Mahmood et al. Iraqi Journal of Science, 2024, Vol. 65, No. 7, pp: 4124 - 4138
DOI: 10.24996/ijs.2024.65.7.45

Iraqi Journal of Science

ISSN: 0067-2904

Optimizing Spatial Accuracy for Photogrammetric Processing of Drone-based 3D Mapping

Mustafa A. Mahmood[1]*, Nawal K. Ghazal[2], Faleh H. Mahmood[2]
[1]*Department of Remote Sensing and GIS, College of Science, University of Baghdad, Baghdad, Iraq*
[2]*Remote Sensing Unit, University of Baghdad, Baghdad, Iraq*

Received: 11/3/2023 Accepted: 20/6/2023 Published: 30/7/2024

Abstract

Unmanned aerial vehicle (UAV) systems have become crucial for gathering information for observation, surveillance, mapping, and 3D modeling tasks. The use of UAVs in close and mid-range sectors has shown potential for cost-effective alternatives to traditional aerial photogrammetry conducted by humans. The research aims to optimize photogrammetric processing for drone-based 3D mapping by examining strategies and applications to increase accuracy and efficiency. The study highlights the significance of image overlap and high-quality camera equipment to obtain reliable outcomes for stereo-photogrammetry and depth measurements. Drones and specialized software like 3DF Zephyr and Pix4D were used to create a 3D map. The software uses automatic structure from motion techniques, including feature extraction, image matching, and bundle block adjustment, to produce a dense point cloud that forms the basis for the 3D model. A DGPS system was implemented to enhance spatial accuracy. The map initially showed inadequate accuracy, with an error rate exceeding 80cm. However, with the use of a DGPS system, the error was reduced to less than 3cm. This study provides suggestions and insights for improving photogrammetric processing for drone-based 3D mapping.

Keywords: Unmanned aerial vehicle (UAV) systems, Photogrammetric processing, photogrammetry, DGPS system, 3D Mapping, Spatial accuracy

تحسين الدقه المكانيه للمعالجة التصويرية لرسم الخرائط ثلاثية الأبعاد القائمة على الطائرات بدون طيار

مصطفى علي محمود [1]*، نوال خلف غزال [2]، فالح حسن محمود [2]
[1]قسم الاستشعار عن بعد ونظم المعلومات الجغرافية، كلية العلوم، جامعة بغداد، بغداد، العراق
[2] وحدة الاستشعار عن بعد، جامعة بغداد، بغداد، العراق

الخلاصة

أصبحت أنظمة الطائرات الجوية بدون طيار (UAV) وسيلة حاسمة لجمع المعلومات لمهام مثل المراقبة والمسح والتصوير الثلاثي الأبعاد والرصد. أظهر استخدام UAVs في القطاعات القريبة والمتوسطة المدى إمكانات جديدة للبدائل الفعالة من حيث التكلفة للتصوير الجوي التقليدي الذي يقوم به البشر. تهدف هذه الدراسة إلى تحسين الدقه المكانيه لمعالجة التصوير الفوتوغراميتري للتصوير الثلاثي الأبعاد المستند إلى الطائرات بدون طيار عن طريق دراسة الاستراتيجيات والتطبيقات لزيادة الدقة والكفاءة. تسلط الدراسة الضوء على أهمية تداخل

---

*Email: mostafa.ali2109m@sc.uobaghdad.edu.iq

الصور ومعدات الكاميرا عالية الجودة للحصول على نتائج موثوقة لتصوير الاستريو وقياس العمق. يوضح هذا المقال استخدام الطائرات بدون طيار والبرامج المتخصصة مثل 3DF Zephyr وPix4D لإنشاء خريطة ثلاثية الأبعاد. تستخدم البرامج تقنيات الهيكل من الحركة الأوتوماتيكية ، بما في ذلك استخراج الميزات ومطابقة الصور وضبط مجموعة الحزمة، لإنتاج سحابة نقطية كثيفة تشكل أساس النموذج الثلاثي الأبعاد. تم استخدام نظام DGPS لتحسين الدقة المكانية. كانت دقة الخريطة في البداية غير كافية ، مع معدل خطأ يتجاوز 80 سم. ومع ذلك ، مع استخدام نظام DGPS ، تم تقليل الخطأ إلى أقل من 3 سم. بشكل عام، توفر هذه الدراسة اقتراحات وإسقاطات لتحسين المعالجة الفوتوغرامترية لإنشاء خرائط ثلاثية الأبعاد باستخدام الطائرات بدون طيار.

1. Introduction

Historically, the primary motivation for developing UAV systems and platforms was rooted in military operations and tasks, such as unmanned surveillance, inspection, mapping, and reconnaissance of enemy territories [1]. However, in recent times, there has been a growing uptake of UAVs in geomatics applications. UAV photogrammetry facilitated novel applications in the close-range aerial sector, presenting a cost-effective substitute to conventional human aerial photogrammetry [2][3]. The proliferation of cost-effective platforms coupled with charge-coupled devices, CCD digital cameras, and GNSS/INS systems necessary to guide the UAV precisely to the designated acquisition locations could account for this trend [4]. The limited size and capacity of various UAV platforms hinder the transportation of high-end IMU devices typically connected to aerial cameras or LiDAR sensors employed for mapping purposes [5] [6]. GNSS was usually utilized in code-based positioning mode, which makes it unsuitable for precise direct sensor orientation. Although incorporating RTK methods can increase the placement accuracy to the centimeter level, it would also make the system complex, expensive, and bulky [7]. The usage of affordable UAV systems that are typically hand-launched and operated autonomously utilizing GPS-driven autopilot and an IMU sensor has grown increasingly popular. However, these systems may face stability issues in regions with strong winds [8].

More robust systems powered by gasoline engines, capable of accommodating higher payloads, are suitable for professional cameras and even LiDAR technology for surveying purposes [9] [10]. However, challenges like scanning non-static objects, narrow-street situations, and combining contributions from terrestrial scan data/images remain [11]. This study aims to address these challenges and present a detailed, textured mesh that accurately depicts reality in its dimensions as a three-dimensional map.

1.2 Related Work

Bi et al. 2016 investigated Structure from Motion (SfM) photogrammetry, a low-cost and flexible method for obtaining high-resolution topographic data, in mapping the topography of the Haiyuan fault zone in northwest China. The study compares the accuracy and resolution of the SfM-derived topography with existing airborne lidar data, which is currently the most popular method for obtaining high-precision topographic data. The results showed that the SfM photogrammetry method could provide an inexpensive and effective alternative to airborne lidar for mapping the topography of the fault zone. The study also highlighted the importance of preserving the surface ruptures and typical tectonic landforms in the Haiyuan fault zone for active fault study [12].

According to Crommelinck et al. 2017, a study was conducted in the Netherlands using a four-rotor UAV to collect aerial photographs of Ningspet at 50 m with an 80% end-lap and side-lap, using an Olympus E-P3 OG camera. The collected data underwent aero triangulation utilizing bundle adjustment and DTM synthesis, resulting in generated orthoimages with a geometrical accuracy of 3 cm. According to the research, using UAVs in cadastral surveys can automate certain aspects of the process by relying on cadastral boundaries, natural features, and relics, decreasing the requirement for on-site inspections and various manual procedures. The researchers indicate that topographical characteristics are visible in UAV photographs, and using UAV data sources for agricultural land testing could potentially lead to the automation of cadastral mapping [13].

Ali and Abed 2019 explored the feasibility of using low-cost Unmanned Aerial Vehicles (UAVs) as mobile mapping devices for photogrammetric topographical surveys. The study examined the impact of different UAV flight settings and parameters on the accuracy of mapping products and proposed an automatic scenario for photogrammetric flight missions and their execution. The research focuses on generating 3D point clouds from digital imagery using low-cost UAVs and showing the relationship between flight mission settings and the quality of the delivered 3D data. The paper presented an automatic solution that can generate 3D point clouds from arbitrary image configurations, and the results were delivered within millimeters based on specific flight settings and optimal quality control considerations. The accuracy assessment and validation process were adopted based on statistical assessments of ground truth 3D adjusted measurements to assure validity [14].

Ahmed et al. 2022 investigated the influence of UAV flight direction and camera orientation on the positioning accuracy of mapping products in an urban area in Iraq. The study used a low-cost UAV system equipped with GNSS receivers for navigation. The study tested different flight directions and camera orientation settings using a UAV autopilot app and evaluated the planimetric and vertical accuracies of 11 different flight cases. The study found that the horizontal accuracy was better than the vertical accuracy for all flight sets. The study also revealed that combining multiple sets of images with different flight directions and camera orientations can significantly improve the overall positional accuracy to reach several centimeters [8].

Du, Li, and Roshanianfard 2022 presented a new approach to generating topographic maps for precision farmland leveling using a low-altitude Unmanned Aerial Vehicle (UAV) equipped with Light Detection and Ranging (LiDAR) distance measurements and Post-Processing Kinematic Global Positioning System (PPK-GNSS) coordinates. The experiment was conducted over two fields in Henan Province, China, and the accuracy of the topographic surveying data was evaluated. The Root Mean Square Error (RMSE) between the elevation data of the UAV-LiDAR topographic mapping system and ground truth data was calculated as 4.1 cm and 3.6 cm for Field 1 and Field 2, respectively, which proved the feasibility and high accuracy of the topographic mapping system. The study also evaluated the accuracies of topographic maps generated using different geospatial interpolation models and concluded that a TIN (Triangulated Irregular Network) interpolation model expressed the best performances for Field 1 and Field 2. The paper suggested that the UAV-LiDAR topographic mapping system could successfully accurately generate topographic maps, providing instructive information for precision farmland leveling [15].

1.3 Datasets

I. Phantom 4 drone dataset

The DJI Phantom 4-drone has a high-resolution camera to capture images and videos from different angles and heights. This visual data may be utilized in surveying, mapping, agriculture, and inspection [16]. The Phantom 4 dataset is a collection of pictures and videos recorded by the DJI Phantom 4 drone, widely utilized in machine learning and computer vision research for tasks such as object detection, categorization, and tracking. The collection covers images and movies from varied settings, such as urban regions, rural areas, woodlands, and aquatic bodies [17]. It is a terrific resource for academics working in remote sensing, machine learning, and computer vision, delivering high-quality and diverse data that may be employed to create algorithms suited for numerous conditions. The combination of the Phantom 4 drone and its dataset highlights the growing significance of drones and visual data in modern-day applications [18].

II. DGPS dataset

DGPS (Differential Global Positioning System) is a navigation system that increases GPS location accuracy by utilizing ground-based reference stations to broadcast correction signals to GPS receivers. A DGPS dataset is a collection of GPS measurements corrected using DGPS technology and may be used for geospatial research and analysis [19]. DGPS datasets are exceedingly precise and may be used for numerous applications such as producing high-resolution maps, monitoring the movement of automobiles or people, and tracking animal migration. DGPS records may be obtained swiftly and, when integrated with other data types, such as aerial photos or LiDAR data, can build complete and accurate maps or 3D models [19]. DGPS files are essential for scholars and researchers in many disciplines and may give comprehensive geographic analysis. In this research, DGPS data was used to enhance the accuracy of GCPs in the 3D map and to measure the amount of error before correcting the map coordinate.

2. Study Area Location

This research paper focuses on the College of Science campus, part of the University of Baghdad and located in Baghdad, Iraq. The campus is situated on a peninsula near the Ministry of Science and Technology and in the heart of Baghdad, on the side of Al-Rusafa within the Al-Jadiriya complex, Al-Karrada district. The Tigris River borders the campus on three sides. The selected site, which spans an area of a one km^2 radius, is positioned between the longitudes (33.0541^o and 33.0486^o) Easting and (44.0722^o and 44.0763^o) Northing, as seen in the map below.

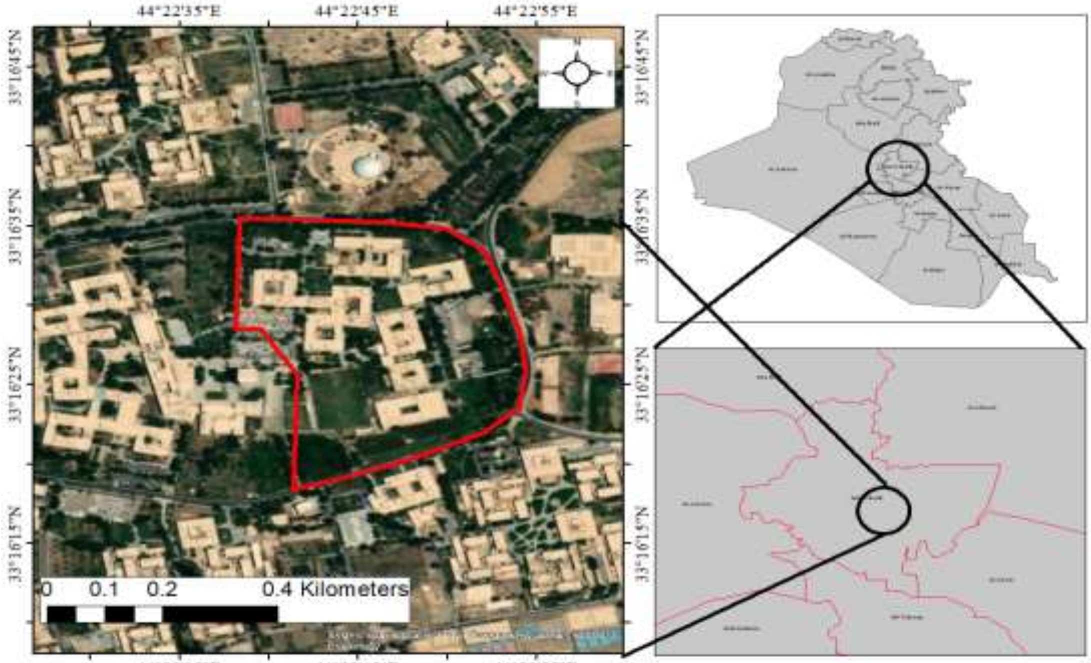

Figure 1: The location of the study area.

3. Theoretical Framework

Photogrammetry is the study of measuring and extracting information from images. It includes using specialized software and gear to extract measurements from images, which may subsequently be used to construct precise 3D mapping of objects, buildings, or landscapes [20]. The idea of photogrammetry is founded on the concept of triangulation, which includes using several photos taken from various angles to estimate the location of objects in space[21].

$$x_p - x_0 = R_{11}(X - X_0) + R_{21}(Y - Y_0) + R_{31}(Z - Z_0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$y_p - y_0 = R_{12}(X - X_0) + R_{22}(Y - Y_0) + R_{32}(Z - Z_0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

And

$$z_p - z_0 = R_{13}(X - X_0) + R_{23}(Y - Y_0) + R_{33}(Z - Z_0) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Substitution of these formulae leads to a set of two equations known as the collinearity equations:

$$x - x_0 = -c\frac{R_{11}(x - x_0) + R_{21}(y - y_0) + R_{31}(z - z_0)}{R_{13}(x - x_0) + R_{23}(y - y_0) + R_{33}(z - z_0)} \ldots\ldots\ldots\ldots\ldots (4)$$

$$y - y_0 = -c\frac{R_{12}(x - x_0) + R_{22}(y - y_0) + R_{32}(z - z_0)}{R_{13}(x - x_0) + R_{23}(y - y_0) + R_{33}(z - z_0)} \ldots\ldots\ldots\ldots\ldots (5)$$

In this mathematical model, the position of the perspective center C was expressed, where x, y, and z represent a coordinate system with the x- and y-axis in the sensor plane, and the projection center was represented by x_0, y_0, z_0. The focal length was denoted as -c, and the translation does not affect the differences in the coordinates. The rotation, also known as camera transformation, was given by a 3×3-matrix R [22].

Distortion values depend on the image's position, i.e., the distortion values were changed according to the photo coordinates. Hence, the image coordinates were obtained in the following phase, and the image coordinates were computed without considering distortions parameters. These image coordinates were then utilized to calculate the distortion values according to the photograph's position. The updated image coordinates were then derived through this equation [21]:

$$X_{on-image} = X_{calc} - \Delta X_p \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$Y_{on-image} = Y_{calc} - \Delta Y_p \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where, X_{calc} and Y_{calc} were the previously estimated xi and yi from collinearity equations (4 and 5) without including distortions parameters.

The fundamental notion of photogrammetry is that photos of an item or scene may be utilized to estimate its spatial location and form [23]. This was done by analyzing the photos and discovering common spots or characteristics that may be utilized to generate a three-dimensional representation of the item. Constructing a 3D model from images requires numerous processes, including image acquisition, Structure from motion (SfM), and 3D reconstruction [24].

4. Methodology

4.1 Flight Planning

Utilizing custom software, project planning (including flying and data collection) was done at the mentioned study area. To conduct a survey using the Phantom 4 drone :

- Mission Planning: Define the survey area boundaries, desired resolution, and accuracy, and select the appropriate flight path and camera settings. Recommended overlap for most cases was at least 75% front-overlap and side-overlap, as seen in Figure 2, using specialized software, such as DJI GO 4 and Pix4Dcapture.
-

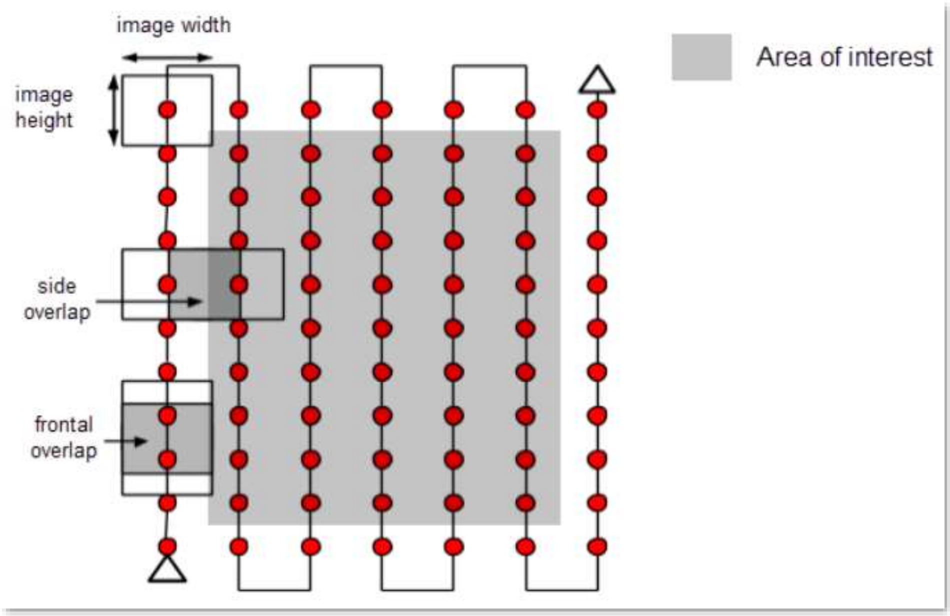

Figure 2: recommends front overlap and side overlap [24].

- Flight Execution: Launch the drone and fly it over the area of interest (AOI), either autonomously following a predetermined flight path or manually controlled by an operator. Capture images and data from multiple angles and altitudes as predefined.

Figure 3: AOI being captured by drone.

- Data pre-processing: Download and remove unwanted images or do some manipulating and analyzing, then preprocess the data to create a 3D map, ortho mosaic maps, and digital elevation models for a detailed representation of the surveyed area.

At this point, approximately 7,300 aerial photographs were taken to create a 3D map, with the side overlap/ front overlap being more than 80 degrees and the Drone's height from the ground being 31 meters.

4.2 Indirect Georeferencing

In order to correct the 3D map coordinates, the study area was surveyed by differential positioning system model hyper II and gathering a precise ground control point. UTM/WGS84 projection was employed in static mode [25]; due to a malfunction in the radio antenna, the RTK mode was not working; that is why six ground control points were measured in static mode to ensure accurate GCPs readings as shown in Figure 4, and 5.

Figure 4: Deferential GPS.

Figure 5: shows the distribution of GCPs across the AOI.

A poster with dimensions of 50 * 50 cm was used as an indicator to represent the real location of the ground control points, Figure 6.

Figure 6: 50*50cm poster that indicates the locations of GCPs from a drone perspective.

Table 1 GCPs accurate locations

Name	X (Easting)	Y (Northing)	Elevation
GCP_1	442322.876	3681913.495	33.953
GCP_2	442237.306	3681769.357	34.836
GCP_3	442320.359	3682043.517	33.809
GCP_4	442142.918	3681894.366	34.631
GCP_5	442139.944	3682036.232	33.485
GCP_6	441975.428	3682009.446	33.866

4.3 Map modeling using specialized software

The 3DF Zephyr software automatically generates 3D models from images without the need for coded targets or specialized equipment. The software was built on advanced in-house reconstruction technology and had an easy-to-use interface. Additionally, the software permits exporting models in a range of standard 3D formats and creating high-quality videos without using supplementary programs [26]. The software mentioned earlier was utilized to construct a three-dimensional map of the area of interest; the process involved several phases:

The first phase involved pre-processing the obtained images by enhancing their color and removing unwanted data through visual inspection [27]. The second phase involved defining the camera pose, also known as "Structure from Motion," which entailed extracting the camera's internal and external parameters, such as focal length, position, and orientation.

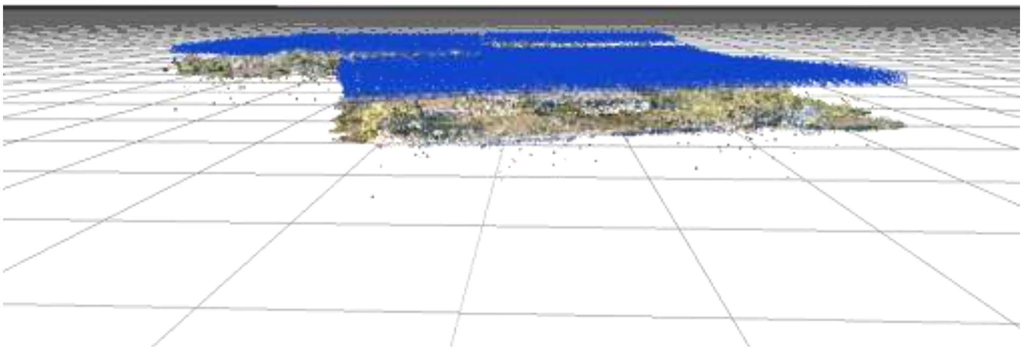

Figure 7: Blue triangles show the sensor's location and orientation (SfM).

The third phase involved extracting a dense point cloud called 'Multi-View Stereo.' This step included identifying and matching features in multiple images to create a set of 3D points that represented the captured object or environment.

Figure 8: part of Dense Point Cloud of AOI.

The final phase involved extracting a textured mesh, which added visual details to the surface model created from the dense point cloud. This step was crucial to create a realistic and accurate 3D model. The software used the digital images taken during the photogrammetry process to map colors and textures onto the surface model created in the previous phase. The process involved aligning the images to the surface model and projecting them onto the surface using (u, v) coordinates in the images, resulting in a detailed and textured mesh model that accurately represented the object or environment captured.

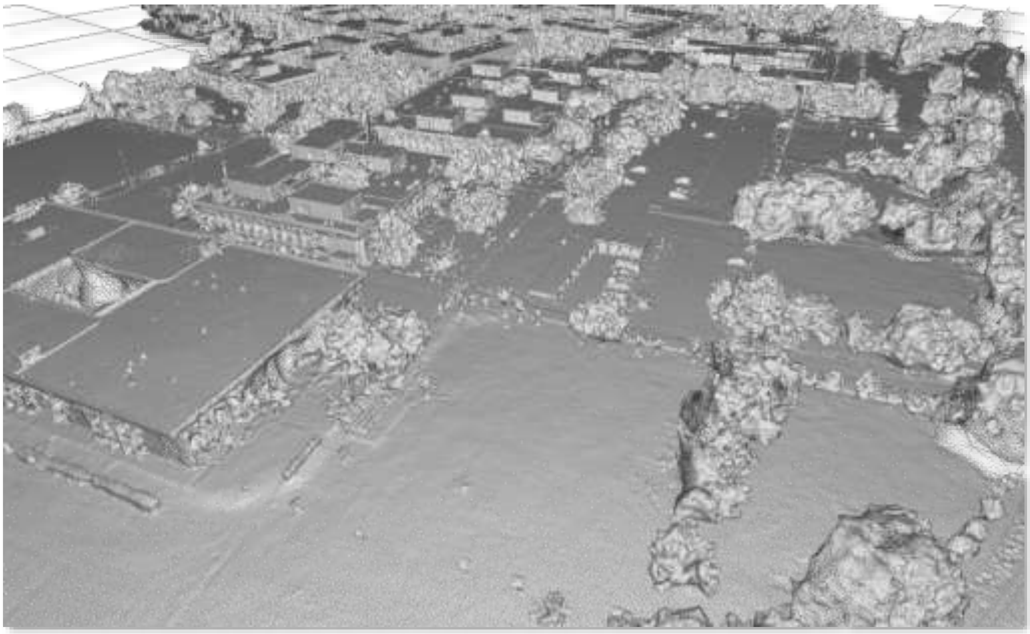

Figure 9: part of the textured mesh of AOI.

5. Results

In photogrammetry, achieving accurate metric reconstruction from images necessitates sensor calibration and image triangulation. For optimal outcomes, camera calibration and image orientation should be performed separately, particularly for drone blocks with cross-strips. Automated aerial triangulation algorithms were used in aerial photogrammetry to extract standard photograph components. Although GNSS/INS data can help directly georeference output photographs, a bundle adjustment was often utilized to refine the precise camera locations and attitudes required. In some cases, direct GNSS/INS observation accuracy may be sufficient for low metric quality requirements, but in surveying applications, an entirely image-based approach may be required when GPS satellite visibility is obstructed or unavailable.

After initial pre-processing and 3D model construction, the captured aerial images were imported into the software for processing. The software used automatic structure from motion techniques, which include feature extraction, image matching, and bundle block adjustment, to generate a dense point cloud, serving as the basis for the 3D model. Georeferencing was performed using the GCPs measured earlier to ensure accurate and precise positioning. The AOI was accurately reconstructed by processing and analyzing dense point cloud data and mesh texturing, as illustrated in Figure 8. Figure 10 depicts the final result of texture mapping, which involves applying the authentic texture from photographs onto the three-dimensional (3D) geometric surface. This process calculates the image coordinates on the photograph corresponding to each triangular face of the 3D surface using the interior and exterior orientation parameters. The textures within the projected triangle were then mapped onto the face to give the model a lifelike appearance as intended.

Figure 10: Three-dimensional model for the College of Sciences.

6. Discussion

Generating a three-dimensional map with low accuracy (more than 50 cm) using 3DF Zephyr Aerial can have positive and negative implications, depending on the context and specific application.

On the positive side, a map model with an accuracy of less than one meter can still be helpful in various applications, such as urban planning, construction, and archaeology. For instance, the model can aid a construction company in visualizing a new building before breaking ground, while an archaeologist can use it to map and analyze a site for historical research. Even if the model is inaccurate, it can provide valuable insights and help inform decision-making.

However, using a map with less than one-meter accuracy also has potential drawbacks. Accuracy may be required to ensure the map is reliable and valuable in surveying or building new sites. Additionally, minor inaccuracies can have significant safety implications in specific applications such as autonomous vehicles or drone navigation.

It is also essential to consider the factors that may have led to the less-than-optimal accuracy of the model. The quality of the input data, such as the images used to create the model, can significantly impact the accuracy of the resulting model. Factors like lighting, weather, and obstructions can affect the model's accuracy.

Overall, while a three-dimensional map created using 3DF Zephyr Aerial with an accuracy of fewer than one meter (without correction) may have limitations, it can still be a valuable tool in many applications. It is crucial to evaluate the model's usefulness by thoroughly studying the specific context and requirements of the application.

7. Conclusion

Unmanned Aerial Vehicles (UAVs) provide high-resolution image data with a low spatial but a high temporal resolution, which can be quickly captured, transmitted, and analyzed. Rotary-wing UAVs do not require a runway, making them suitable for small-scale applications or as a supplement to terrestrial image or range data collection. These high-resolution photographs may be employed for texture mapping, mosaic, and drawing development with existing 3D data. Unlike conventional airborne platforms, UAVs offer cost savings and increased safety, particularly in hostile environments, while maintaining high accuracy, while the low spatial accuracy can be an issue in some cases; if an RTK system is not available, indirect ground control points can be used as an alternative, as described earlier, using a poster with a size that depends on the drone's altitude. This approach has improved accuracy, as the map accuracy without correction was 86cm. However, after correcting the map using DGPS models, the accuracy improved to less than 3cm. In conclusion, using photogrammetry and UAVs in mapping applications provides various benefits, including the ability to produce maps at different scales and levels of accuracy, 3D reconstruction and modeling, and real-time data capture, transmission, and analysis. UAV capabilities continue to improve, and as technology advances, they are likely to have increased potential for more advanced applications.

8. Future Work and Limitations

Automated image processing has already demonstrated reliable and accurate results, but advancements are still possible. With high-end navigation sensors such as RTK and expensive INS, it may be possible to georeference the collected photos on-site directly. Additionally, powerful DSM-generating algorithms could offer fast surface models using GPU programming. Many countries worldwide are developing UAV regulations that specify technical requirements and permissible usage locations, such as over urban areas, which will expand the potential range of applications for these devices.

References

[1] F. Banfi and A. Mandelli, “Computer vision meets image processing and UAS photogrammetric data integration: From HBIM to the extended reality project of arco della pace in Milan and its decorative complexity,” *J. Imaging*, vol. 7, no. 7, 2021, doi: 10.3390/jimaging7070118.

[2] F. Remondino, L. Barazzetti, F. Nex, M. Scaioni, and D. Sarazzi, “Uav Photogrammetry for Mapping and 3D Modeling – Current Status and Future Perspectives,” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. XXXVIII-1/, no. September, pp. 25–31, 2012, doi: 10.5194/isprsarchives-xxxviii-1-c22-25-2011.

[3] H. Eisenbeiss, “The autonomous mini-helicopter: a powerful platform for mobile mapping,” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 37, pp. 977–983, 2008, [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.184.2109&rep=rep1&type=pdf

[4] S. F. Behadili and B. H. Sayed, “Oli and gas explorations via satellite remote sensing techniques for Al_Nasiriya,” *Iraqi J. Sci.*, vol. 60, no. 10, pp. 2308–2314, 2019, doi: 10.24996/ijs.2019.60.10.25.

[5] A. A. N. Al-Jasim, T. A. Naji, and A. H. Shaban, “The Effect of Using the Different Satellite Spatial Resolution on the Fusion Technique,” *Iraqi J. Sci.*, vol. 63, no. 9, pp. 4131–4141, 2022, doi: 10.24996/ijs.2022.63.9.40.

[6] A. K. Mohammed Ali and F. K. Mashee Al Ramahi, “A study of the effect of urbanization on annual evaporation rates in Baghdad city using remote sensing,” *Iraqi J. Sci.*, vol. 61, no. 8, pp. 2142–2149, 2020, doi: 10.24996/ijs.2020.61.8.29.

[7] X. Qiu, B. Rong, J. Ben-Othman, S. Han, and M. Kodach, “Emerging Intelligent Systems and Smart Computational Technologies for Future IoT,” *IEEE Netw.*, vol. 34, no. 5, pp. 6–7, 2020, doi: 10.1109/MNET.2020.9199784.

[8] S. Ahmed, A. El-Shazly, F. Abed, and W. Ahmed, “The Influence of Flight Direction and Camera Orientation on the Quality Products of UAV-Based SfM-Photogrammetry,” *Appl. Sci.*, vol. 12, no. 20, 2022, doi: 10.3390/app122010492.

[9] M. F. Allawai and B. A. Ahmed, “Using Remote Sensing and GIS in Measuring Vegetation Cover Change from Satellite Imagery in Mosul City, North of Iraq,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 757, no. 1, 2020, doi: 10.1088/1757-899X/757/1/012062.

[10] H. Tsunetaka, N. Hotta, Y. S. Hayakawa, and F. Imaizumi, “Spatial accuracy assessment of unmanned aerial vehicle-based structures from motion multi-view stereo photogrammetry for geomorphic observations in initiation zones of debris flows, Ohya landslide, Japan,” *Prog. Earth Planet. Sci.*, vol. 7, no. 1, 2020, doi: 10.1186/s40645-020-00336-0.

[11] M. Saponaro, A. Capolupo, G. Caporusso, E. Borgogno Mondino, and E. Tarantino, “PREDICTING the ACCURACY of PHOTOGRAMMETRIC 3D RECONSTRUCTION from CAMERA CALIBRATION PARAMETERS through A MULTIVARIATE STATISTICAL APPROACH,” *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch.*, vol. 43, no. B2, pp. 479–486, 2020, doi: 10.5194/isprs-archives-XLIII-B2-2020-479-2020.

[12] H. Bi, W. Zheng, Z. Ren, J. Zeng, and J. Yu, “Using an unmanned aerial vehicle for topography mapping of the fault zone based on structure from motion photogrammetry,” *Int. J. Remote Sens.*, vol. 0, no. 0, pp. 1–16, 2016, doi: 10.1080/01431161.2016.1249308.

[13] S. Crommelinck, R. Bennett, M. Gerke, M. Y. Yang, and G. Vosselman, “Contour detection for UAV-based cadastral mapping,” *Remote Sens.*, vol. 9, no. 2, pp. 1–13, 2017, doi: 10.3390/rs9020171.

[14] H. H. Ali and F. M. Abed, “The impact of UAV flight planning parameters on topographic mapping quality control,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 518, no. 2, pp. 0–11, 2019, doi: 10.1088/1757-899X/518/2/022018.

[15] M. Du, H. Li, and A. Roshanianfard, “Design and Experimental Study on an Innovative UAV-LiDAR Topographic Mapping System for Precision Land Levelling,” *Drones*, vol. 6, no. 12, 2022, doi: 10.3390/drones6120403.

[16] DJI, “Phantom 4 User Manual V1.0,” p. 65, 2016, [Online]. Available:

https://dl.djicdn.com/downloads/phantom_4/en/Phantom_4_User_Manual_en_v1.0.pdf

[17] N. Cavalagli, M. Gioffrè, S. Grassi, V. Gusella, C. Pepi, and G. M. Volpi, “On the accuracy of UAV photogrammetric survey for the evaluation of historic masonry structural damages,” *Procedia Struct. Integr.*, vol. 29, pp. 165–174, 2020, doi: 10.1016/j.prostr.2020.11.153.

[18] A. Ozimek, P. Ozimek, K. Skabek, and P. Łabędź, “Digital modelling and accuracy verification of a complex architectural object based on photogrammetric reconstruction,” *Buildings*, vol. 11, no. 5, pp. 1–19, 2021, doi: 10.3390/buildings11050206.

[19] N. A. Al Naqeeb, J. S. Al Hassany, and F. K. Mashee, “Use Remote Sensing Techniques to Study Epiphytic Algae on Phragmites australis in Um El-Naaj Lake, Mysan Province, Southern Iraq,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1002, no. 1, 2022, doi: 10.1088/1755-1315/1002/1/012012.

[20] M. Honarmand and H. Shahriari, “Geological mapping using drone-based photogrammetry: An application for exploration of vein-type cu mineralization,” *Minerals*, vol. 11, no. 6, pp. 1–13, 2021, doi: 10.3390/min11060585.

[21] K. Hanke and P. Grussenmeyer, “ARCHITECTURAL PHOTOGRAMMETRY : Basic theory, Procedures, Tools,” no. September, pp. 1–27, 2002.

[22] M. Lehoczky and Z. Abdurakhmonov, “Present software of photogrammetric processing of digital images,” *E3S Web Conf.*, vol. 227, 2021, doi: 10.1051/e3sconf/202122704001.

[23] M. K. Bennett, N. Younes, and K. Joyce, “Automating drone image processing to map coral reef substrates using google earth engine,” *Drones*, vol. 4, no. 3, pp. 1–13, 2020, doi: 10.3390/drones4030050.

[24] W. Budiharto, E. Irwansyah, J. S. Suroso, A. Chowanda, H. Ngarianto, and A. A. S. Gunawan, “Mapping and 3D modelling using quadrotor drone and GIS software,” *J. Big Data*, vol. 8, no. 1, 2021, doi: 10.1186/s40537-021-00436-8.

[25] H. J. Alatta, S. F. Behadili, and B. H. Sayyid, “Analyze Water Scarcity in Basrah City Via Geoinformatics,” *AIP Conf. Proc.*, vol. 2398, no. October 2022, doi: 10.1063/5.0093409.

[26] “Copyright © 2013 by 3Dflow srl. All Rights Reserved.,” 2013.

[27] M. Colloredo-Mansfeld, F. J. Laso, and J. Arce-Nazario, “Uav-based participatory mapping: Examining local agricultural knowledge in the Galapagos,” *Drones*, vol. 4, no. 4, pp. 1–13, 2020, doi: 10.3390/drones4040062.