North American Academic Research

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*Research*

# *Unmanned Aerial Vehicle (UAV) Based Point Cloud for 3D Mapping and Modelling*

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***Accepted**: 22 November , 2020; **Online**: 30 November, 2020*
***DOI**: https://doi.org/10.5281/zenodo.4304997*

***Abstract:** UAV based 3D mapping and point clouding became one of the most interesting topic in recent years. UAV based mapping solution is way cheaper than the conventional techniques and time saving method. This paper carried out the workflow for developing a 3D model based on geo-referenced images, particularly from aerial photos obtained by a UAS; the case study also showed the latest developments of UAV image processing.*

***Keywords**: Unmanned Aerial Vehicle (UAV); 3D Mapping; Point Cloud; Photogrammetry; Triangle Mash.*

## *Introduction*

An unmanned aerial vehicle (UAV) (commonly known as a drone) is an aircraft without a human pilot on board and a type of unmanned vehicle. UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. UAVs have seen a rising number of applications in a variety of domains such as policing and firefighting, nonmilitary security work, surveillance of pipelines, land management, earth observations, and infrastructure inspection, (in the field of agricultural plant protection, public safety, mapping and land surveying, energy surveys, environmental protection or urban planning). In particular, in recent years, UAVs have received special attention in the field of 3D Mapping and Modeling. The drone is usually equipped with various sensors, such as cameras, Global Positioning System (GPS), compass or other specialized communication devices. The cameras are used to capture the field and to complete data acquisition, helps to obtain high-precision 3D data of the surface. After that can quickly make the model by using oblique photography, it also provides the topographic map of the corresponding scale. It provides the all the task in a short time which is also safe for the operator to complete the task. The UAV remote sensing technology is mature and the precision is better than the traditional computing method with reducing the working time and increases the efficiency. Surveying and mapping drones serve all aspects of economic and social development with high mobility, cost-effectiveness and high security. This project is accomplished in Dhaka under the Research & Development department of Avion Aerospace, Bangladesh.

The aim of this paper is to study the workflow for developing a 3D model based on geo-referenced images, particularly from aerial photos obtained by a UAS. It also identifies the challenges of the 3D modeling process and the accuracy of 3D mapping for surveying or measuring tasks in the AEC industry. The field test flights were conducted at a residential site.

## *Experimental Details*

For this experiment, a multirotor UAV or UAS platform for collecting visual assets was used and the Pix4D application was used for 3D mapping based on the collected images. We used the manual drone photo capturing and then processed them in the dedicated mapping software to get the result.

The Average Ground Sampling Distance (GSD) was 1.3 inch. Area covered 0.0362 $km^2$. As a dataset we used 27 images calibrated (100%), 6.41% relative difference between initial and optimized internal camera parameters with georeferencing.

Internal Camera Parameters:

- FC7203_4.5_4000 x 2250(1SFLGBB0AB0461) (RGB).
- Sensor Dimensions: 6.548 [mm] x 3.683 [mm].
- EXIF ID: FC7203_4.5_4000x2250.

**Table1: Camera lens parameters**

| Values | Focal Length | Principal Point x | Principal Point y | R1 | R2 | R3 | T1 | T2 |
|---|---|---|---|---|---|---|---|---|
| Initial Values | 2742.857 [pixel] 4.490 [mm] | 2000.000 [pixel] 3.274 [mm] | 1125.000 [pixel] 1.842 [mm] | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Optimized Values | 2918.765 [pixel] 4.778 [mm] | 2020.286 [pixel] 3.307 [mm] | 1144.721 [pixel] 1.874 [mm] | 0.198 | -0.596 | 0.432 | 0.001 | 0.000 |

The number of Automatic Tie Points (ATPs) Fig1 per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location.

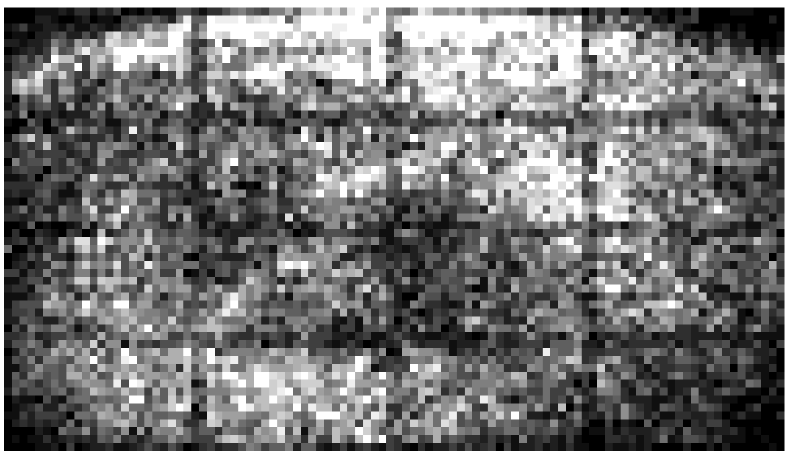

**Fig1 Tie Points (ATPs) per pixel**

### Initial Image Positions

In total, 27 photos were taken manually by in a circular flight method. The green line follows the position of the images in time starting from the large blue dot. In the left photo-'Computed Image/GCPs/Manual Tie Points Positions' where the offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane).

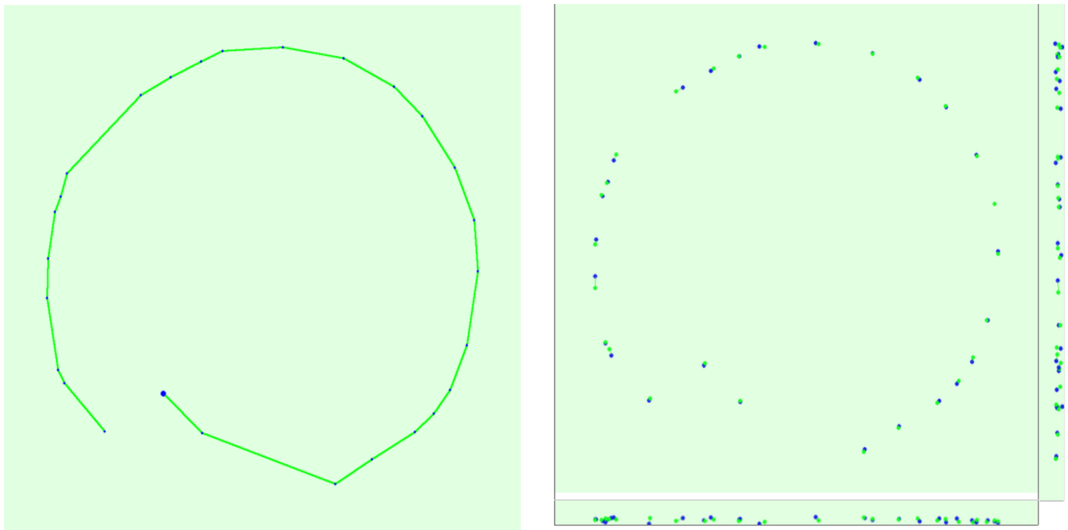

**Fig2 Top view of the initial image position**

## Software

We used Pix4D mapper instinctively that converts images taken by our UAV, and delivers highly precise, georeferenced 2D maps and 3D models. It's customizable, timely, and complement a wide range of applications and software.

**Main steps for 3D mapping**

| **Initial processing** | **Point densification** | **DSM and ortho-mosaic** |
|---|---|---|
| Developing images: Calibrate cameras and exterior orientation<br>• Key point extraction<br>• Key point matching<br>• Camera model optimization<br>Geo-location process | Developing point clouds<br>• Point densification<br>• Point filtering | Developing digital surface model and ortho-mosaic<br>• DSM generation<br>• Ortho-mosaic images<br>• Ortho-mosaic blending |

3D Point Cloud: Laser scanner quality 3D points from a consumer-grade camera. Clean from moving objects, aerial perspective with limited occlusions, and low acquisition time.

Ortho mosaics: High-resolution aerial map with corrected perspective, putting you in control of geographic data generation.

3D Textured Model: Full 3D triangle mesh with photorealistic texturing, perfect for sharing and online visualization.

Digital Surface Model: Accurate, georeferenced elevation map, ready for your preferred GIS workflow.

## *Result and Discussion*

### Digital Surface Model

We used Pix4d mapping software to get the result. From these twenty-seven images, we got the 0.0362 $km^2$ high definition 3D mapped images from top. Shown in fig3. From this DSM we can measure the distance area and density of the area.

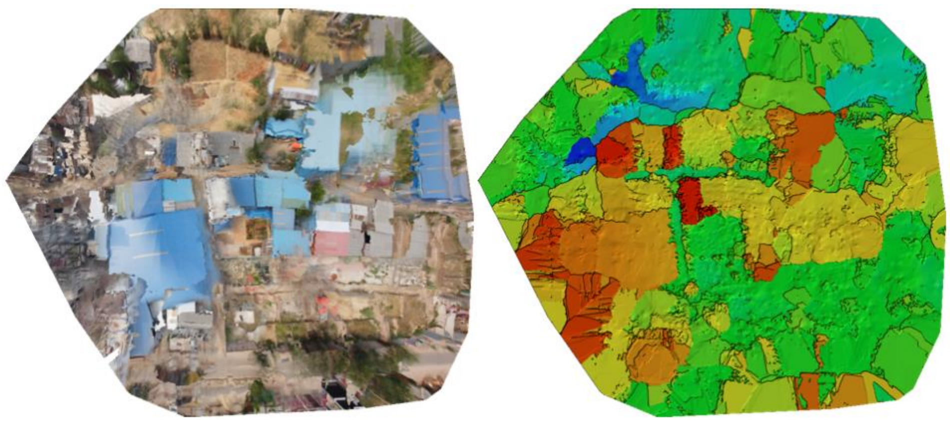

**Fig3 Ortho-mosaic and the corresponding sparse Digital Surface Model (DSM) before densification**

Red and yellow areas Fig4 indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over five images for every pixel. Overlapping is very important to get good quality results will be generated as long as the number of key point matches is also sufficient for these areas.

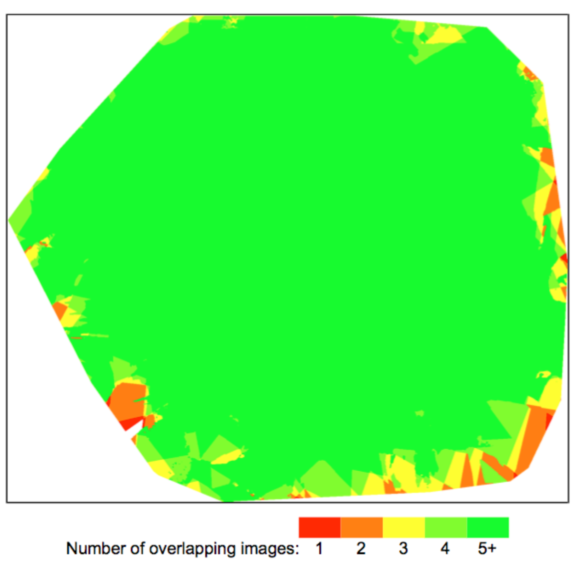


**Fig4 Number of overlapping images computed for each pixel of the ortho-mosaic**

**Key point Matches**

**Table2: 2D key pints**

| Exp | Number of 2D keypoints per image | Number of matched 2D keypoints per image |
|---|---|---|
| Median | 19126 | 4673 |
| Min | 17390 | 1113 |
| Max | 21768 | 6883 |
| Mean | 19326 | 4707 |

**Table3: 3D pints from 2D**

| E.I | Number of 3D points observed |
|---|---|
| In 2 Images | 43404 |
| In 3 Images | 7367 |
| In 4 Images | 2259 |
| In 5 Images | 853 |
| In 6 Images | 378 |
| In 7 Images | 167 |
| In 8 Images | 110 |
| In 9 Images | 33 |
| In 10 Images | 13 |
| In 11 Images | 6 |
| In 12 Images | 4 |
| In 13 Images | 2 |

Top view of the image. Fig5 computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D key points between the images. Bright links indicate weak links and require manual tie points or more images.

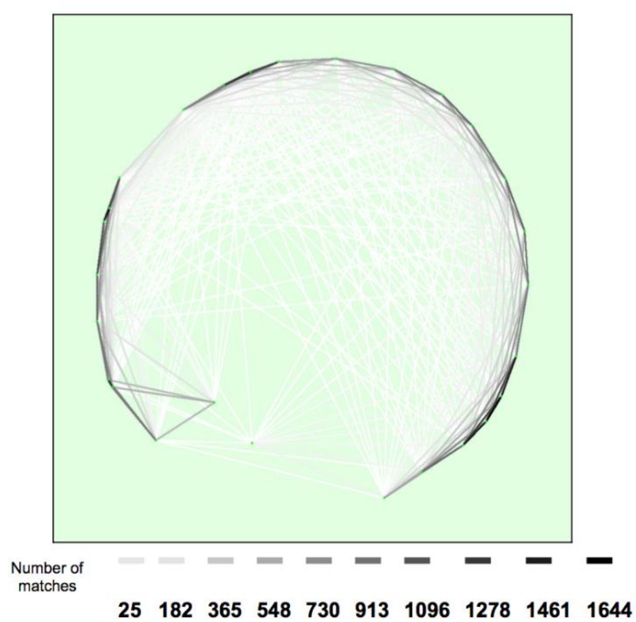


**Fig5 Top view of the key point image**

**Geolocation Details**

Photos with geolocation is another important thigs here. With geolocation tags of the photos creates 3D map which mainly overlaps multiple photos by getting their latitude and longitude.

**Table4: Absolute geolocation variance**

| Min Error [m] | Max Error [m] | Geolocation Error X [%] | Geolocation Error Y [%] | Geolocation Error Z [%] |
|---|---|---|---|---|
| - | -15.00 | 0.00 | 0.00 | 0.00 |
| -15.00 | -12.00 | 0.00 | 0.00 | 0.00 |
| -12.00 | -9.00 | 0.00 | 0.00 | 0.00 |
| -9.00 | -6.00 | 0.00 | 0.00 | 0.00 |
| -6.00 | -3.00 | 0.00 | 0.00 | 0.00 |
| -3.00 | 0.00 | 44.44 | 48.15 | 40.74 |
| 0.00 | 3.00 | 55.56 | 51.85 | 59.26 |
| 3.00 | 6.00 | 0.00 | 0.00 | 0.00 |
| 6.00 | 9.00 | 0.00 | 0.00 | 0.00 |
| 9.00 | 12.00 | 0.00 | 0.00 | 0.00 |
| 12.00 | 15.00 | 0.00 | 0.00 | 0.00 |
| 15.00 | - | 0.00 | 0.00 | 0.00 |
| **Mean [m]** | | -0.000071 | 0.000086 | 0.000508 |
| **Sigma [m]** | | 0.536636 | 0.852256 | 0.568079 |
| **RMS Error [m]** | | 0.536636 | 0.852256 | 0.568079 |

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z. Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions.

**Table5: Relative geolocation variance**

| Relative Geolocation Error | Images X [%] | Images Y [%] | Images Z [%] |
|---|---|---|---|
| [-1.00, 1.00] | 100.00 | 100.00 | 100.00 |
| [-2.00, 2.00] | 100.00 | 100.00 | 100.00 |
| [-3.00, 3.00] | 100.00 | 100.00 | 100.00 |
| Mean of Geolocation Accuracy [m] | 5.000000 | 5.000000 | 10.000000 |
| Sigma of Geolocation Accuracy [m] | 0.000000 | 0.000000 | 0.000000 |

**Table6: Point cloud densification details**

| Image Scale | Multiscale, 1/2 (Half image size, Default) |
|---|---|
| Point Density | Optimal |
| Minimum Number of Matches | 3 |
| 3D Textured Mesh Generation | yes, Maximum Number of Triangles: 1000000, Texture Size: 8192x8192 |
| Advanced: Matching Window Size | 7x7 pixels |
| Advanced: Image Groups | group1 |
| Advanced: Use Densification Area | yes |
| Advanced: Use Annotations | yes |
| Advanced: Limit Camera Depth Automatically | no |

We finally generated the 3D of our targeted object and location by ray cloud by circular flight of our UAV. We also generated altitude to view of our location, with red, green and blue. Red show the pic pints of our location and then green and blue. From this images we can identify the altitude information of our location.

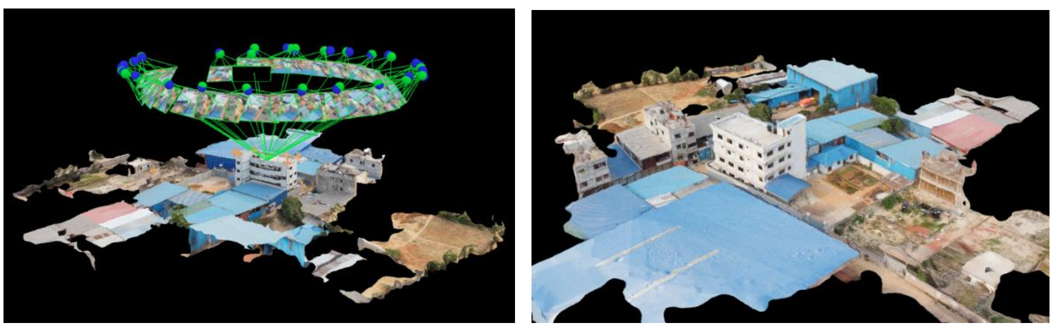

**Fig6 3D Model generated by Ray cloud and circular fight**

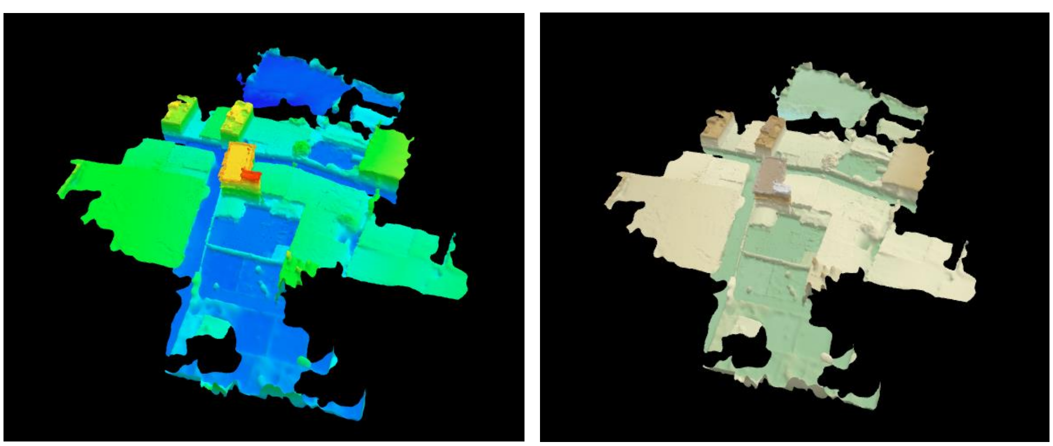

**Fig7 Altitude identification with color code (Red=Highest, Green=Middle and Blue=Lowest)**

## *Conclusions*

This study was implemented as a demonstration for the potential of 3D mapping using UAV. The principle workflow was introduced to acquire and process aerial photos for 3D mapping. The 3D derivations such as DSM, orthophotos and 3D objects are crucial value for quantitative of topography, geomorphology, landscape and ecology dynamics. We used manual UAV control to take photos and concluded as follows:

1. When an appropriate flight mode can be applied the UAV photos would be able to derivate 3D maps with high level of details.
2. Comparing to using ground laser scanner or total station for ground measures the UAV mapping shows it advantages.
3. More overlapping photos provide better result for mapping image and it was optimal.

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## *Dedication*

This research is dedicated to our motherland, Bangladesh. Best wishes for Bangladesh; we wish a strong aviation, drone industry and development of Bangladesh. We had a vast study on the possibilities of Bangladesh with the fastest growing economy and technology.

## *Conflicts of Interest*

All authors declare that there is no conflict of interest.