CAMERA CALIBRATION FOR
UNMANNED AERIAL VEHICLE MAPPING

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ABSTRACT

Unmanned Aerial Vehicle (UAV) can be used to acquire highly accurate data in deformation survey and low-cost digital cameras are commonly used in UAV mapping. Thus, camera calibration is considered important in high-accuracy UAV mapping using low-cost digital camera. The main focus of this study is to calibrate UAV camera at different camera distances and to assess the accuracy of the image mapping. The scope of this study includes camera calibration for short and long interval range and UAV image mapping accuracy assessment using calibration parameters of different camera distances. The camera distances for the image calibration acquisition and mapping accuracy assessment were 2, 3, 4, 5, and 6 metres for the short interval range using the Sony F828 camera, and 1.4, 15, 25, and 55 metres for the long interval range using Sony NEX6. The study was conducted on a flat football field of about 2,500 square metres and in the 3D Measurement Laboratory, both located in Universiti Teknologi Malaysia. The large calibration field and a portable calibration frame were used as the tools for the camera calibration and for checking the mapping accuracy at different camera distances. Australis software was used to perform the camera calibration and image mapping processes. The results show that camera distance changes the camera calibration parameters, i.e. principal point (xp, yp), lens distortion (k_1, k_2, k_3, p_1, p_2), and affinity (b_1). From different camera distances in calibration process, only specific camera distance resulting the best highly accurate UAV mapping, which can achieve millimetre and sub-millimetre levels. In conclusion, camera calibration using UAV can be done at several distance intervals to choose the best camera parameters for highly accurate UAV mapping.

ABSTRAK

Pesawat udara tanpa pemandu (UAV) boleh digunakan bagi memperolehi data yang berketepatan tinggi dalam ukur deformasi, dan kamera digital kos rendah biasanya digunakan dalam pemetaan UAV. Justeru, kalibrasi kamera dianggap penting untuk pemetaan UAV berketepatan tinggi menggunakan kamera digital kos rendah. Fokus utama dalam kajian ini adalah melakukan kalibrasi kamera UAV pada jarak kamera yang berbeza dan menilai ketepatan pemetaan bergambar. Skop kajian ini merangkumi kalibrasi kamera pada sela jarak kamera yang pendek dan panjang dan penilaian ketepatan dalam proses pemetaan UAV bergambar menggunakan kalibrasi parameter pada jarak kamera yang berbeza. Jarak kamera untuk perolehan gambar kalibrasi dan penilaian ketepatan pemetaan adalah 2, 3, 4, 5, dan 6 meter untuk jarak sela pendek menggunakan kamera Sony F828, dan 1.4, 15, 25, dan 55 meter untuk jarak sela panjang menggunakan kamera Sony NEX6. Kajian ini dijalankan di kawasan padang bola yang rata bersaiz 2,500 meter persegi dan di dalam makmal pengukuran 3D dimana kedua-duanya adalah dalam kawasan Universiti Teknologi Malaysia. Padang kalibrasi besar dan kalibrasi kamera mudah alih adalah alat yang digunakan untuk kalibrasi kamera dan pemeriksaan ketepatan pemetaan pada pelbagai jarak kamera. Perisian Australis digunakan bagi melakukan kalibrasi kamera dan proses pemetan bergambar. Hasil kajian menunjukkan jarak kamera mengubah parameter kalibrasi kamera iaitu titik utama (xp, yp), herotan kanta (k_1, k_2, k_3, p_1, p_2), dan afiniti (b_1). Daripada jarak kamera yang berbeza dalam proses kalibrasi, hanya jarak kamera yang spesifik menghasilkan ketepatan pemetaan UAV yang terbaik, iaitu mencapai tahap milimeter dan sub-milimeter. Kesimpulannya, kalibrasi kamera menggunakan UAV boleh dilakukan pada beberapa sela jarak kamera untuk memilih parameter kamera yang terbaik bagi menghasilkan pemetaan UAV yang berketepatan tinggi.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Photogrammetry is an indirect measurement method derived from images of an object, where the object itself can be recognized by its location, shape, and size (Gruen *et al.*, 2009). The term "close-range photogrammetry" is used to describe the technique of when the extent of the object to be measured is below 100 meters and the cameras are positioned close to it (Atkinson, 1996).

Unmanned Aerial Vehicle (UAV) photogrammetry is different from close-range photogrammetry in their distance to the object (Kerle *et al.*, 2008). According to Eisenbei (2009), UAVs can be used as a new photogrammetric measurement tool. Table 1.1 shows the differences between aerial, close-range, and UAV photogrammetry.

Table 1.1: Photogrammetry feature classification (Kerle *et al.*, 2008)

	Aerial	Close-Range	UAV
Planning	(semi-) Automatic	Manual	Automatic-manual
Data acquisition / Flight	Assisted / manual	Autonomy / assisted / manual	Autonomy / assisted / manual
Size of area	km^2	mm^2–m^2	m^2–km^2
Image resolution	cm–m	mm–dm	mm–m
Distance to the object	100m–10km	cm– ~300m	m–km
Orientation	Normal case, recently also oblique	Normal / oblique	Normal / oblique
Absolute accuracy of the initial orientation values	cm–dm	mm–m	cm–10m
Image block size / number of scans	10–1000	1–500	1–1000
Special application (with examples) and features	Large-scale areas (mapping, forestry, glaciology, 3D-city modelling)	Small-scale areas and objects (archaeological documentation, 3D modelling of buildings)	Small and large scale areas (archaeological documentation, monitoring of hazards, 3D modelling of buildings and objects)
		Architectural and industrial photogrammetry	Applied in inaccessible areas and to dangerous objects
	Aerial view	Terrestrial view	Aerial view
			Real-time application (monitoring)

The UAV photogrammetry growth depends on the general development of science and technology. For the last decade, research on UAVs has increased a lot in terms of the system, sensor integration, and data processing, in addition to being applied in different scientific disciplines such as robotics, computer vision, and geomatics (Sauerbier *et al.*, 2011).

The development of UAV camera calibration platform is a fragment of the evolving photogrammetry technology. There are dozens of aerial photo calibration targets—curious land-based two-dimensional optical artefacts used in the development of aerial photography and aircraft across the United States of America (USA) (CLUI, 2013). Thus, the UAV camera calibration is part of the calibration procedure for mapping purpose. Although in Malaysia, large calibration fields for aerial camera calibration are not as common as in countries like the USA, this research develops a large UAV camera calibration platform to answer its objectives. Figure 1.1 shows a large calibration field at Eglin Air Force Base, Florida, USA.

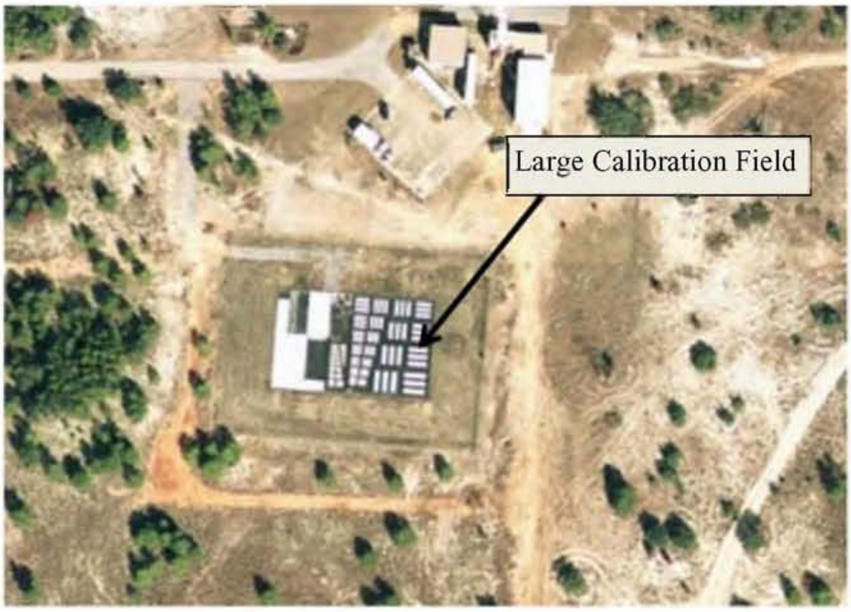

Figure 1.1: A tri-bar array aerial calibration field in USA (CLUI, 2013)

1.2 Problem Statement

UAVs can be used to acquire aerial photographs of a small area using a digital camera. This technique can be used as an alternative to the conventional photogrammetric technique due to its advantages in terms of time, cost, and weather constraint. However, the camera calibration needs to be considered in the UAV photo mapping process. An accurate determination of the interior orientation parameters is needed for the calibration of the camera. In order to gain accurate calibration results, the altitude of the UAV camera mapping must be similar to the distance of the camera calibration (Pérez *et al.*, 2011).

Unmanned Aerial Vehicles (UAV) are able to to acquire high-accuracy UAV mapping such as in deformation survey, and low-cost digital cameras are commonly used in UAV mapping. Hence, camera calibration is considered important and needs to be studied to obtain highly accurate UAV mapping using low cost camera. Lichti and Qi (2012) mentioned that the accuracy of the calibration parameters for long camera distances can be improved in UAV mapping. There are many camera calibration techniques that have been developed in the last several years, but only a few involves images acquired using UAVs (Pérez *et al.*, 2011).

The calibration process often uses close-range calibration in laboratory condition to acquire the camera parameters as the prerequisite for the mapping process. There are many recent studies on calibration techniques for short camera distance such as by Sauerbier *et al.* (2011), Chiang *et al.* (2012), Tahar (2012), Deng and Li (2015), Jimenez and Agudelo (2015), and Zhou and Liu (2015). On the other hand, research on camera calibration with long object distance has already been done by Mohamed and Klaus-Peter (1999), Liu *et al.* (2011), Pérez *et al.* (2011), Rehak *et al.* (2013), and Skaloud *et al.* (2014). These researches focus on a single long camera distance calibration and compare it to laboratory condition, then the accuracy of the single UAV mapping on single camera calibration parameters are assessed and compared to the laboratory result.

This study explores and extends the calibration of non-metric cameras for several distances in short interval range and long interval range. Based on the literature review, the analysis of calibration parameter values for camera calibration in several camera distances are not the emphasis of other researches. Furthermore, these researchers do focus much on assessing the accuracy of mapping between calibration parameters at different camera distances.

Hence, the research gap zeroed on in this study is camera calibration value analysis and mapping accuracy assessment using several camera parameters at different camera distances. In other words, the difference in the camera calibration parameter values from different UAV flying heights (camera distance) and the accuracy of several heights of UAV mapping using calibration parameters of different camera distances were being analyzed.

1.3 Aim and Objectives of Study

The aim of the research was to investigate the relationship between different camera calibration parameters and the UAV image mapping accuracy, and to develop a UAV camera calibration method for various distances. The specific objectives of the research are below:

1. To analyze the difference in camera calibration parameter values from different UAV flying heights (camera distances).
2. To evaluate the accuracy of UAV image mapping from several flying heights using the calibration parameters of different camera distances.

1.4 Research Questions

In order to fulfil its objectives, this research was carried out to answer the following five questions.

a) How is the UAV camera calibration for long and short camera distances developed?
b) Do UAV camera parameter values differ with respect to camera distance?
c) What is the correlation between camera distance and camera parameter value?
d) Does field camera calibration using the same UAV flying height for mapping provide better mapping accuracy?
e) What is the relationship between camera calibration parameters and UAV image mapping accuracy?

1.5 Scopes of Study

The scope of the study includes UAV camera calibration and image mapping accuracy assessment. The cameras used were Sony F828 and Sony NEX5. The UAV used in this study was a rotary wing (Octocopter) with Sony NEX5 mounted on it. It has the ability to vertically take off and land with autonomous and semiautonomous control capacities; provides position hold and autonomous waypoint navigation; and is equipped with GPS, altimeter, and magnetometer to determine the coordinates and heights during the flight. The detection of the camera height is important for camera calibration in different flying heights. Manual mode was used in the camera calibration at the calibration field. Eight convergent images with the same geometric position of the camera were used in the study.

The distance aspect in performing camera calibration and mapping accuracy assessment was the main focus of this study. The camera distances were 2, 3, 4, 5, and 6 metres for short interval range using Sony F828 camera, and 1.4, 15, 25, and 55 metres for long interval range using Sony NEX5. The images for camera calibration and mapping accuracy assessment include big calibration fields and a portable calibration frame. The study areas were a square flat area on a hostel football field with the size of about 2,500 square metres (i.e. calibration field) and at the 3D Measurement Laboratory, both located in Universiti Teknologi Malaysia (UTM). Australis software was used in this study to obtain accurate mapping measurement and it is suitable for camera calibration based on the bundle adjustment principle.

In order to obtain good calibration results, the camera images need to cover the whole image area with high sharpness and contrast. White circular targets on black background were used in the experiment for accurate calibration control point as applied by Jean-Nicolas *et al.* (2008), Heikkila (2000), and Sung and Wolfgang (2001), and there were 108 calibration targets used in 3 calibration fields. Each calibration field differs from each other based on the size of the white circular targets. The calibration distances experimented were 15, 25, and 55 metres, while for 1.4-metre camera distance, the portable calibration frame was used. As for the 2, 3, 4, 5, and 6 meters of camera distances for short interval range, the size of the circular targets were already fixed on the portable calibration frame.

The image mapping accuracy assessment for different UAV flying heights was based on the calibration fields and portable calibration frame. Australis software was used to process the short and long range image mapping. Short range image mapping was processed on the same camera distance calibration parameters, while long range image mapping was processed using several camera calibration parameters.

1.6 Contribution of the Study

There are many contributions that this study can offer, some of them are

i. Procedure for camera calibration at different distances in UAV mapping.

   This research outlines a procedure for camera calibration in several camera distances. This calibration procedure will aid in UAV mapping for deformation survey to provide more accurate mapping.

ii. Development of long-range camera calibration platform for UAV cameras.

   The development of a long-range camera calibration platform for UAV cameras will assist in designing the field calibration platform, setting the automated detection of calibration target, and conduction the calibration technique. The long-range camera calibration platform in several camera distances can provide the best camera parameters for better high-accuracy mapping.

iii. Data sets using UAV for UTM mapping project.

This study provides sets of data for UTM mapping project using the Sony NEX 6 UAV camera. The data sets include several camera distance parameters with the accuracy assessment analysis. The best camera calibration parameters may be used to process UTM's mapping area in highly accurate measurements, such as the sloped places for landslide monitoring.

iv. Pilot study for large camera calibration platform in Malaysia like the USA.

There are many aerial photo calibration targets located in the USA (CLUI, 2013). This scenario does not apply to Malaysia. Large-sized calibration fields for UAV camera calibration has not been developed yet in Malaysia. Thus, this study will be a pilot study in developing large camera calibration platform to be used in Malaysia like the USA for mapping purpose.

v. Advantage of low-cost camera for long camera distance deformation survey.

The conventional technique requires high-accuracy UAV cameras for deformation survey. Many UAV users commonly use low-cost digital cameras. The determination of the interior orientation parameters is needed to process the mapping using low-cost cameras in an accurate manner. So, the development of camera calibration for long camera distance deformation survey makes the use low-cost digital cameras feasible.

vi. Option for recent UAV mapping users.

The development of camera calibration with several camera distances provides options for UAV users such as surveyors, remote-sensing users, and any aerial mapping projects. This study would be an advantage for UAV mapping measurement using non-metric cameras such as for deformation survey.

1.7 Research Framework

Figure 1.2 shows the overall research framework for this study.

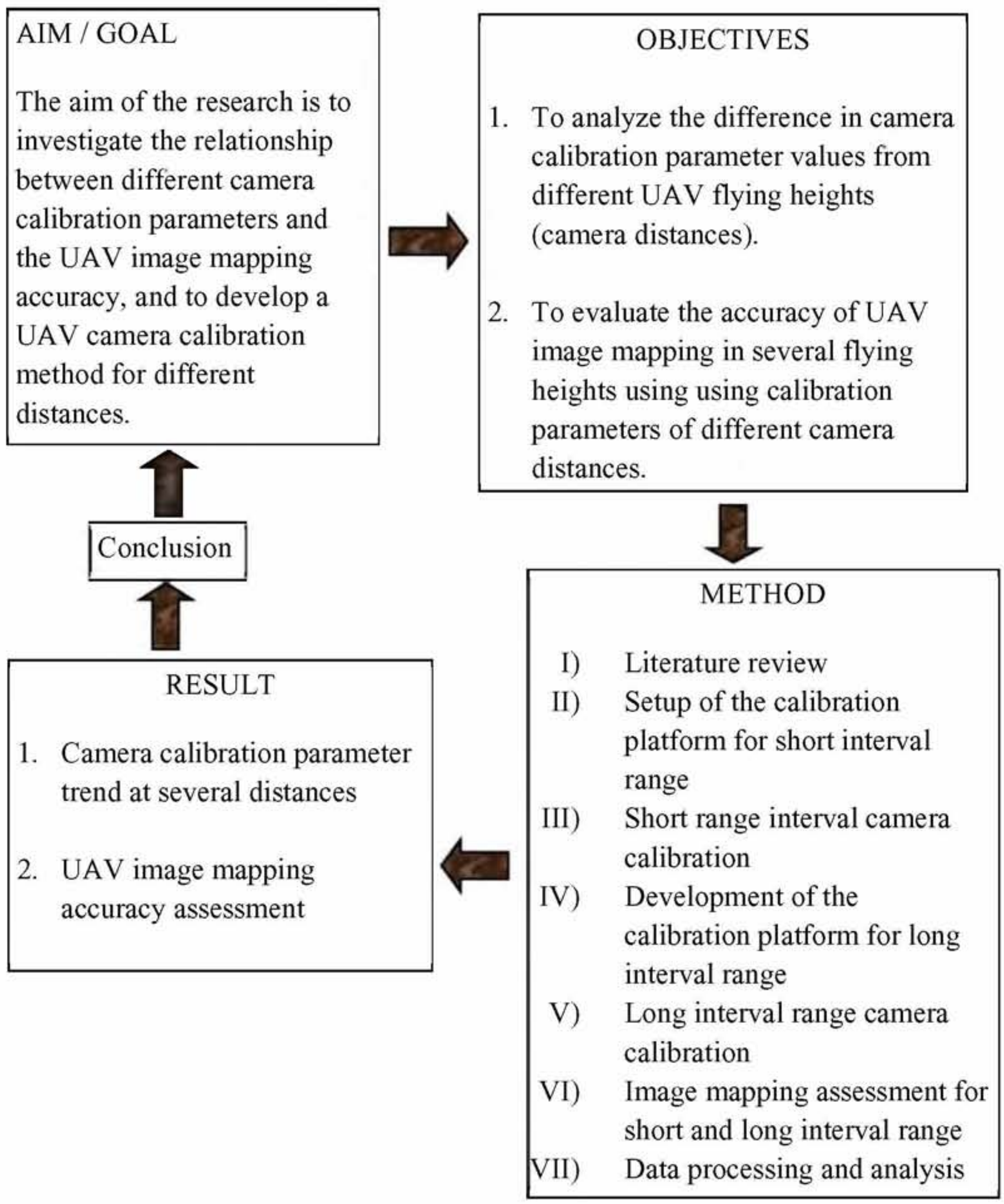

Figure 1.2: Research framework

1.8 Thesis Structure

This thesis contains 5 chapters: the introduction of the research, literature review, research methodology, result and analysis, discussion, and conclusion and recommendation. The contents of the 5 chapters are shown in Table 1.2.

Table 1.2: Thesis structure and content

Chapter 1: Introduction	Background of the study, problem statement, aim and objectives, scope, contribution of the study, and research framework.	
Chapter 2: Literature Review	UAV	Development, classification, and application of UAV.
	Camera calibration component	Camera error source, photogrammetry mapping, concept of camera calibration, bundle adjustment, elements of calibration, software used, and calibration target detection.
	Camera calibration approach	Approaches in UAV camera calibration, indoor camera calibration, outdoor camera calibration, and accuracy assessment.
Chapter 3: Research Methodology	Overview of the current research scenario, short camera distance calibration, development of long camera distance calibration, and data processing.	
Chapter 4: Result and Analysis	Calibration results, camera distance calibration trends, mapping accuracy assessment, relationship between camera calibration of different distances and mapping accuracy.	
Chapter 5: Conclusion and Recommendation	Conclusion based of the research questions and recommendations.	

Chapter 1 is the introduction to the research which has explained the background of the study, problem statement, the objectives, scope, significant of the study, and the research framework. Chapter 2 is the literature review discussing previous works and the area of study for research development. The research methodology in Chapter 3 describes the data collection procedure and the development of the field calibration.

Next, the objectives of the research are answered in Chapters 4. The results and analysis of the findings include calibration results, camera distance calibration trends, mapping accuracy assessment, and relationship between camera calibration at different distances and mapping accuracy, followed by the discussion on the research findings. Lastly, Chapter 5 presents the conclusion of the research according to each research questions and it lists down recommendations for future studies.

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