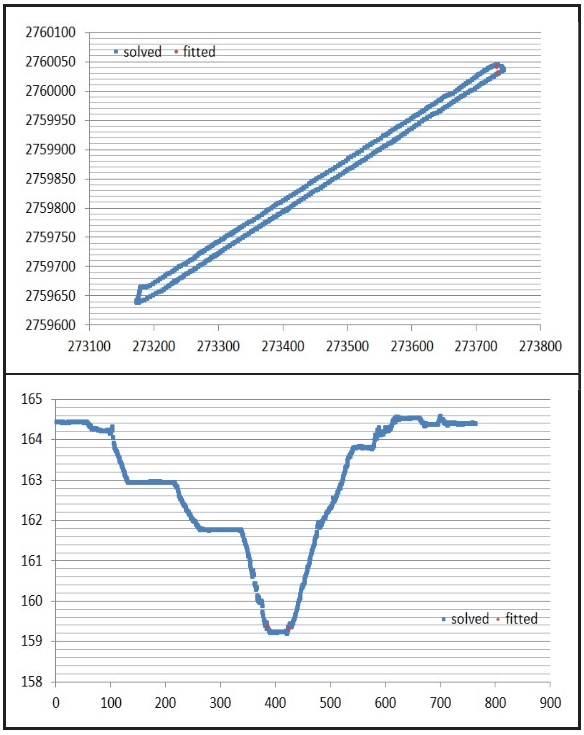

Fig. 13. Plane track (upper) and elevation profile (lower) of ANN data completion for Road B

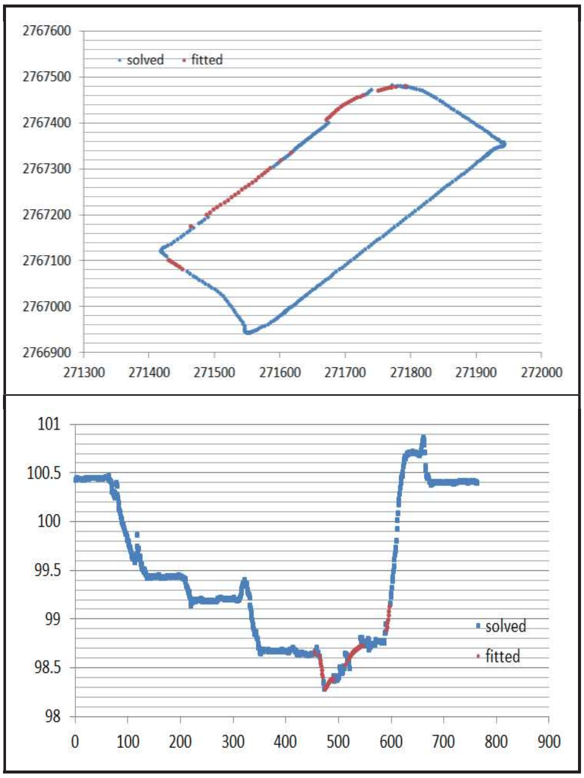

Fig. 14. Plane track (upper) and elevation profile (lower) of ANN data completion for Road C

4.4 External Check of Road Elevation

In order to carry on an external check of the PPK-based road elevation information, this study set up two check points on each of the three test roads, and the vehicle stayed on the check points for about 10 seconds to obtain the elevation information of each check point within the positioning solutions.

A Sokkia SDL1X electronic precise level was used to measure the height difference between the two check points, in order to obtain the standard check data with a round trip closure of less than 2 mm. The accuracy checked by comparing the 5 m grid DEM and PPK solutions with the leveling height difference on the same check points of the road is listed in Table 4.

Table 4. External accuracy check of road elevation

Rd.	Height difference (m)			Error (cm)	
	Level	PPK	DEM	PPK	DEM
A	2.785	2.887	2.7	10.2	8.5
B	1.396	1.486	0.8	9.0	59.6
C	0.408	0.520	1.3	11.2	-89.2
RMS				10.2	62.1

According to the road elevation information provided by the PPK solutions, the RMS error of the height difference, as compared with the precise leveling, was about 10 cm, which was larger than the internal precision obtained by the pre-test (about 4 cm), and highly likely caused by the uncertainty of the position of the check point identified in the PPK coordinate data sets.

In addition, the 3D pipeline GIS using the 5 m grid DEM to provide road elevation information shows that the RMS error was about 62 cm. Compared with PPK solution, the road elevation information with a 10 cm level of error from GNSS observations is significantly better than that from the 5 m grid DEM, which also proves that the on-board GNSS should have the technical value of expanding or revising the current road elevation information in use.

Moreover, based on the collected data of 201,671 ground measuring of manhole cover in Taoyuan City, when the road elevation information was changed from the 5 m grid

DEM to the 1 m grid DEM, as measured by LiDAR, the RMS error were estimated to be 58 cm (5 m grid) and 11 cm (1 m grid), respectively. Among them, the 58 cm error of the 5 m grid DEM was close to the 62 cm error in Table 4, while the 11 cm error of the 1 m grid DEM was approximately equal to the 10 cm error of the PPK results in Table 4. Such results show once again that the technology of measuring road elevation information by on-board GNSS can be applied to the determination of road elevation identification.

In a further test, DJI P-4 UAV was used for low-altitude aerial photography of Road A, and PIX4Dmapper was applied to quickly build a 3D model without ground control, in order to obtain the road elevation information under the application of photogrammetry (see Fig. 15). The road elevations, as measured by the 10 ground points from 3D model and PPK solutions, were compared with those provided by the precise leveling, regarded as the standard check data. The evaluation results show that the RMS error of the road elevation information of the UAV-based 3D model was about 24.8 cm, while the RMS error of the road elevation measured by PPK was about 6.8 cm.

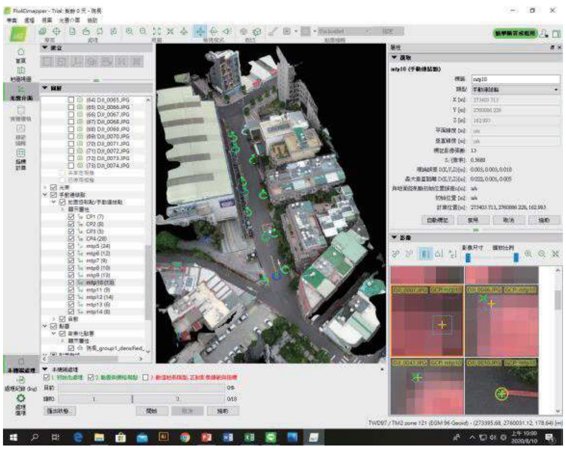

Fig. 15. UAV-based 3D model and check point measurement of Road A

According to the test results, the 25 cm level of road elevation error measured by UAV modeling without ground control was better than the 60 cm level of error measured by the 5 m grid DEM in Table 4. As the check points used in this test were clearly marked on the road, the 7 cm road elevation error provided by PPK was slightly better than the 10 cm error in Table 4, which also shows the availability of GNSS for the determination of road elevation information.

V. CONCLUSIONS AND SUGGESTIONS

This study tested a road elevation information method for 3D pipeline data elevation reduction, which used the GNSS satellite observation data recorded by a moving vehicle, and applied the PPK model for solutions. The operational advantages of this method include:

1. The vehicle is easy to move, and is suitable for long-distance linear data (such as a road) sensing;
2. The instrument configuration is simple (only a GNSS receiver is used), and the cost is lower than the mobile mapping system;
3. It can provide 3D road geometry information, which can easily add interpretation and application value (such as road length and longitudinal slope determination), for ride comfort or fuel saving [19][20];
4. Compared with the DEM obtained by aerial photography, it is more suitable for roads and beneficial to using 3D pipeline data.

In addition, this study provides useful information regarding the road application test of GNSS determination technology, as follows:

1. On roads where permeability is divided into three levels, the GNSS missing data rate is about 6% on average, the success rate of the fixed solution is about 97%, and the internal precision of the PPK solution is about 2 cm in plane and 4 cm in elevation.
2. The ANN method was used to supplement the coordinates of PPK missing points, which was only effective for the vertical component, and the RMS error of the provided elevation estimate was about 4 cm.
3. The external precision of the PPK road elevation information ranged from 7 cm to 10 cm under different conditions with or without clear identification of the checkpoints through an external check of horizontal measurement.
4. For UAV aerial photography modeling without using ground control points, the

precision of the road elevation measured in the 3D model was about 25 cm.

5. The error magnitude of road elevation information in the 3D pipeline system using the 5 m grid DEM can reach 60 cm but can be reduced to about 11 cm by using the 1 m grid DEM, and the precision of road elevation obtained by PPK using 1 Hz GNSS observation was about the same as that of the 1 m grid DEM.

After discussion of the determination and application of PPK-based road elevation information, this study suggests that in the established 3D pipeline system, the basic topographic information used in the GIS map platform should be the 1 m grid DEM to improve the fitness between the hole cover, the pipeline, and the road. In addition, when the road elevation information is required to be partially densified or modified, the PPK method of onboard GNSS can be used.

Moreover, the use of vehicle-mounted GNSS is limited by the visibility of the sky, especially in urban areas, where the number of satellites is easily affected. It is suggested to analyze the poor solutions in the data sets to further explore any other factors that are actually affect the quality of the observation and the result. Also, in order to reduce the operation cost of the base station used in PPK observation, it can be combined with a continuous base station, as established by NRTK, to improve the data quality of the 3D pipeline system.

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