Research and Application of 3D Real Modelling from Oblique Images for City Planning

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Abstract. With the continuous advancement of urban informationization, the requirements of diverse information systems are abundant and various. Meanwhile the integrity of information resources is also improved. The 3D real model data has become an important part in the construction of digital city database with its perceptual intuition, objectivity and accuracy characteristics. Taking a region in Beijing as an example, the oblique photogrammetry is carried out by using multi-rotor unmanned aerial vehicle (UAV) and the 3D city models are made by the Context Capture which is a powerful tool for image control point matching, aerial triangulation encryption and 3D real scene modeling. Moreover, the quality of 3D real model is quantitatively evaluated by the point accuracy assessment and plane accuracy assessment. The experimental results show that the median error of plane accuracy position is 0.01315 m and the median error of elevation accuracy is 0.02621 m. Furthermore, the median error of both directions are less than 10 cm, and the elevation accuracy is slightly higher than that of plane.

Keywords: urban informationization; 3D real model; oblique images; city planning; unmanned aerial vehicle

1. Introduction

The urbanization is rapid development all over the world. Geographic Information Systems (GIS), vehicle navigation systems and remote sensing have been witnessed in a rapid growth of urban informatization (Guler et al., 2015; Virtual City Systems, 2006). The 3D city model data, with the characteristics of high simulation and high precision, has gradually become the basic information resources of digital city and smart city construction (Singh et al., 2013; 2014). The application and service system of urban information resources based on 3D city model data will lay a solid foundation for the construction of digital city and smart city information infrastructure (Dokonal et al., 2000; Chen et al.,1997). In addition, with the rapid development of surveying and mapping science and technology, data acquisition efficiency is increasingly high and 3D data is more and more common, such as oblique photographic model, point cloud data and so on (Xie et al., 2013; Biljecki et al., 2014). It is irreplaceable that taking 3D data as the main data source is effective and precision at present.

However, due to the characteristics of 3D data, such as large amount of data, great difficulty in data format analysis and integrating with traditional 2D data and 2D GIS algorithm, many difficulties have been brought to developers in data analyzing and releasing, map rendering, data fusing and applying (Simic et al., 2015; Demir et al., 2018; Schubigerbanz et al., 2014).

Taking a region in Beijing as an example in this research, the local image data obtained from oblique photogrammetry is studied experimentally in the aspects of the data import, aerial triangulation solution, model building and model quality. In order to evaluate the quality of the 3D real model data accuracy, the positional accuracy and plane precision quantitative evaluation methods are comprehensively used, which can make the evaluation results have a certain theoretical basis.

2. Material and Methods

2.1 Data Source

In this research, the aerial oblique photogrammetry was selected for data acquisition as one of the photogrammetric methods. Meanwhile it combined conventional nadir images with oblique images obtained at high angles to build 3D city models with texture data acquired from nadir and oblique images (Petrie, 2008; 2009). Global Positioning System (GPS)-Inertial Measurement Unit (IMU) integration was adopted in classical aerial photogrammetry as position data acquisition. The oblique images could expose every side of a building, structure or feature, which was previously impossible to locate on vertical photography. It was able to directly measure the length, height and area from 3D real models. It improved the identification of assets and facilities which was hard to see such as telegraph poles, lamp-posts etc. which could be hard to tell apart on traditional orthodox images. It was possible that non-cartographic skilled people could improve the "readability" of geographical information by integrating GIS database with visualizing GIS data in 3D real models (Karbo and Schroth, 2009).

2.2 Operating Steps

The technical route of system construction mainly included three parts—data source preparation, 3D scene data construction and system function development.

(1) Preparation of data sources

The data sources required by this system were oblique photographic images, 3D building model data and so on. Preliminary examination was carried out on the image and corresponding pre-processing judgment was made according to the specific data. The Excel file production, which was to list pictures information, the Position and Orientation System (POS) information and sensor information together, was in accordance with certain rules for the organization.

(2) Construction of 3D scene data

The Context Capture was adopted in this research which was a powerful tool for image control point matching, aerial triangulation encryption and 3D real scene modeling. The organized Excel file was imported into the 3D real modeling software, which was used to analyze and check the image coverage of the whole project, especially the key areas. The first step was to select the appropriate production parameters for the project through multiple trial production. After the parameters were determined, the whole project was produced, including three steps of aerial triangulation encryption solution, multi-view matching construction of dense point cloud, triangular network construction, automatic texture mapping, and model construction. It was necessary to check the quality of the built model when which was needed to repair. The monomer of the 3D real model was prepared for the subsequent business applications.

(3) Development of system functions

With the script language and other development tools, B/S（browser/server）structure was selected to achieve the function of the system according to the needs of system development. Tomcat was used for network publishing of the system to realize data sharing and exchange data.

2.2.1.Infrastructure layer

In the aspect of 3D real scene mapping hardware construction, it was necessary to shoot oblique images of UAV and mass-produce 3D real models in a high-performance computing environment.

In terms of the construction of basic hardware environment, in order to ensure the normal and stable operation of the platform and application demonstration, it needed to be composed of host environment, security environment, storage system and network environment, mainly composed of client, server, storage device, router, firewall and switch. In terms of software environment, it was mainly consisted of system software, database software and other professional software.

2.2.2.Data resource layer

The content of data layer mainly covered four aspects: metadata acquisition, data preprocessing, data warehousing and data management.

(1) The metadata was mainly generated through infrastructure layer production or existing data integration. It mainly included attribute information data, oblique photography 3D real model data, existing 3D data integration database and relevant 3D business data.

(2) The data preprocessing mainly included slicing elevation data and building pyramid model based on quad tree. The multi-level level of detail (LOD) model generation and the building monomer processing were performed on the 3D real model data.

(3) The data management mainly realized through the data management system, which mainly included data preparation software, data warehousing software, data management software, basic geographic information management software and data distribution and service software.

(4) The database construction mainly realized the construction of attribute database, oblique photography 3D real model database and existing achievements database through data management related software.

2.2.3.Application service layer

This layer mainly achieved the functions of the practical application supported by data services and 3D analysis service. And the GIS system contains vector data services, including tiles data services (image tiles and vector tiles), two-dimensional business data services and oblique photography 3D real model data services.

2.2.4.The application layer

This layer mainly provided 3D visual rendering for the application and the secondary development ability of 3D GIS engine, including the realization and application of map display, scene roaming, layer control, application command and dispatch, multi-source information of application, application information statistics, auxiliary tools and other functions.

3. Data Acquisition

3.1 Oblique Images- UAV Oblique Image Data Acquisition System

The 3D imaging data collection was mainly referred to the use of oblique aerial technology for aerial images. Aerial image data acquisition was on the platform of unmanned aerial vehicle (UAV) which also carried the multiple angle of oblique aerial camera and the intelligent automatic cruise flight control system. And then the professional flight control team needed to ensure that the surveying and mapping system was qualified as aerial photography by topographic survey, aerial point calculation, the UAV aerial path planning and optical camera parameter adjustment operation. 3D data acquisition system was needed to meet the large areas of real 3D map of real data of the surveying and mapping work.

The obliquity image acquisition requirements were as follows. The aerophotograph ground average resolution was 0.05 m. both directional overlap rate and the lateral overlap rate of the adjacent images was guaranteed above 70%. Moreover, it was necessary to ensure that the center and edge of each lens image were solid. The precise control of the camera exposure was able to ensure that there was no ghosting and obvious image shift in the image data. By precisely controlling the flight attitude of the UAV, each image was guaranteed to be free from the direct sunlight and glare. At the same time, the imaging of each camera should be guaranteed without obvious color bias and there should be no obvious color difference between different cameras. It was also necessary to ensure that the images obtained from the different sorties would be shot at the same time in different days and that the similarity of solar altitude angle, air pressure, air temperature and other climatic conditions. In addition, it was needed to ensure the consistency of the tone of the photographed data. Besides, all buildings in the design survey area should be covered with the images collected from all 5 oblique angles of the cameras. However, it was not allowed that the images were discontinuous in the experimental area and the lateral overlap rate was less than 50% at three consecutive exposure points. The position and attitude information of the exposure moment of each image should be acquired

3.2 Process of 3D Real Model

The production system of the 3D real model data was based on the aviation images of the oblique data sources, which combined oblique image data with vertical image data to a unified operating system. And then the 3D real model building environment was built and multiple points of different views were used to form the precise reconstruction of model under the strict imaging relations. It was made up for the perspective of a single data source. And the accuracy and efficiency were greatly increased through integrating modeling environment.

The data source of the oblique photography combination overcame the differences in the aspects of the image resolution, the photography angle, the image radiation characteristics and so on. Moreover, it was realized that the high-precision 3D real model was highly automatically built through the comprehensive application of the POS assistance, the DSM guidance and other technologies (Nex and Remondino, 2014). The process of 3D real model building was shown in Fig. 1. The obtained multi-view image data was processed by the data collation, the regional network joint adjustment, the multi-view image matching, the orthophoto correction and the 3D real model building.

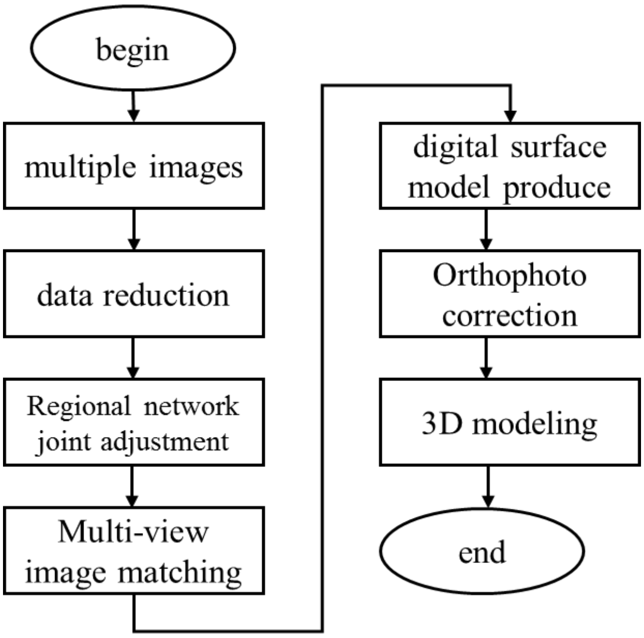

Fig. 1 3D real model building process

The area network joint adjustment was used to the aerial triangulation solution of the oblique photographic data, which needed to fully consider the geometric deformation and the occlusion relationship between the effective images. And the vertical downward-looking images and the oblique images are also mixed for adjustment.

By combining with the POS system which provided the exterior orientation elements and the camera installation position, the 3D real modeling software could simulate the surface projection of all images including oblique images, the pyramid matching strategy from coarse to fine and at all levels of image and the corresponding point matching free net adjustment method. At the same time, through the establishment of connection point and control point coordinates file, it was needed to combine with GPS/IMU information to achieve the multi-perspective image self-checking area network adjustment iterative calculation. Finally, the accuracy requirements were met through repeating the joint solution.

The model was constructed by the block computing and the optimal image pair model from different perspectives was automatically selected to generate the 3D scale of dense point cloud. The point cloud was automatically transformed into the TIN model of irregular triangulation network. According to the spatial location information of the 3D TIN, the image texture was obtained at optimal visual angle and the model texture was automatically endowed. At last the 3D real model results were exported.

4. Discussion

4.1 Data Quality Validation

Through the intuitive 3D real model data obtained above, the 3D geographic coordinate information of the required point position could be obtained directly from the model. And the actual distance between points and the practical area of the selected area could also be measured directly from the model. Many spatial analysis functions such as visibility analysis, slope analysis and submergence analysis were developed and applied based on the 3D real model (Kobayashi, 2006). For the actual ground objects, the 3D real model data was generally not determinable. There were some factors that affected the model precision such as the acquisition of the original data, the oblique data and the preprocessing of the auxiliary data, the construction stage of the 3D real model and so on. In order to apply the 3D real model data to the urban planning, the evaluation indexes were needed to evaluate and verify the model accuracy. However, so far, there was no general and mature method and evaluation system to analyze and verify the 3D real model. Therefore, the accuracy of the model was verified from the perspective of experimental analysis, which was of great significance for the correctness and practicability of the 3D real model (Wang et al., 2010). In this study, the point accuracy analysis and the plane accuracy analysis were synergistically used to evaluate the quality of the obtained 3D real scene model quantitatively.

4.1.1.The point accuracy analysis and verification

In the actual measurement, the commonly used method to verify the data accuracy was to compare the high-precision instrument measurement results with the measurement data. And the same method could be also applied to the evaluation of the image data quality of the oblique photogrammetry. The specific method was shown as below.

Firstly, the 30 feature points was extracted from the oblique 3D real model and their coordinates were recorded in the 3D spatial coordinate system (x, y, z). The high-precision network RTK was used to measure and record the WGS-84, the ellipsoidal height and the 3D coordinates (x, y, z) of the same 30 feature points in the experimental area, so as to analyze and verify the accuracy of the obtained oblique 3D real scene model with reference data.

Secondly, it was needed to calculate the difference between the coordinates of the oblique 3D real model and the network RTK measurement reference coordinates to get the values of x, y and z respectively. As shown in Fig. 2, it was different between the coordinate of the oblique 3D real scene model and the measured reference coordinate of the network RTK. As can be seen from Fig. 2, the elevation coordinate difference was mostly negative and the maximum value of the X-axis was at the 30th point. Moreover, the minimum value appeared at the 6th point. In addition, the maximum value of the Y-axis was at the 27th point and the minimum value appeared at the 1st point. The maximum of the Z-axis was at point 30 and the minimum was at point 27. In general, the coordinate differences were concentrated in negative values. The mean values of X, Y and Z were 0.00222, 0.0005 and -0.00443 respectively. It could be concluded from the analysis in Fig. 2 that the observed value of the Y-axis changed relatively stable with relatively small errors, while the value of the Z-axis presented relatively large errors. The reason for this may be that there were many redundant point clouds in the oblique 3D real model, which resulted in the lack of accuracy in point location selection.

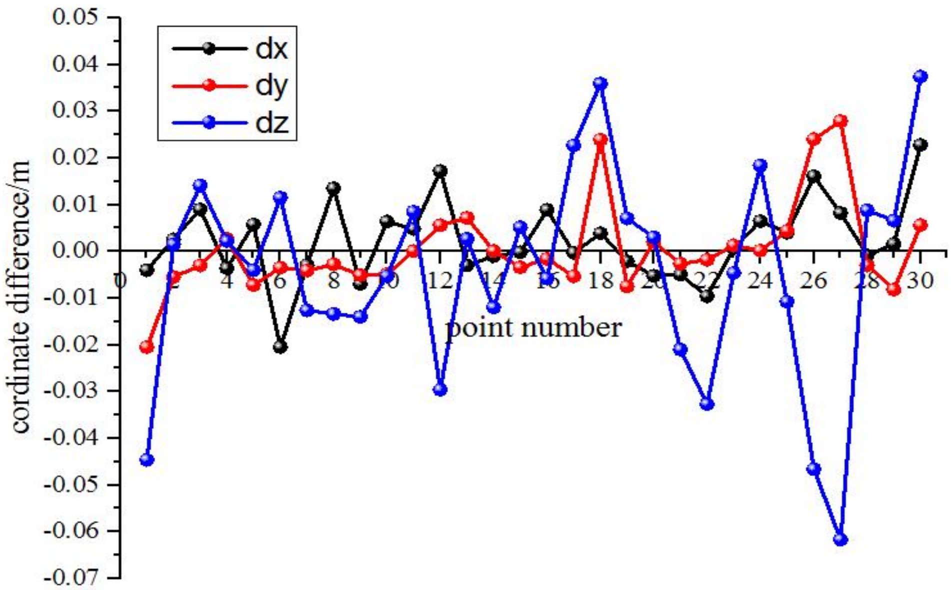

Fig. 2 Schematic diagram of coordinate difference between oblique photogrammetry and RTK measurement

Taking N as the number of all points, where N=30. Based on this calculation, the axial errors and point median errors of each coordinate were shown as follows.

$$\delta_x = \pm\sqrt{\frac{\sum_{i=1}^{N} \Delta x_i^{\ 2}}{N}} = \pm 0.00822 \tag{1}$$

$$\delta_y = \pm\sqrt{\frac{\sum_{i=1}^{N} \Delta y_i^{\ 2}}{N}} = \pm 0.00976 \tag{2}$$

$$\delta_z = \pm\sqrt{\frac{\sum_{i=1}^{N} \Delta z_i^{\ 2}}{N}} = \pm 0.02267 \tag{3}$$

$$\delta_{xy} = \pm\sqrt{\delta_x^2 + \delta_y^2} = \pm 0.01315 \tag{4}$$

$$\delta_p = \pm\sqrt{\delta_x^2 + \delta_y^2 + \delta_z^2} = \pm 0.02621 \tag{5}$$

According to the above formulas, the median error of the 30 feature points in the experimental area was 0.00822 m in the X-axis direction, 0.00976 m in the Y-axis direction, 0.02267 m in the z-axis direction and 0.01315 m in the plane elevation direction. It could be concluded that the errors of both the elevation and the plane were less than 10 cm (two pixels). It could be seen from the comparison with Table 1 that the accuracy could meet the accuracy of 1:2000 and 1:5000 scale topographic maps and the verification results of the point accuracy could meet the application requirements of the 3D real models.

Table 1 Scale accuracy

Scale	1:500	1:1000	1:2000	1:5000	1:10000
Scale accuracy	0.05	0.10	0.20	0.50	1.00

4.1.2.Verification of plane accuracy analysis

To further validate the plane precision of the model, it was necessary to use the multiple planar sampling points to do the surface fitting. According to the 30 feature points' coordinates selected from the 3D real model, the same points' coordinates were selected by using the high-precision GPS-RTK equipment as the reference data. And then the reference plane equation was fitted out and the selected 30 points' distances to the plane were finally calculated, which were used to validate the precision of the model. In the actual measurement operation, the errors would be inevitably generated and transmitted to the subsequent data processing. A small number of points were selected for the plane fitting, which would generate a large error. Therefore, in order to reduce the errors, multiple sets of the observation data could be used to control the fitting errors.

In the first place, the Pi= (Xi, Yi, Zi), (I =1,2,3..., 30) was set as the data of the 30 points on the plane and the plane equation was solved as ax+ by+ cz =1.

In the second place, it was supposed that the equation coefficient matrix composed of the 30 groups of the known point position data was as follows.

$$G = \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \vdots & \vdots & \vdots \\ x_N & y_N & z_N \end{bmatrix} \tag{6}$$

And then the unknown parameter matrix was set as $k = [a \quad b \quad c]^T$. If h= $h = [1 \quad \cdots \quad 1]^T$, the system of equations could be constitute as $Gk = h$. According to the nature of the adjustment, the equations could not directly get the unknown parameters k. So the transposed matrix GT was multiplied on the left in the both sides of the equations, so the equations was obtained as follow

$$G^T G k = G^T h \tag{7}$$

According to the least square principle, the equations was obtained as follow.

$$k = \left(G^T G\right)^{-1} G^T h \tag{8}$$

The plane equation of the reference plane obtained through the above calculation was as follow.

$$7.493 \times 10^{-8}x + 2.616 \times 10^{-7}y - 4.78 \times 10^{-5}z = 1 \tag{9}$$

The distance di from the oblique photogrammetric coordinate point to the fitting plane was as follow.

$$d_i = \frac{ax_i + by_i + cz_i - 1}{\sqrt{a^2 + b^2 + c^2}} \tag{10}$$

It was calculated that the maximum distance between the feature point data of the oblique 3D real model and the reference fitting plane was 2.643 mm and the minimum value was 0.111 mm. The distribution was relatively uniform and the average distance was -0.01612 mm. All of the distances were relatively close and the accuracy was relatively high.

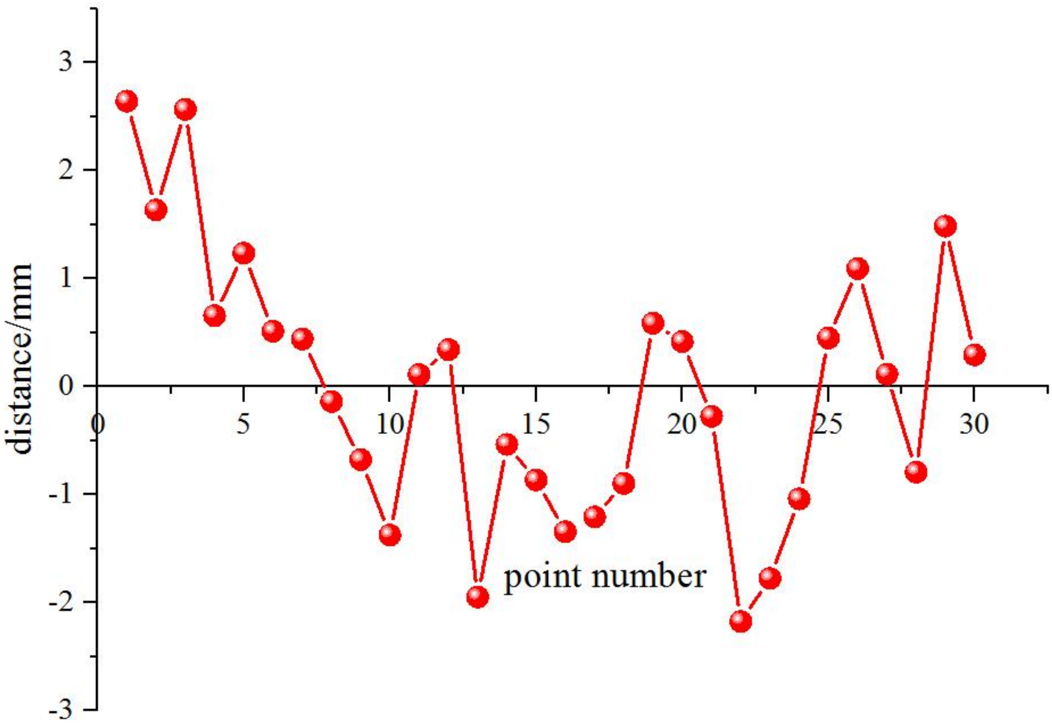

Fig.3 The distance from the data collected by RTK to the fitted plane

As the broken line trend in Fig.3, the plane fitting accuracy was high and the distance deviation between the feature point of the inclined data and the reference fitting plane was small.

5. The application

With the development of GIS, only using the plane representation method had been unable to meet some requirements. Therefore, 3D GIS had become a research hotspot in GIS field. At present, the limitation of the plane planning and planning scheme was obviously increasing. Firstly, the information obtained by the planners before the planning was incomplete. Even if they went to the field survey, they could not understand the current situation of the whole city. Therefore, even if the planning plan was good, it may be inconsistent with the field situation. Secondly, the users were lacked the sense of reality when comparing schemes and they needed to have a strong professional quality to understand designers' design ideas, which was not conducive to the display of planning schemes.

Nowadays, with the development of 3D GIS, the expression and the analysis of urban 3D visualization had been realized, so that we could present the massive spatial information and the attribute information of the city in the form of 3D real model. In addition to managing this information, a series of 3D real models and the prediction schemes can be made. In this way, the planners could observe the effect of different schemes in different urban environments in real time, so as to design more appropriate planning schemes. And we could do a lot of analysis in 3D GIS such as illumination analysis, viewable analysis, pass-through analysis and so on. The urban auxiliary planning decision support system was developed in this way of 3D GIS, which could build an intuitive, real and accurate 3D simulation scene with geographical coordinates for urban planning and managers. And it can also conduct the intuitive and scientific analysis and the evaluation of the planning scheme to assist the decision-making of the urban planning.

The sunshine analysis was taken in the system as an example. The application scheme was introduced into the system for the sunshine simulation and the real-time sunshine analysis, the shadow simulation and the sunshine statistics were realized according to the real sunshine situation of the sun and buildings. It truly reflected the surrounding environment, the structures and the topography. Moreover, the geographical location and the date of the current project could be set, so that the system could display the sunshine situation at any time of the day. In addition, it could simulate the 24-hour sunshine situation with animation, so as to analyze the influence of sunshine on the surrounding projects, which could provide the intuitive basis for the program review, the reporting and the research.

6. Conclusion

In this study, the oblique aerial photogrammetry was efficiently used to obtain the multi-angle oblique image data and other auxiliary data. And the 3D real model data was acquired by the combination adjustment of regional network, the air triangulation solution, the TIN triangulation, the automatic texture mapping and other technologies. Both of the point accuracy and plane accuracy verification methods were used to evaluate the quality of the 3D real model data, which provided a reference for the data application in urban planning. The experimental analysis showed that the median error of plane position was 0.01315 m and the median error of elevation was 0.02621 m. In addition, the median errors of both directions were less than 10 cm and the elevation accuracy was slightly higher than that of plane. So the results showed that the quality of 3D real model was qualified and could be used in practical application.

In the future, the new smart city will rely more and more on the 3D city model to build an intelligent system based on 3D geographic information, which will be used for urban planning, management, command and scheduling. Therefore, it can be predicted that the demand of the new smart cities for 3D geographic data will gradually become a huge market. The 3D city geographic data will become one of the important infrastructure information of a new smart city. On this basis, not only can the geographic information system in urban planning, management, command and scheduling used by managers be constructed, but also the basic setting can be opened to the enterprises and the public as a way of service to drive the development of 3D geographic information related industries in a widely scope (Demir and Koramaz, 2018; Liang et al., 2017).

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