LOW COST AERIAL MAPPING WITH CONSUMER-GRADE DRONES

S.L. Madawalagama[1], N. Munasinghe[2], S.D.P.J.Dampegama[3], L. Samarakoon[1]
[1] Geoinformatics Centre (GIC), Asian Institute of Technology (AIT), PO Box 04, Klong Luang, Pathumthani 12120, Thailand.
Email: madawalagama@gmail.com, lalsamarakoon@gmail.com
[2]Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka.
Email: mniluka@gmail.com
[3]Survey Department of Sri Lanka, Colombo, Sri Lanka.
Email: dampegama@yahoo.com

KEY WORDS: Photogrammetry, Orthoimage, DSM

ABSTRACT: Drones are innovative equipment which are now being used in geographic mapping as an alternative to high cost traditional photogrammetry and ground surveying. Considering the advantages of surveying with drones, pioneering companies in the geomatics industry like senseFly, Trimble, and Leica, etc. have built survey-grade drones specifically for mapping purposes; but in today's market, there are cheaper consumer-grade drones available. Moving beyond the intentional purpose of these consumer-grade drones, this study was undertaken to identify the potential of using them for mapping purposes. In this study, the Phantom 3 Professional drone was successfully used to map a landscape in Sri Lanka to a horizontal accuracy of 17cm and a vertical accuracy of 28cm. An area of 1.28km^2 was covered by 241 images with an average ground sampling distance of 6.93cm. These high resolution images were processed using Pix4D software to obtain orthoimages and a digital surface model (DSM) of the area. Ground control points surveyed by a differential global navigation satellite system (GNSS) were used to access the accuracy of the products. The results were further compared with a survey-grade drone and other common mapping techniques available today to further understand the benefits and limitations. It was shown that a GPS-enabled consumer-grade drone with an armature camera is a low cost but yet accurate and powerful mapping device which makes it possible to provide necessary aerial maps, DSMs etc. for many applications.

1 INTRODUCTION

Drones are defined as flying robots in simple terms which are formally known as unmanned aerial vehicles (UAV). The main distinctive characteristic of drones is their design to be operated with no onboard pilot. They are operated by remote control or can fly autonomously through software controlled flight plans.

Drones were initially invented for military purposes but these exciting equipment are now being used for civilian applications like photography, filmography, journalism, delivery systems, structural safety inspections and many others. Usage of drones in the field of geomatics has been explored in recent studies and they are now being used as a platform for photogrammetric and LiDAR data collection. The emerging technology of drones can be used in geographic mapping as an alternative to high cost traditional photogrammetry and ground surveying.

Remotely sensed data obtained from drones are suited for various applications of mapping in both 2D and 3D domains. As described in the literature (Nex & Remondino, 2014; Zongijan, 2008), fields such as environmental surveying, forestry and agricultural mapping, archeology and cultural heritage mapping, disaster mapping and traffic monitoring are typical fields for aerial mapping and are highly compatible with drones. Also drones can be used as a mapping platform for a number of critical scenarios such as emergency response, reconnaissance surveying, rapid mapping, etc. where immediate access to 3D geo-information is necessary. In view of these applications, commercially available survey-grade drones like senseFly eBee and Trimble UX5 have now been developed.

Compared to traditional remote sensing methods, there are significant advantages with drones in the application to mapping (Dustin, 2015). Drones provide an inexpensive platform for aerial data collection with no requirement of onboard personnel to carry out flight operations. They are inherently safe and can reach places where manned flight is difficult or dangerous to access.

Drones establish a powerful alternative for traditional data capture in a mapping application with high spatial and temporal resolution. They can fly at low altitudes enabling the collection of data with a high amount of detail and can be deployed rapidly as soon as there is a requirement. The limitations of satellites and traditional aerial remote sensing with restricted maneuverability and limited availability (Zongijan, 2008) can be overcome with drones but there are certain limitations such as low range and endurance. Conventional space-borne remote sensing still has some advantages and the tremendous improvements in very high-resolution satellite imagery are closing the gap between airborne and satellite mapping (Zongijan, 2008).

Despite there being drones designed for the specific application of mapping, there are consumer-grade drones which are popular among the community. Consumer-grade personal drones are currently a hobbyist's item most often used for aerial photography, but there is a high potential for their use in mapping. Drones are now receiving a lot of attention for consumer application since the costs are very affordable. The costs have been drastically reduced with the availability of low cost navigation and control devices as well as imaging sensors. Today's consumer-grade drones are equipped with a GNSS navigation system and inertial measurement unit (IMU) which fulfill the essential requirement of automated aerial surveys as the drone is required to follow a pre-determined flight plan. Hence, accurate determination of the position of the aircraft by the GNSS system and its orientation by the IMU is vital for accurate aerial surveying. The payload of consumer-grade drones is either fixed with a digital camera or it can provide facilities to carry an external instrument, mainly an imaging device.

The recent technological advancements and availability of GNSS systems (such as GPS/GLONASS), IMUs and digital compact cameras have introduced great potential for using inexpensive consumer-grade drones as mobile mapping systems; they provide a low-cost alternative to survey-grade drones which further reduces the costs compared to traditional aerial mapping. This study was undertaken to assess the applicability and accuracy of low cost consumer-grade drones for aerial mapping.

2 STUDY AREA AND EQUIPMENT

The study area in Colombo 7, Sri Lanka was chosen because previously surveyed ground control points were available. The study area is approximately 1.28 km^2 in size, and is situated in the commercial capital of Sri Lanka which is a high density urban area. The area was aerially surveyed with a Phantom 3 Professional consumer-grade drone and senseFly eBee survey-grade drone. To meet the primary objective of this study, the accuracy of the results, costs and overall complexity of the two different systems are compared with the specific focus of the photogrammetric performance.

Both the senseFly eBee and Phantom 3 Professional drone fall into the micro-UAV category (Bendea et al., 2008) according to their weight, endurance and range. The senseFly eBee is a survey-grade fixed wing drone manufactured by senseFly Ltd. in Switzerland. It has become popular as a professional mapping drone with the geomatics industry for various applications. The eBee drone comes with a ground station and dedicated flight planning and management software, eMotion. The camera should be separately mounted as it should be chosen to suit the purpose of the survey. The Phantom 3 Professional drone is a quadcopter by Da-Jiang Innovations Science and Technology Co., Ltd. (DJI) which comes with a factory built 4K camera with 3-axis gimbal stabilizer. The controller is an easy to operate remote device which works with a smart phone. The Phantom 3 Professional drone was chosen as the consumer-grade drone in this study because of its affordability and popularity among the civilian community for photography.

Table 1. Specification of drones used in the study

GENERAL		
Vendor	DJI	senseFly
Drone	Phantom 3 Professional	eBee
Type	Quadcopter	Fixed wing
Weight	1280 g	690 g
Charging time (1 battery)	~1 hour	~1 hour
Camera	Sony EXMOR 4K RGB	Canon PowerShot S110 RGB
Maximum speed	16 ms^{-1}	25 ms^{-1}
Price	USD 999	USD 12,000

MAPPING		
Flying time on a single deployment	18 mins (mapping) 23 mins (manual control)	45 mins (mapping)
Maximum flying height	300m AGL(mapping)	1,000m AGL (mapping)
Maximum coverage for a single deployment	~0.9 km^2	12 km^2

Figure 1. Phantom 3 Professional drone (left) & senseFly eBee drone (right)

3 PHOTOGRAMMETRIC GROUND CONTROL

Ground control points (GCP) are points of known coordinates in the area of interest. These coordinates have been measured with traditional surveying methods or have been obtained by other sources (LiDAR, older maps of the area, Web Map Service). A ground control is required to calculate the scale, orientation, and absolute position information of the products for increased accuracy (Wolf & Dewitt, 2000). It is possible to obtain georeferenced products even without GCP as the images are geocoded by the GPS device of the drone, but it is highly recommended to have a significant number of GCP to obtain reliable products. GCP increase the absolute accuracy of a project, placing the model at the exact position on the Earth.

In modern surveying applications, kinematic GNSS positioning is identified as the most efficient and effective way of establishing ground control as it meets the required aspects in most scenarios (Wolf & Dewitt, 2000). For this study, pre-existing survey data were used to establish the ground control, which was measured with the latest continuously operating reference station (CORS) GNSS technology introduced very recently in Sri Lanka. A CORS network is a virtual real time kinematic (RTK) correction broadcasting network comprising several permanent ground located high accuracy GNSS receivers (Snay & Soler, 2008). It has a high accuracy at 8mm+0.5ppm RMS in planimetric measurements and 15mm+0.5ppm RMS in vertical measurements. The availability of these types of networks eliminates the necessity of having ground marked reference points for control surveying. Location data observed by several high accuracy GNSS receivers, commonly known as CORS, are processed at a central server. Processed data will be broadcast to RTK receivers via GPRS allowing users to obtain high accuracy in positioning coordinates.

The GCP are selected from the total of 79 measured points which meet the general criteria to establish a photogrammetric control. In general, images of acceptable photographic control points must lie in favorable locations in the photographs and should be sharp, well defined, and positively identified on the photographs. The GCP should be placed homogeneously in the area of interest. A minimum number of 5 GCP is recommended and 5 to 10 GCP are usually enough, even for large projects (Agisoft, 2013). More GCP do not contribute significantly to increasing the accuracy. However, in cases where the topography of the area is complex, then more GCP will, indeed, lead to a better and more accurate reconstruction.

Figure 2. Sample GCP

4 FLIGHT PLANNING AND IMAGE ACQUISITION

Designing and executing a good image acquisition plan is the most important part of any aerial photogrammetric project as the ultimate success of any photogrammetric project depends more upon good quality photography than on any other aspect (Wolf & Dewitt, 2000). If the collected dataset is insufficient in quality, it will lead to poor results and even a total failure in processing. To avoid redoing field work which is expensive and time consuming, it is essential to plan the work correctly according to the requirements.

A flight plan generally consists of two items: a flight map, which shows where the photographs are to be taken, and specifications, which outline how to take them, including specific requirements such as the camera requirements, scale, flying height, end lap, side lap, and tilt and crab tolerances. A flight plan which gives the optimum specifications for a project can be prepared only after careful consideration of all the many variables which influence aerial photography. But with today's flight planning software, a flight map is generated automatically as only the vital parameters are given to the software manually. These include the area of interest, flying altitude, overlap, maximum speed, etc. The flying height and image overlap are considered to be the vital parameters in every flight plan. The relative accuracy capabilities in photogrammetric mapping, whether planimetric or vertical, depend upon many variables, but the most important is the flying height above ground. The ground sampling distance varies with the flying height so it has a direct influence on the achievable accuracy and the amount of detail in the final products.

In modern photogrammetric processing, the entire process is based on automatically finding thousands of common points between images. These points are called key points. When there is a high overlap between 2 successive images, the common area captured is larger and more key points can be matched together. The more key points there are, the more accurately 3D points can be computed. The image overlap parameter should be determined with an awareness of the terrain geometry. Considering the general recommendations, an overlap of 80% for the side and end overlap is used.

Table 2. Flight planning parameters

Drone	Phantom 3 Professional	eBee
Flying height	160m AGL	150m MSL
Forward overlap	80%	80%
Side overlap	80%	80%
Maximum speed	15 m/s	auto
Maximum mapping time	17 min	35 min

The flights were done in full autonomous mode for both drones with continuous monitoring. The availability onboard of the GNSS/INS navigation devices in both drones makes it possible for full autonomous flight (take-off, navigation, and landing) and guidance of image acquisition according to the flight plan.

4.1 Flight Planning Software

The senseFly eBee drone comes with dedicated flight planning and management software called eMotion. It is used to plan, simulate, monitor and control the mapping flights of eBee drones and it supports all eBee standard, eBee RTK and eBee Ag drones (senseFly, 2015). The software operates in the Windows environment and is used for flight planning simulation, flight monitoring and in-flight control. The software comes with features like automatic flight planning, automatic calculation of flight altitude, real time flight status monitoring, one click emergency maneuvers, etc.

Unlike survey-grade drones, other consumer-grade drones do not come with photogrammetric flight planning software, but there are third party flight planning applications developed for some consumer-grade drones. For flight planning with the Phantom 3 drone, such an application named Map Pilot for DJI is used. Map Pilot for DJI is a software program for flight planning, mission management and the actual mission flight operation for DJI drones. Currently the software operates in the iOS environment for Apple iPhone and iPad devices. This app was developed by Maps Made Easy using the DJI SDK for easy data acquisition for aerial mapping with drones. The app combines advanced features like automatic flight path creation, overlap management, speed management, multi-flight coordination, multi-battery management, base map caching for offline operations, etc., yet it preserves an easy to operate environment.

Both the flight planning and management software used for survey-grade and consumer-grade drones require minimum manual computations which provides the capability for the user to focus only on onsite issues. The automated flight management software works without a flaw to design and execute the flight plan.

5 PHOTOGRAMMETRIC PROCESSING AND GROUND CONTROL

5.1 Point Cloud and Mesh Generation

Once a set of images has been oriented, the next step is surface reconstruction by generating the point cloud and mesh. Starting from the known exterior orientation and camera calibration parameters, a scene can be digitally reconstructed by means of automated dense image matching techniques. A powerful image matching algorithm in the software is able to extract dense 3D point clouds with a sufficient resolution to describe the object's surface. The generated point cloud is then triangulated to create a mesh.

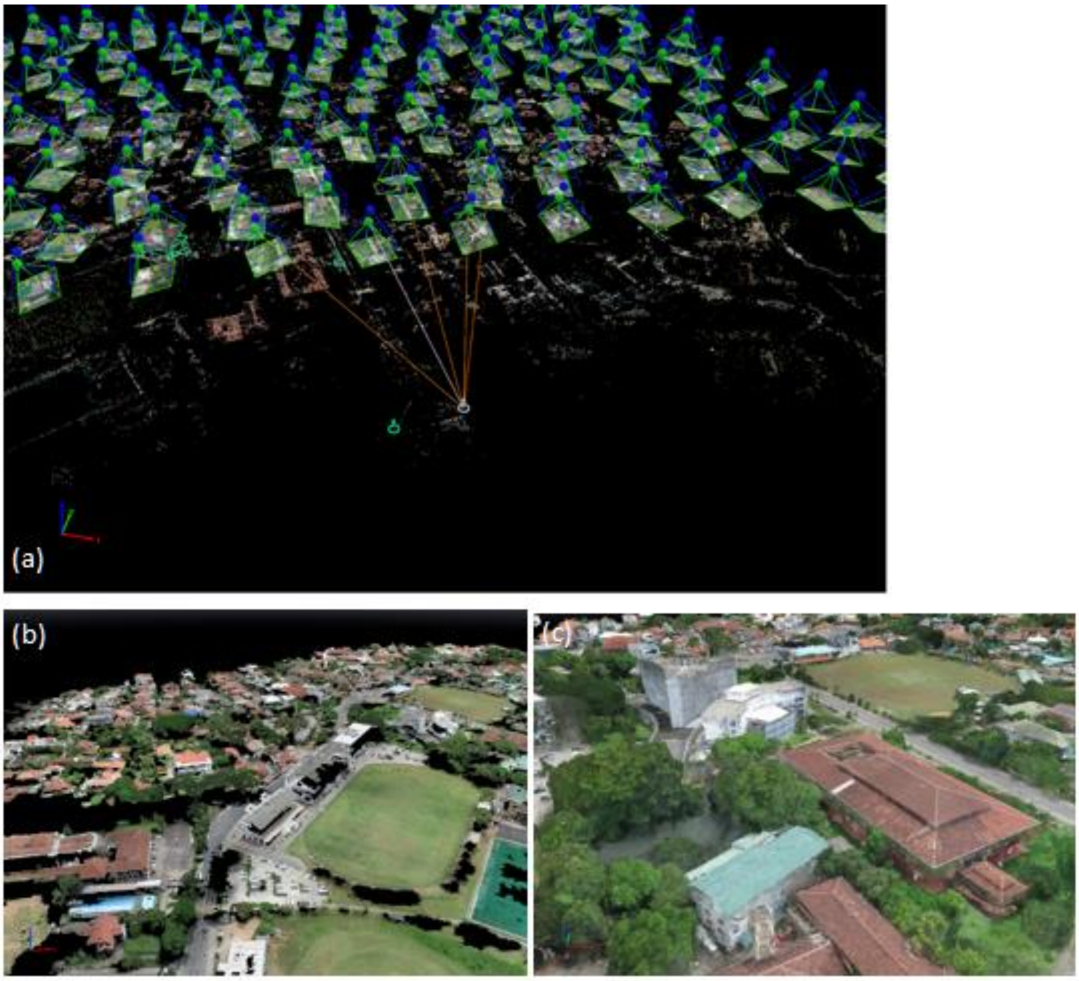

Figure 3. (a) Sparse point cloud and relationship between images, (b) Dense point cloud, (c) Mesh

5.2 DSM and Orthophoto Generation

A digital surface model (DSM) is a digital 3D representation of an area by elevation (Uysal et al., 2015). Pix4D allows the generation and visualization of a digital surface model after generating the point cloud. A DSM represents a surface model as a regular grid of height values. Each pixel of the raster image is assigned to represent the elevation of the ground location at that pixel. The DSM can be generated from a dense point cloud, and the most accurate results are calculated based on the dense point cloud data. Additionally, the contour lines can be calculated for the model.

An orthoimage is generally a photo-map which is geometrically corrected so that the scale is uniform. Orthoimages are commonly used in aerial photographic survey measurements, but it may be also useful when a detailed view of the object is required. An orthoimage can be directly used for 2D measurements for calculating distances and areas and can be used in geographic information systems. Pix4D allows the projection of an orthomosaic onto the desired coordinate system of the user. The processing for our final orthoimages and DSM was done both using ground control points and without ground control points.

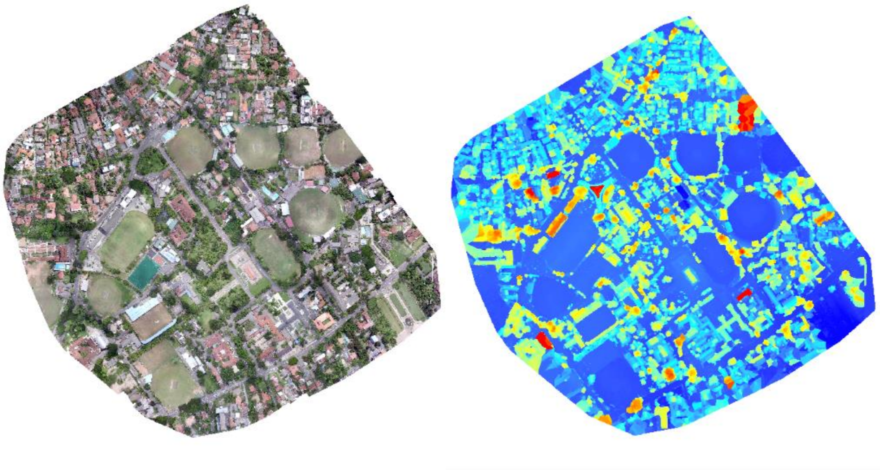

Figure 4. Orthoimage (left) and DSM (right) created by images from Phantom 3

5.3 Geolocation Accuracy

The results of the 3D mapping with both drones achieved a remarkable sub-meter level of accuracy by processing with the GCP which fulfils most of the aerial mapping requirements. Accuracy is computed by comparing the point locations of the products with the ground truth data.

Table 3. Geolocation accuracy

	Without GCP		With GCP	
	Planimetric accuracy (m)	Height accuracy (m)	Planimetric accuracy (m)	Height accuracy (m)
Phantom 3	1.750	16.098	0.174	0.275
eBee	2.187	8.283	0.274	0.132

Even without using GCP it was possible to obtain georeferenced aerial maps by using only images with relevant exposure locations obtained from the drones' GNSS devices. The accuracy of the products obtained without taking account the GCPs is low for both drones because the GNSS units of drones do not provide a high level of accuracy. When examining the height accuracy of the products obtained without taking account of the GCP, calculation of the mean error and standard deviation of error shows that there is a significant systematic error. It is suspected that the well-known problem of low accuracy in height observation with the GNSS system induced a shift for measurement of heights in both drones.

The accuracy of the final products which are orthoimages and a DSM is ultimately dependent upon the characteristics of the imagery which in turn depend on several factors such as camera quality (geometric and radiometric quality / photographic resolution), platform stability, successful planning and execution of the flight plan and the terrain type. The modern photogrammetric processing combined with state of the art computer vision algorithms (Hartley & Mundy, 1993) makes it possible to obtain mapping products even with cameras with high distortion such as fish eye lens cameras. For this study, both cameras used for acquiring images are consumer-grade cameras with a low focal length. It is a known factor that low focal length cameras introduce significant geometric distortions and effects such as a rolling shutter but the processing software successfully models these distortions and is able to produce an accuracy level down to 17 cm. With the advancement of today's technology, cameras like the DSLR and mirrorless provide very high image quality but yet are very much cheaper than traditional photogrammetric cameras. It is advisable to use such types of cameras for aerial surveying with drones for applications that require a higher level of accuracy.

6 COMPARISON OF DRONES

The accuracy assessment of this study shows slightly better planimetric accuracy for the Phantom 3 compared to the eBee when direct georeferencing is used, but the accuracy for the height is better in the eBee. It can be clearly concluded that survey-grade drones as well as inexpensive consumer-grade drones provide remarkable accuracy in 3D aerial mapping with the aid of the state of the art photogrammetric processing which is available today.

Compared with survey-grade drones, the most significant advantage of consumer-grade drones is the price. The price tag of the Phantom 3 drone is 12 times lower than that of the eBee, giving it a very low price compared with other survey-grade drones also.

Another drawback of the senseFly eBee is the combination of a lightweight fixed wing design and a fixed camera mount. Fixed wing designs perform fairly well in most windy conditions but this ultra-light platform had a difficult time taking stable pictures in wind and turbulence. For this study, near vertical photographs provide the best geometric conditions but some pictures taken from the eBee were tilted from the vertical plane due to heavy winds. We had a successful mapping mission with the Phantom 3 in these windy conditions due to the gimbal stabilization of the camera.

When it comes to simplicity, the Phantom 3 has better advantages. Rotary wing drone platforms like the Phantom 3 can take-off and land vertically, thus no runway area is required, while the fixed wing eBee requires an open space to operate. The Phantom 3's simple design of the flight controller with a plug and play functionality enables quick and easy operations. When the flight controller is combined with the flight management application, the data acquisition for aerial mapping becomes highly automated and an easy task while operation of the eBee requires specific training. The UAV platform of the Phantom 3 is extremely user friendly and can be operated by an inexperienced operator in a short period of time, although prior knowledge about aerial mapping is essential for any drone operation to plan, acquire data and successfully process the data.

The main advantage of the eBee's design is the safety. UAVs will always involve an element of risk, but the senseFly eBee's lightweight design minimizes those risks as effectively as possible. Flight time is also a prime reason for choosing fixed wing drones over a quadcopter. In aerial mapping the eBee and other fixed wing drones have better endurance compared to rotary wing drones like the Phantom 3, for which it was necessary to map the area in four successive flights as a change of battery was required. Fixed wing mapping drones consume less power, so are able to cover a large area in a single deploy.

Table 4. Comparison of Phantom 3 & eBee drones considering the advantages in mapping

Advantages of Phantom 3	**Advantages of eBee**
• Low cost • Stabilized imagery • Wind resistance • Available in the worldwide market • Easy & affordable maintenance • Simple to Operate • Live visual video feedback	• Specifically designed for aerial mapping – all necessary apparatus provided • Able to swap the imaging sensor according to mapping requirement • Minimum safety risk • High flying altitude • High mapping time

7 CONCLUSION

This study presents an overview of using inexpensive drones for aerial mapping complementary to traditional photogrammetry, as well as modern survey-grade drones. Regardless of the low cost, consumer-grade drones provide a platform capable enough to be applied for accurate aerial mapping which used to be a costly and time consuming task a decade ago. In this study, photogrammetric products were obtained with planimetric accuracy of 17 cm and vertical accuracy of 28 cm by a Phantom 3 consumer grade drone which is equip with an amateur camera. The selected study area was successfully covered by both consumer-grade and survey-grade drones, covering most of the study area with 5 or more photographs. As the drones combine with the GNSS and IMU devices, the flying operation is automated. The study proves that inexpensive drones can provide highly accurate and high resolution products with a very high level of automation which suits many geomatics applications.

8 REFERENCES

Agisoft. (2013). Agisoft PhotoScan user manual. Professional edition, version 0.9. 0. AgiSoft LLC (Pub), Calgary, CA.

Bendea, H., Boccardo, P., Dequal, S., Tonolo, F.G., Marenchino, D., & Piras, M. (2008). Low cost UAV for post-disaster assessment. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37(Part B), 1373–1379.

Dustin, M. C. (2015). Monitoring Parks with Inexpensive UAVs: Cost Benefits Analysis for Monitoring and Maintaining Parks Facilities. University of Southern California.

Hartley, R. I. & Mundy, J. L. (1993). Relationship between photogrammetry and computer vision. Optical engineering and photonics in aerospace sensing (pp. 92–105). International Society for Optics and Photonics.

Nex, F. & Remondino, F. (2014). UAV for 3D mapping applications: a review. Applied Geomatics, 6(1), 1–15.

Snay, R. A. & Soler, T. (2008). Continuously operating reference station (CORS): history, applications, and future enhancements. Journal of Surveying Engineering, 134(4), 95–104.

senseFly (2015). senseFly Swinglet.

Uysal, M., Toprak, A., & Polat, N. (2015). DEM generation with UAV Photogrammetry and accuracy analysis in Sahitler hill. Measurement, 73, 539–543.

Wolf, P. R. & Dewitt, B. A. (2000). Elements of Photogrammetry: with Applications in GIS (Vol. 3). McGraw-Hill New York.

Zongijan, L. (2008). UAV for mapping–low altitude photogrammetric survey. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B, 1.