The Influence of Control Point Distribution of Unmanned Aerial Vehicles for the Results of Aerial Stitching

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Abstract. Unmanned aerial vehicles are an important development direction for today's aviation telemetry technology, and have gradually become an essential technology for three-dimensional space acquisition. To date, the flight stability of unmanned aerial vehicles has been greatly improved, and space positioning is miniaturized, which ensures the UAV to play the most role in battery life, image real-time transmission, high-risk area detection and other occasions. In the past, natural disasters relied on traditional technology to obtain local conditions, thus, it was impossible to obtain immediate on-site information. However, the immediacy and convenience of unmanned aerial vehicles have been used to grasp the immediate situation of disaster relief sites, providing information for substantial benefits to disaster relief related units. In this study, Pix4Dmapper image processing software is used to quickly create orthophotos, thus, three-dimensional terrain elevation models of stereoscopic view and terrain data can be constructed. The captured images are spliced through the software, and the measurement accuracy of the aerial stitching images is discussed according to the different distribution positions of the control points. The results show that the number of control points is too small to improve accuracy. Regarding the study area, the optimal distribution route of 20 control points is the best. In more complex terrain, the control points should be selected at locations that contain various elevation changes. If it is not possible to evenly arrange the control points, it is recommended to select the circular route method.

1. Introduction
In recent years, the progress of aerial photography and the rapid development of computing power have made obtained telemetry data more accurate and more real, and image resolution has been increased from meters to centimeters. As unmanned aerial vehicles (UAVs) are used with consumer cameras to take photographs, a database is established by photogrammetry, which has become the development focus in academy and industry in recent years. Limited by the influence of vehicle hardware, camera technology integration, and other tools, there is still much room for development in studies of the evaluation of the quality and accuracy of spatial data results. Huang et al. (2006) pointed out that, by combining different geometric correction modules with different numbers of control points, the test results of this method show that the non-linear rubber sheeting method is more suitable for
correcting the aerial images of unmanned vehicles, and accuracy can be improved by increasing the number of control points. The main purpose of quality inspection is to inspect the root mean square errors of the check points beyond the control points. Rau et al. (2014) pointed out that, by using Pix4UAV software, as produced by Pix4D, to produce DSM and taking the control points on the road as the check points to evaluate the accuracy, the results show that a DSM of 1m mesh can be produced at the flight height of 600m, and a DSM of 2m meshes can be produced at the flight height of 1,200m. If ground control points are used for the adjustment of aerial triangulation, the absolute elevation accuracy can be up to 50-60cm. Hsu et al. (2014) Using Electronic total station measure precise control point, and then with a close-range photogrammetry to quickly build the terrain and topography of the slope terrain model, provides a quick reference for engineering renovation. Wang and Huang (2015) pointed out that, rotor type unmanned vehicles can be used in aerial photography for vertical take-off and landing, as well as automatic flights in mountainous areas with terrain fluctuations, and can effectively improve the accuracy of the numerical terrain model by means of the control points laid on the ground. Chang et al. (2015) pointed out that an unmanned air system can achieve the purposes and requirements of general measurement, and the distribution of control points is more important than their numbers. In addition to uniform distribution, control points shall be laid in areas with large elevation fluctuations, which shall be located in open areas to avoid errors in the matching software. Yang et al. (2015) pointed out that the produced control point Marker can still be interpreted correctly in photos taken at high altitudes, and the overlapping ratio of all photos shall be at least 80% to build complete models in image modeling. Tsai and Hsu (2017) Orthophoto map data is the dot height and tilt of an image displacement aerial image on removal, which provides the correct geometry and radiation information as basemap of geographic information, or nested numerical simulation of three-dimensional terrain and elevation model as for related research purposes.

In the past, sensors and aircrafts with high unit prices were used in unmanned vehicles for ground space measurement, and the costs were relatively high. In this study, low-price unmanned vehicles are used to produce high-accuracy image information and numerical models in combination with control points, in order to further explore the relationship among the number, locations, and distribution of control points and the changes in accuracy. This study area is located in the soil and water conservation pilot area of the mountain behind the National Pingtung University of Science and Technology, which has an altitude difference of about 90m and a shooting area of 113ha.

The aerial photography equipment used in this test is Phantom4, which is equipped with a high-quality 720p camera and a Trimble R8 GNSS receiver, in order to generate stereoscopic images in the principle of photograph overlap, and to produce the required numerical model with the required accuracy after the control points are given. In this study, a total of 40 control points are given, including 24 fixed check points, and then, the various distributions and numbers of control points and check points are matched to produces models that compare their accuracy, where model accuracy is closely related to the number of control points. The control points are measured by the real-time kinematic technology (RTK) of the virtual reference station for satellite positioning. It is expected that the digital terrain model, as established by unmanned vehicles matched with Pix4Dmapper software, can be applied for planning future soil and water conservation efforts, disaster prevention, and engineering with the expected reasonable accuracy.

2. Materials and Method

2.1. Profile of the study area
The study area is located on the mountain behind the National Pingtung University of Science and Technology in Pingtung County, Neipu Township, and adjacent to Niujiaowan creek. Due to the large number of control points, the outdoor classrooms of the soil and water conservation department and the downstream areas, namely, the areas of the tropical agriculture department and the marine product department, are also included, for a total area of about 113 ha.
2.2. **Test materials**

The 4-rotor type unmanned aerial vehicle used in this study is the Phantom4 commercial unmanned aerial vehicle, as produced by DJI Technology. The 5350mAh high-capacity smart batteries and high-efficiency power system provides up to 28 minutes of battery life for the machine. The built-in DJI Lightbridge high-definition video transmission system can display 720p high-definition images within 5km. The Phantom4 can shoot 4K/30fps and 1080p/120fps videos, and features an overall optimized lens, signal processing, and image stability.

In order to improve accuracy, this study integrates the Trimble R8 GNSS receiver, a GPS antenna, data stations, and acceptors, which only weighs 1.3kg, with plane precision up to 1cm and vertical precision up to 2cm. The Pix4Dmapper used in this study is the image analysis software developed by Pix4D Swiss company, which functions as image processing for ground photography, UAV photography, or general aerial photography. It can simultaneously process multi-camera images, skewed images, identify accurate geographical positioning by using the geographic locations of images and inputting the locations of control points, produce numerical models by clouding image points, improve result quality and accuracy, and produce orthophotos by image mosaic and editing. It can be applied to civil engineering, geotechnical engineering, disaster prevention and relief, geological applications, and other aspects, and its interfaces are comprehensively localized and quite easy to operate.

2.3. **Research Process**

Regarding accuracy analysis, this study uses the designed black cloth for improving the accuracy of control points and check points. The black cloth is a square with the full size of 150cm × 150cm and the yellow part is 30cm × 150cm. The black cloth is placed as a manual control point.

Regarding accuracy analysis, this study selects 24 check points for location fixation to indentify the basis for accuracy comparison, as shown in figure 1. Before the control points are placed, control point distribution and selection are performed indoors, and then, marks are made on site. After the point locations are confirmed, the black cloth is placed to verify whether the accuracy is affected by the control points due to tree shading, and held in place with stones to prevent it from blowing away or being displaced, which may affect the analysis results.

![figure 1. A total of 24 fixed check points in the study area to check the aerial survey accuracy](image-url)
The yellow points in figure 1 are the locations of the check points in this test, and all accuracies are calculated based on these check points for comparison. During the test, after the black cloth was placed, the 4-rotor type unmanned aerial vehicles were used to take orthophotos (the unmanned aerial vehicles used this time were the general commercial type, in order to explore whether it is possible to achieve considerable measurement accuracies if non-specialized unmanned aerial vehicles are used under proper control), from the flight height of 250m. Due to the large shooting area, and considering battery capacity and the wind direction on that day, this study divided the flight area into upper, middle, and lower parts, and shooting was conducted in an s shape. A total of 950 photos were taken, and after selection, the remaining 931 photos were stitched.

The Pix4Dmapper software is used in this study for stitching the photos. Regarding accuracy analysis, the stitched 3D models were divided into the uniform distribution type and the concentrated distribution type. If the points cannot be uniformly distributed in the task terrain, the locations can be arranged separately. Uniform distribution refers to control points that are uniformly distributed throughout the map, while concentrated distribution refers to control points that are concentrated in a block or route. The analysis of control point distribution types is shown in figure 2. The in-situ situations are used to determine whether the control points routes are laid accurately and practically, understand the real-time conditions, and analyze the current situations for disaster prevention and relief. The analysis process chart is shown in figure 3.
3. Results and Discussion

3.1. Criteria for accuracy analysis

In the analysis of this study, the root mean square error (RMSE) is used as the basis to compare the accuracies of all routes. In exploring multi-point errors, the root mean square error equation is often used to calculate location accuracy. RMSEX, RMSEY, and RMSEZ are the root mean square errors of X, Y, and Z differences, respectively, and RMSE is the 3D root mean square error of the check points. Theoretically, the smaller RMSE represents the better shooting effects from parameter conversion, but this does not completely represent the improvement of the effect accuracy. According to the operation manual of the 1/1000 numerical aerial topographic map (2010), the allowable error standard of the plane accuracy of 30cm and elevation accuracy of 50cm shall be met if UAV is used for topographic mapping operations, which is also one of the key points in the comparison of analysis results.

Data analysis shows that only the plane accuracies of the Y-axis of route Latitudinal 3 and the X-axis of the Lower Circular are lower than the allowable mapping standard (exceeding the allowable error by 30cm), while the plane accuracies of the other 13 routes meet the allowable standard. In addition, due to the small difference in the plane accuracies after comparing the check points, as shown in figure 4, this study focuses on the vertical accuracy as the basis for discussion.

![Figure 4. Comparison of plane accuracy of check points for different distribution types](image)

3.2. Accuracy analysis of route selection

3.2.1 Circular routes of the concentrated type. The external circular distribution is the best with the RMSEZ of 0.152m. Due to the widely distributed control points on this route, the accuracy is high, and meets the mapping standards of the Ministry of Interior.

The lower circular is the worst, because the control points on this route are located in an area with less changed slopes, thus, it is determined that the vertical accuracy is low with the RMSEZ of 0.305m, as shown in figure 5.
3.2.2 Linear routes of the concentrated type. In the linear routes, the route of latitudinal 3 is the best, with the RMSEZ of 0.282m. Moreover, the accuracies of the longitudinal routes fail to meet the mapping standards required by the Ministry of Interior, and the data show that the check points are closer to the control points on the routes, and thus, can achieve higher accuracies. However, the control points of the longitudinal routes are located in an area with less changed slopes, thus, the errors of the remote check points increase sharply and cannot show the unanticipated errors, as shown in figure 6.

3.2.3 Uniformly distributed routes. In this study, the vertical axis is used as the criterion to determine accuracy. In the selected uniformly distributed routes, the accuracies of those with 20 control points are the best with Error Z of 0.110m, and the accuracies of those with 10 control points are the worst with Error Z of 0.187m, which shows that, in the 4 types of routes with more than 20 uniformly distributed points, more points do not imply that accuracy will improve linearly. However, the effects of more distributed points can still be shown, which may be further planned and discussed in the future, as shown in figure 7.

3.2.4 Internal routes of the concentrated type. While the distribution is relatively uniform in the routes, the control points are concentrated internally, meaning that the external check points are far away from the internal control points, which leads to increased total errors, with Error Z of 0.251m. The
comparison of vertical accuracy of check points for different distribution types, as shown in figure 8.

![Figure 8](image)

**Figure 8.** Comparison of vertical accuracy of check points for different distribution types

Overall, plane accuracy is more controllable than vertical accuracy. In order to simultaneously improve plane and vertical accuracy (three-dimensional accuracy), a certain number of control points, more terrain changes covered in distribution, uniform distribution, and internal and external considerations are the main factors affecting the inspection accuracy of UAV aerial photography. Other factors, such as flight heights, climate, flight routes, and quantities, may be planned and discussed in future studies.

4. Conclusion and Suggestions

4.1. Conclusion
1. The uniformly distributed routes show that the excessive number of control points is insignificantly helpful for the improvement of accuracy. In this study area, uniformly distributed routes with 20 control points are the best.
2. In complicated terrains, control points shall be laid in places with various elevation changes.
3. If the control points cannot be laid uniformly, circular routes can be selected.
4. If the points cannot be laid extensively due to the limitation of terrain, but can only be laid linearly, they shall be laid in areas with great elevation changes.
5. In case of few control points, many check points will be located at the edge and far away from the control points, leading to unanticipated errors.
6. In this study area, if more than 10 control points are laid and distributed widely, the three-dimensional accuracy can be greatly improved.

4.2. Suggestions
1. For further discussion in the future, the number of control points can be fixed for further correlation analysis of the selection of routes or points.
2. If the overlap ratio of the measurement area is low, the flight routes can be expanded or the flight heights can be raised to enhance the ratio, and the influence on accuracy can be separately discussed.
3. The definition of the control point distribution can be quantified, such as the fixed distance between points or the uncertain factors that may be met in the fixed area reduction test.

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