SAMAVTOL: A new unmanned aircraft system for remotely sensed data collection

Mohammad Reza Bayanlou 1 and Mehdi Khoshboresh-Masouleh 2

1 Aerospace Engineering Department, Sharif University of Technology, Tehran, Iran.
   E-mail: mohammadreza.bayanlou@ae.sharif.edu, ORCID: https://orcid.org/0000-0003-4031-9238
2 School of Surveying and Geospatial Engineering, College of Engineering, University of Tehran, Tehran, Iran.
   E-mail: m.khoshboresh@ut.ac.ir, ORCID: https://orcid.org/0000-0002-9565-3615

Abstract
In recent years, unmanned aircraft systems (UASs) are frequently used in many different applications of photogrammetry such as building damage monitoring, archaeological mapping and vegetation monitoring. In this paper, a new state-of-the-art vertical take-off and landing fixed-wing UAS is proposed to robust photogrammetry missions, called SAMAVTOL. In this study, the capability of SAMAVTOL is investigated for generating orthophoto. The major stages are including designing, building and experimental scenario. First, a brief description of design and build is introduced. Next, an experiment was done to generate accurate orthophoto with minimum ground control points requirements. The processing step, which includes automatic aerial triangulation with camera calibration and model generation. In this regard, the Pix4Dmapper software was used to orientate the images, produce point clouds, creating digital surface model and generating orthophoto mosaic. Experimental results based on the test area covering 26.3 hectares indicate that our SAMAVTOL performs well in the orthophoto mosaic task.

Keywords: Unmanned Aircraft System, Remote Sensing, Photogrammetry, Post-Processed Kinematic, SAMAVTOL.
1. Introduction

In recent years, Unmanned Aircraft Systems (UASs) has been used in new applications such as marine wildlife detection [1], agricultural production management [2], moving object detection [3]–[6], search and rescue missions [7], disaster management [8], [9], real-time building damage mapping [10]–[13], 3D mapping [14]–[18], and automatic building monitoring [19], [20]. In this regard, one of the most comprehensive studies on the application of UASs is photogrammetry mission [8], [14], [21]–[23]. Generating orthophoto with UAS-based images is an important product for applied photogrammetry [24], [25]. Nowadays, the role of traditional methods such as terrestrial mapping and traditional aerial photogrammetry techniques, has been dimmed due to the high cost and also the need for a long time to produce an orthophoto [26]. An affordable and accurate way to generate orthophoto is to use the combination of UAS with a calibrated digital camera and the global positioning system [27]. Although this method also requires fieldwork, it requires less manpower than traditional methods.

Digital Elevation Model (DEM), Digital Surface Model (DSM) and orthophoto are useful geospatial products of photogrammetry missions. They are useful for all operators because they combine geometry and photorealism in order to provide a metric visualization of the real-world areas [28]. Particularly, they are essential datasets used in many different fields of geomatics science and geospatial engineering. Therefore, it is very important to provide an efficient solution for generating geospatial products with an easy and straightforward way [29]. The use of UAS is a good solution for generating geospatial products. The main purpose
of this study was to design and construction of a new state-of-the-art vertical take-off and landing (VTOL) fixed-wing UAS for photogrammetry applications. The proposed UAS called SAMA-VTOL. The SAMA-VTOL introduces a variety of new features and capabilities for users. In this regard, the major contributions of this study to the remotely sensed data collection techniques are as follows:

(1) An original fixed-wing system is proposed for smart surveying.

(2) Flight safety has improved due to perform the VTOL.

(3) The use of an 18-megapixel digital camera to improvement the image quality.

(4) Integrate GNSS-PPK with SAMA-VTOL platform for reduces the time consuming field work.

These features make SAMA-VTOL well suited to photogrammetry applications. The proposed novel UAS, on paper, involves two main stages. First, conceptual design and construction process of the SAMA-VTOL. Second, performance evaluation of the SAMA-VTOL for generating DSM and orthophotos in case study research.

2. Methodology

2.1 SAMA-VTOL: A brief description of design and build

The proposed UAS based on conceptual designing to real prototyping workflow. The systematic conceptual layout flow diagram for designing the SAMA-VTOL is presented in Figure 1. The stages of systematic conceptual layout include mission requirement (e.g. flight
time), platform configuration (e.g. stability and flight dynamics), mathematical modelling for UAS weight estimation, and wing configuration based on flight mission.

Figure 1. Systematic conceptual design flow diagram for SAMA-VTOL.

The main purpose of real prototyping stage is the iterative development (effective feedback for optimizing model), testing (checking activities), and refinement (highest performance) of the improved concept layout. The workflow from conceptual designing to real prototyping is
presented in Figure 2. In this section, the SAMA-VTOL has been successfully built and tested for robust and safe flight.

Figure 2. SAMA-VTOL design and manufacturing steps, (a) structure designing and sub-system placement, (b) final structure, (c) making the SAMA-VTOL body out of carbon fiber fabric, and (d) control parameters tuning.
2.2 Experimental scenario

As a metric for evaluating the SAMA-VTOL, we designed an experimental scenario. This scenario includes, the preparation of equipment to generate geospatial products (e.g. DSM and orthophoto). The workflow of the research is shown in Figure 3.

![Figure 3](image)

**Figure 3.** Workflow schematic as for evaluating the SAMA-VTOL.

3. Experiments

3.1 Data acquisition

The case study research is part of the Ahmadabad-e Mostowfi district, Iran. It covers a research area of 26.3 hectares inside the Ahmadabad-e Mostowfi district with an average altitude of 1090 m (Figure 4). The land cover consists of built-up areas and vegetation regions.
In this study, SAMA-VTOL was equipped with a CANON EOS M digital camera (18M APS-C Sensor) to acquire georeferenced aerial images without ground control points. We established the checkpoints by using the Post-Processed Kinematic (PPK) positioning and 1×1 meter targets were made to mark various checkpoints throughout the case study (Figure 5). Moreover, the Pix4Dmapper software was used to orientate the images and produce point clouds, DSM and orthophoto mosaics and QGroundControl software was used to mission planning and flight control.
Figure 5. Overview of the research equipment, (a) SAMA-VTOL equipped with CANON EOS M digital camera, (b) SAMA-VTOL taking off, (c) checkpoint template, and (d) distribution of checkpoints.

3.2 Processing

The processing steps, includes aerial triangulation based bundle adjustment with camera calibration and model generation with Pix4Dmapper software. Pix4Dmapper using Scale-Invariant Feature Transform (SIFT) algorithm for accurate key points extraction (image matching) from single images [30]. In addition, the use of checkpoints helps to improving accuracy assessment stage in products generated. Table 1 shows the bundle block adjustment details, and Table 2 shows the summary initial and optimized results for camera calibration.

| Number of 2-D keypoint | Number of 3-D points | Mean Reprojection Error |
|------------------------|----------------------|-------------------------|
| 5776111                | 2260338              | 0.202 pixels             |

Table 1. Bundle block adjustment details.
Table 2. Internal camera parameters.

| Focal Length | Principal Point | Radial lens distortions |
|--------------|-----------------|-------------------------|
|              |                 | K1 | K2 | K3 | T1 | T2 |
| Initial Values | 22.000 mm | 11.354 mm | 0.000 | 0.000 | 0.000 | 0.000 |
| Optimized Values | 21.949 mm | 11.547 mm | -0.011 | 0.085 | -0.151 | 0.000 | 0.000 |

3.3 Performance evaluation

Ahmadabad-e Mostowfi dataset contains 209 images that were acquired over a test area specifically prepared for this study. The flight height is 100 m while forward/side overlaps are 60% and 60%, respectively. Figure 6 shows the results of the DSM and orthophoto from the test region. Table 3 shows the error details of checkpoints in this test. Experimental results based on the test area indicate that our SAMA-VTOL performs well in the generating geospatial products task.

![Figure 6](image)

Figure 6. Products generated from Pix4Dmapper, (a) orthomosaic, and (b) digital surface model (DSM) with average ground sampling distance (GSD) equal to 1.91 cm.

Table 3. Error details of checkpoints.

| Error | Mean (meter) | Sigma (meter) | RMSE (meter) |
|-------|--------------|---------------|--------------|
| X     | -0.00326     | 0.03288       | 0.03304      |
| Y     | -0.01404     | 0.03280       | 0.03855      |
| Z     | 0.01792      | 0.03855       | 0.04251      |
4. Conclusions

In this paper, we proposed a new state-of-the-art VTOL fixed-wing UAS for photogrammetry missions, called SAMA-VTOL. The purpose of this study is to investigate the capabilities of the SAMA-VTOL in the field of photogrammetry, particularly, orthophoto generation. The results of the experiments in test area indicate that the SAMA-VTOL is affordable, and robust. Therefore, SAMA-VTOL is the accurate and advanced tool for professional surveying. In future work, we will expand and continue to improve SAMA-VTOL performance in larger areas.

References

[1] A. C. Seymour, J. Dale, M. Hammill, P. N. Halpin, and D. W. Johnston, “Automated detection and enumeration of marine wildlife using unmanned aircraft systems (UAS) and thermal imagery,” Sci. Rep., vol. 7, p. 45127, Mar. 2017, doi: 10.1038/srep45127.

[2] A. Gracia-Romero, O. Vergara-Díaz, C. Thierfelder, J. E. Cairns, S. C. Kefauver, and J. L. Araus, “Phenotyping Conservation Agriculture Management Effects on Ground and Aerial Remote Sensing Assessments of Maize Hybrids Performance in Zimbabwe,” Remote Sens., vol. 10, no. 2, p. 349, Feb. 2018, doi: 10.3390/rs10020349.

[3] M. Bindemann, M. C. Fysh, S. S. K. Sage, K. Douglas, and H. M. Tummon, “Person identification from aerial footage by a remote-controlled drone,” Sci. Rep., vol. 7, no. 1, p. 13629, Oct. 2017, doi: 10.1038/s41598-017-14026-3.

[4] X. Xiang, M. Zhai, N. Lv, and A. El Saddik, “Vehicle Counting Based on Vehicle Detection and Tracking from Aerial Videos,” Sensors, vol. 18, no. 8, Aug. 2018, doi: 10.3390/s18082560.

[5] M. Khoshboresh Masouleh and R. Shah-Hosseini, “A hybrid deep learning–based model for automatic car extraction from high-resolution airborne imagery,” Appl. Geomat., Aug. 2019, doi: 10.1007/s12518-019-00285-4.

[6] M. Khoshboresh Masouleh and R. Shah-Hosseini, “Development and evaluation of a deep learning model for real-time ground vehicle semantic segmentation from UAV-based thermal infrared imagery,” ISPRS J. Photogramm. Remote Sens., vol. 155, pp. 172–186, Sep. 2019, doi: 10.1016/j.isprsjprs.2019.07.009.

[7] P. Oettershagen et al., “Robotic technologies for solar-powered UAVs: Fully autonomous updraft-aware aerial sensing for multiday search-and-rescue missions,” J. Field Robot., vol. 35, no. 4, pp. 612–640, 2018, doi: 10.1002/rob.21765.
I. Colomina and P. Molina, “Unmanned aerial systems for photogrammetry and remote sensing: A review,” ISPRS J. Photogramm. Remote Sens., vol. 92, pp. 79–97, Jun. 2014, doi: 10.1016/j.isprsjprs.2014.02.013.

L. Hashemi-Beni, J. Jones, G. Thompson, C. Johnson, and A. Gebrehiwot, “Challenges and Opportunities for UAV-Based Digital Elevation Model Generation for Flood-Risk Management: A Case of Princeville, North Carolina,” Sensors, vol. 18, no. 11, Nov. 2018, doi: 10.3390/s18113843.

F. Nex, D. Duarte, A. Steenbeek, and N. Kerle, “Towards Real-Time Building Damage Mapping with Low-Cost UAV Solutions,” Remote Sens., vol. 11, no. 3, p. 287, Jan. 2019, doi: 10.3390/rs11030287.

M. Khoshboresh-Masouleh, F. Alidoost, and H. Arefi, “Multiscale building segmentation based on deep learning for remote sensing RGB images from different sensors,” J. Appl. Remote Sens., vol. 14, no. 03, p. 1, Jul. 2020, doi: 10.1117/1.JRS.14.034503.

M. Khoshboresh Masouleh and M. R. Saradjian, “ROBUST BUILDING FOOTPRINT EXTRACTION FROM BIG MULTI-SENSOR DATA USING DEEP COMPETITION NETWORK,” in ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Oct. 2019, vol. XLII-4-W18, pp. 615–621, doi: https://doi.org/10.5194/isprs-archives-XLII-4-W18-615-2019.

M. Khoshboresh-Masouleh, Deploying superpixel segmentation and deep learning to improve the accuracy of the building extraction from remote sensing data, vol. 1. Tehran: University of Tehran, 2019.

F. Nex and F. Remondino, “UAV for 3D mapping applications: a review,” Appl. Geomat., vol. 6, no. 1, pp. 1–15, Mar. 2014, doi: 10.1007/s12518-013-0120-x.

A. Spanò, G. Sammartano, F. Calcagno Tunin, S. Cerise, and G. Possi, “GIS-based detection of terraced landscape heritage: comparative tests using regional DEMs and UAV data,” Appl. Geomat., vol. 10, no. 2, pp. 77–97, Jun. 2018, doi: 10.1007/s12518-018-0205-7.

Y. Taddia, P. Russo, S. Lovo, and A. Pellegrinelli, “Multispectral UAV monitoring of submerged seaweed in shallow water,” Appl. Geomat., May 2019, doi: 10.1007/s12518-019-00270-x.

M. Khoshboresh-Masouleh, 3D cadastre modeling in urban areas using potentials of aerial images and deep learning, vol. 1. Tehran: Geomatics College of National Cartographic Center, 2017.

M. K. Masouleh and S. Sadeghian, “Deep learning-based method for reconstructing three-dimensional building cadastre models from aerial images,” J. Appl. Remote Sens., vol. 13, no. 2, p. 024508, Apr. 2019, doi: 10.1117/1.JRS.13.024508.

Y. Dai, J. Gong, Y. Li, and Q. Feng, “Building segmentation and outline extraction from UAV image-derived point clouds by a line growing algorithm,” Int. J. Digit. Earth, vol. 10, no. 11, pp. 1077–1097, Nov. 2017, doi: 10.1080/17538947.2016.1269841.

M. K. Masouleh and R. Shah-Hosseini, “Fusion of deep learning with adaptive bilateral filter for building outline extraction from remote sensing imagery,” J. Appl. Remote Sens., vol. 12, no. 04, p. 1, Nov. 2018, doi: 10.1117/1.JRS.12.046018.

J. A. Gonçalves and R. Henriques, “UAV photogrammetry for topographic monitoring of coastal areas,” ISPRS J. Photogramm. Remote Sens., vol. 104, pp. 101–111, Jun. 2015, doi: 10.1016/j.isprsjprs.2015.02.009.

C. M. Gevaert, C. Persello, R. Sluizas, and G. Vosselman, “Informal settlement classification using point-cloud and image-based features from UAV data,” ISPRS J. Photogramm. Remote Sens., vol. 125, pp. 225–236, Mar. 2017, doi: 10.1016/j.isprsjprs.2017.01.017.

G. W. Roberts, “Costas Armenakis and Petros Patias: Unmanned vehicle systems for geomatics, towards robotic mapping,” Appl. Geomat., Dec. 2019, doi: 10.1007/s12518-019-00293-4.
[24] Y. Liu, X. Zheng, G. Ai, Y. Zhang, and Y. Zuo, “Generating a High-Precision True Digital Orthophoto Map Based on UAV Images,” *ISPRS Int. J. Geo-Inf.*, vol. 7, no. 9, p. 333, Aug. 2018, doi: 10.3390/ijgi7090333.

[25] D. Wierzbicki, “Multi-Camera Imaging System for UAV Photogrammetry,” *Sensors*, vol. 18, no. 8, p. 2433, Jul. 2018, doi: 10.3390/s18082433.

[26] E. Akturk and A. O. Altunel, “Accuracy assessment of a low-cost UAV derived digital elevation model (DEM) in a highly broken and vegetated terrain,” *Measurement*, vol. 136, pp. 382–386, Mar. 2019, doi: 10.1016/j.measurement.2018.12.101.

[27] F. Benassi et al., “Testing Accuracy and Repeatability of UAV Blocks Oriented with GNSS-Supported Aerial Triangulation,” *Remote Sens.*, vol. 9, no. 2, p. 172, Feb. 2017, doi: 10.3390/rs9020172.

[28] L. Barazzetti, R. Brumana, D. Oreni, M. Previtali, and F. Roncoroni, “True-orthophoto generation from UAV images: Implementation of a combined photogrammetric and computer vision approach,” *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. II–5, pp. 57–63, May 2014, doi: 10.5194/isprsannals-II-5-57-2014.

[29] M. Khoshboresh-Masouleh and R. Shah-Hosseini, “A Deep Learning Method for Near-Real-Time Cloud and Cloud Shadow Segmentation from Gaofen-1 Images,” *Computational Intelligence and Neuroscience*, Oct. 29, 2020. https://www.hindawi.com/journals/cin/2020/8811630/ (accessed Nov. 22, 2020).

[30] D. G. Lowe, “Distinctive Image Features from Scale-Invariant Keypoints,” *Int. J. Comput. Vis.*, vol. 60, no. 2, pp. 91–110, Nov. 2004, doi: 10.1023/B:VISI.0000029664.99615.94.