TOPOGRAPHIC MAP UPDATING USING RASTER BASED DATASETS

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DEDICATION

I would like to dedicate this thesis to my mother and my late father, who taught me to strive for the best in everything I do. It is also dedicated to my husband and my children for being understanding and supportive especially during trying times in completing this thesis.

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ABSTRACT

Aerial images from conventional aerial photogrammetry technique has been used to produce photogrammetric map. Topographic map updating is necessary when there are changes on the ground surface. The Department of Survey and Mapping Malaysia (DSMM) policy states that topographic map scale of 1:50000 and 1:10000 need to be updated in three, five and ten years for urban, developed and rural area respectively especially for man-made features and infrastructures. Updating topographic map using conventional aerial photogrammetry is tedious, timely and costly. However this problem could be solved using other data sources. The aim of this research is to update the 1:10000 topographic map in the area of study using WorldView-3 satellite imaging, Unmanned Aerial Vehicle (UAV) data and Digital Elevation Model (DEM) from Synthetic Aperture Radar (SAR). The study was conducted in Putrajaya where certain areas that required updates on the existing topographic map published in 2012 were identified. The assessment for coordinate and orthometric height were carried out by calculating the Root Mean Square Error (RMSE) for each component. Comparison between orthometric heights showed the RMSE of ±0.320 m and ±1.323 m for difference between check points (CP) and UAV and difference between SAR and UAV, respectively. The RMSE values for the planimetric coordinates differences between conventional aerial photogrammetry and CP, UAV and CP and WorldView-3 and CP were ±1.112 m, 0.892 m and 1.160 m, respectively. Lower RMSE indicated higher accuracy. In terms of cost and time comparison, UAV showed cost effectiveness in data acquisition and processing. All data sets were in compliance with large scale topographic map updating in accordance with DSMM's Quality Management System Profile MS ISO 9001:2015. The study indicates that UAV is the most economical tool to be used in updating a small area.

ABSTRAK

Imej udara dari teknik fotografi udara konvensional telah digunakan untuk menghasilkan peta fotogrametri. Pengemaskinian peta topografi diperlukan apabila berlaku perubahan pada permukaan tanah. Polisi Jabatan Ukur dan Pemetaan Malaysia (JUPEM) telah menyatakan bahawa peta topografi berskala 1:50000 dan 1:10000 perlu dikemaskini pada setiap tiga, lima dan sepuluh tahun masing-masing bagi kawasan bandar, membangun dan luar bandar terutama bagi butiran buatan manusia dan infrastruktur. Pengemaskinian peta topografi menggunakan fotogrametri udara konvensional adalah menjemukan, mengambil masa yang lama dan melibatkan kos yang tinggi. Masalah ini boleh diatasi dengan mengunakan sumber data lain. Tujuan penyelidikan ini adalah untuk mengemas kini peta topografi berskala 1:10000 di kawasan kajian dengan menggunakan imej satelit WorldView-3, pesawat udara tanpa pemandu (UAV) dan Model Ketinggian Berdigit (DEM) dari Radar Apertur Sintetik (SAR). Kajian ini dijalankan di Putrajaya di mana kawasan tertentu telah dikenal pasti yang perlu dikemas kini dari peta topografi sedia ada yang diterbitkan pada tahun 2012. Analisis terhadap koordinat dan ketinggian ortometrik dijalankan dengan mengira ralat min punca kuasa dua (RMSE) untuk setiap komponen. Hasil perbandingan ketinggian ortometrik telah menunjukkan RMSE sebanyak ±0.320 m antara titik semakan (CP) dan UAV, manakala RMSE sebanyak ±1.323 m bagi perbezaan antara SAR dan UAV. Nilai RMSE bagi perbezaan koordinat planimetri bagi fotogrametri udara konvensional dan CP, UAV dan CP serta WorldView-3 dan CP adalah masing-masing ±1.112 m, ±0.892 m dan ±1.160 m. Nilai RMSE yang rendah menunjukkan ketepatan yang lebih tinggi. Daripada segi perbandingan kos dan masa, UAV menunjukkan keberkesanan kos dalam pemerolehan dan pemprosesan data. Semua set data adalah mematuhi syarat ketepatan bagi pengemaskinian peta topografi skala besar mengikut Profil Sistem Pengurusan Kualiti JUPEM MS ISO 9001:2015. Hasil penyelidikan menunjukkan bahawa data UAV adalah yang paling ekonomi untuk tujuan mengemas kini kawasan yang kecil.

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LIST OF ABBREVIATIONS

3D	-	Three dimensional
BGSP	-	*Bahagian Geospatial Pertahanan*
CAR	-	Civil Aviation Regulations
CAVIS	-	Clouds, Aerosol, Water Vapor, Ice and Snow
CE90	-	Circular Error at the 90^{th} percentile
CIA	-	Central Intelligence Agency
CP	-	Check Point
DEM	-	Digital Elevation Model
DSMM	-	Department of Survey and Mapping Malaysia
DTM	-	Digital Terrain Model
GCP	-	Ground Control Point
GNSS	-	Global Navigation Satellite System
GPS	-	Global Positioning System
GSD	-	Ground Sample Distance
ICAO	-	International Civil Aviation Organization
LiDAR	-	Light Detection and Ranging
MINDEF	-	Ministry of Defense Malaysia
MPOU	-	*Markas Pemerintahan Operasi Udara*
MSL	-	Mean Sea Level
RMSE	-	Root Mean Square Error
RTK	-	Real Time Kinematic
SAR	-	Synthetic Aperture Radar
UAS	-	Unmanned Aerial System
UAV	-	Unmanned Aerial Vehicle

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Topographic maps are detailed and accurate graphic that represent features on Earth's surface including buildings, roads, railways, administrative boundaries, hydrographic features, and commercial areas. It also shows contour lines that represent elevation. The height of the ground is referring to Mean Sea Level (MSL) and can be drawn at suitable interval depending on the map scale (Natural Resources Canada, 2017).

Topographic map is made to scale and it represents the distance on the map to the actual distance on the ground. Large scale map represents smaller area in greater details. When changes of the features on the ground happen in certain areas, a topographic map should be updated to show the current information possible.

Currently, conventional aerial photogrammetry through large-format digital aerial camera mounted on a conventional aircraft has been used to create topographic map. To use this method, an aircraft needs to be leased. Thus, it will require a big amount of money. In terms of data acquisition, it is not cost effective to update a small area only because it is suitable to capture images of a large area. The maintenance of the camera is also very high.

In Malaysia, Department of Civil Aviation (DCA) under the Ministry of Transportation is in charge of all aviation related matters, including safety and efficiency. It is also responsible ensure that all aviation activities in Malaysia is in accordance to the standard and recommended practices of the International Civil

Aviation Organization (ICAO). According to Civil Aviation Regulations (CAR) 1996, P.U.(A) 139/96; aerial work is an aircraft operation used to provide services in a variety of fields such as in agriculture, photography, construction, surveying, observation and patrol, search and rescue, aerial advertisement, and in other similar activities other than public transport services.

Nowadays, there are other sources of data that can be used to replace the conventional aerial photogrammetry technique. For example, the use of satellite images becomes more useful and convenient for mapping than using aerial images.

Satellite images may vary from high resolution images like Worldview-3, Quickbird and Ikonos where their image resolution is up to 15cm, to low resolution satellite images like Sentinel which gives up to 60 meters in resolution. The performance indexes such as geo-referencing accuracy and mapping capability of high resolution commercial satellite have a qualitative leap. High resolution satellite imagery data has a lot of advantages and they can be used to update the available maps in GIS software packages.

Unmanned aerial system (UAS) is a system where the vehicle flies without a pilot onboard. It is known as autonomous flying where it is equipped with an autopilot system and automatic method that can be used for aerial data acquisition. This system makes it possible to fly at low altitude and under the cloud and could be used in various applications. A compact and high resolution digital camera was used to acquire the aerial images at an altitude in order to achieve high resolution imagery. (Darwin, Ahmad and Zainon, 2014)

Synthetic Aperture Radar (SAR) is a remote sensing technique that uses radar to obtain data by transmitting radiation from its antennas to the surface of an object and the differences of its returned signals represent the information of the surface. SAR has a weather and light independent capability and is suitable for tropical countries. It allows operation in variable weather conditions because the signal can penetrate haze, clouds, fog and rain with a very little attenuation by using suitable operating frequency (Chan and Koo, 2008)

Digital Terrain Model (DTM) is an important feature in topographic map as it represents the height of the area and in a very high demand for many applications. Traditional methods for creating DTM are through land surveying which is very costly and time consuming. After that, photogrammetry takes over and become one of the major methods in generating DTM. Other than that, airborne Light Detection and Ranging (LiDAR) system has become a powerful way to produce a DTM due to the advantages it has in collecting a 3-dimensional information over a large area accurately (Polat and Uysal, 2015). But the disadvantage of LiDAR data is that it is costly.

1.2 Problem Statement

Department of Survey and Mapping Malaysia (DSMM) states that the topographic map update policy should be conducted every 3, 5 and 10 years respectively for city, developing, and rural areas. Manned aircraft is not practical to be used for 1:10000 map updating in a small area so other methods should be identified.

UAV has the ability to fly at a lower altitude and is very capable to fly for small area thus it is suitable for map updating purposes where only certain areas need to be updated. UAV is also a light weight aircraft so it is easier to operate. UAV doesn't need a pilot or an engineer and no aircraft hangar is needed. It is a low cost alternative for many fields that require aerial photograph in the projects.

There are a few other methods that can be used to replace the usage of conventional aerial photogrammetry for topographic map updating such as remote sensing technique (satellite imaging and SAR) where the data acquisition is much easier because the data can be directly purchased from supplier at an affordable price, but between these three methods, it is imperative to identify which datasets have the biggest potential in terms of accuracy and lowest cost for small area updating.

1.3 Research Aim and Objectives

The aim of this research is to identify the most suitable method which offers both accuracy and cost effectiveness in updating large scale topographic map in a small area. In order to achieve the aim, a few objectives need to be obtained:

i. To evaluate the criteria of large scale topographic map at 1:10000 scale
ii. To analyse the potential and accuracy between datasets
iii. To analyse cost benefits between datasets

Table 1.1 listed the concerns or issues that lead to this study and the relationship with the objectives.

Table 1.1 : Research Questions

Subject	**Research Questions**	**Future Research**
Accuracy	Which of these 4 is the most accurate?	The RMSE between all 4 datasets is calculated. (Objective 2)
Cost and Time	Which of this 4 data sets offers the lowest cost in terms of data acquisitions and processing?	Cost and time is calculated using the method and formula using by DSMM since DSMM is the agency that in charge for topographic mapping in Malaysia. (Objective 3)

	How much time is needed in acquiring and processing each dataset? Which of these 4 datasets are giving the lowest time in updating the topographic map?	
Updating Large Scale Map	Which of these 4 datasets is the best and the most suitable method to update 1:10000 topographic map?	The results are compared to DSMM's Quality Management System MS ISO 9001:2015 for 1:10000 topographic map specifications (Objective 1)

1.4 Research Scope

This research will focus on the 1:10000 topographic map updating for DSMM using four (4) types of data. It involves :

i. Research Area is inside the red area as shown in Figure 1.1. It is a topographic map scale 1:10000. The current topographic map is published in 2012 using data from conventional aircraft method.

Figure 1.1 : Study Area

ii. Evaluate other three datasets as shown in Table 1.2 ; unmanned aerial vehicle (UAV) data, WorldView-3 satellite image and Synthetic Aperture Radar (SAR) data. Details are below :

Table 1.2 : Details of unmanned aerial vehicle data, satellite image and synthetic aperture radar datasets

Data	**Details**
Unmanned Aerial Vehicle (UAV)	**Year** = 2018 **Area** = 3000m x 5000m **Equipment =** Sensefly eBee employing compact camera Sony Cybershot DSC-WX 220 RGB 18.2 MP **Altitude** = 350 meter **Photo Overlap** = 80% front overlap and 60% side overlap. **GSD** = 0.09 m
SAR	**Year** = 2017 **Type** = Airborne IFSAR **Altitude** = 8534 m **Resolution** = 0.50 m
WorldView-3 satellite image	**Year =** 2014 **Altitude** : 617 000 m **Resolution =** 0.31 m panchromatic resolution, 1.24 m multispectral resolution, 3.7 m shortwave infrared resolution and 30 m CAVIS resolution.

iii. Process UAV data using Agisoft Photoscan - image processing, DEM and orthophoto generation.

iv. Establishment of Ground Control Point (GCP) and Check Point (CP) using Trimble R8 receiver. Static technique (1 hour observation each point) for GCP and rapid static technique (15 minutes observation each point) for CP.

v. Process GPS data using Trimble Business Centre. MyGeoid data application for orthometric height.

vi. Data integration and analysis using Global Mapper software

vii. Calculate Root Mean Square Error (RMSE), time and cost involve in topographic map updating

viii. Generate updated topographic features

ix. Limitation of Study – This study focus on DSMM's topographic map updating so the time and cost calculation is limited to DSMM's environment.

1.5 Significant of Research

Currently, Department of Mapping and Survey spends more than one million ringgit every year for data acquisition using aircraft in order to produce and update the topographic map of Malaysia. Using manned aircraft for 1:10000 topographic map updating is not practical because normally only a small area needs to be updated. Besides time consuming, this method can also risk the men onboard and the cloudy weather in Malaysia often resulted in wastage of images captured.. This study is done to identify other data sources to replace the aircraft method in updating large topographic map in terms of cost and accuracy in order to replace the usage of leased aircraft. It is also to identify which method is the most time efficient in data acquisition and processing. The outcome of this research is expected to benefit the DSMM in terms of cost and time, on top of complying with the map update policy.

1.6 Chapter Outline

There are five chapters in this thesis. Chapter 1 discusses the overview of research topics. It includes a problem statement, the objective, scopes involved and the significance of this study.

Chapter 2 contains literature review of topographic map updating, conventional aerial photogrammetry, UAV, SAR, WorldView-3, DEM, MyGeoid and its applications. This literature reviews are from journals, articles, dissertations, books and any relevant sources associated with the scope of the study. This will provide a general overview about the difference in each method. Chapter 2 also entails the research gap, or a research problem which has not been answered in previous studies.

Chapter 3 covers the research methodology carried out to achieve the objectives of this study. This includes the data acquisition on site for UAV and GCP while other data is from DSMM's database, data processing which involves UAV data processing using Agisoft Photoscan, GPS data processing using Trimble Business Centre, and data integration using Global Mapper.

Chapter 4 encompasses the results and analysis of the research. In this chapter, the assessment is carried out quantitatively and qualitatively. The RMSE of each dataset will be compared with GCP and CP. Other than that, the assessment for image resolution, contour pattern, feature positioning is conducted too.

Chapter 5 summarises the conclusion from the results and analysis. It also offers recommendations for future studies.

REFERENCES

Abbott, M., Bamforth, J. (2019) *The Early Development of the Aviation Industry* . 1. New York. Routledge.

Abdullah, S., Tahar, K.N., Abdul Rashid, M.F. and Ossoman, M.A. (2019) 'Camera Calibration Performance on Different Non Metric Cameras', Science and Technology, 27(3), 1397 – 1406.

Ahmad, M.J. (2018). Topographic Mapping Based On Unmanned Aerial Vehicle And Aerial Photogrammetric Technique. 9th IGRSM Interntional Conference and Exhibition on Geospatial and Remote Sensing. 24 – 25 April. Kuala Lumpur, Malaysia.

Asadzadeh, S. and de Souza Filho, C.R. (2016) 'Investigating The Capability Of WorldView-3 Superspectral Data For Direct Hydrocarbon Detection', *Remote Sensing of Environment*, 17(1), 162 – 173.

Baghdadi, N. and Zribi, M., (2017) *Microwave Remote Sensing of Land Surfaces: Techniques and Methods*. 1. France: Elsevier.

Barazzetti, L., Brovelli, M.A. and Valentini, L. (2010) ' LiDAR Digital Building Models for True Orthophoto Generation', *Applied Geomatic*, 2(2), 187-196.

Barnes, B. and Hu, C. (2016) 'Dependence of satellite ocean color data products on viewing angles: A comparison between SeaWiFS, MODIS, and VIIRS', *Remote Sensing of Environment*, 175(1), 120-129.

Bristeau, P., Martin, P., Salaun, E. and Petit, N. (2009) The Role of Propeller Aerodynamics in the Model of a Quadcopter UAV. *European Control Conference 2009.* 23 – 26 August. Budapest, Hungary, 683 – 688.

Cantemir, A., Visan, A., Parvulescu, N. and Dogaru, M. (2016) The Use Of Multiple Data Sources In The Process Of Topographic Maps Updating. *Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B4, 2016 XXIII ISPRS Congress*. 12–19 July. Prague, Czech Republic, 19 – 24.

Colefax, A.P., Butcher, P. A. and Kelaher, B. P. (2017) 'The potential for unmanned aerial vehicles (UAVs) to conduct marine fauna surveys in place of manned aircraft', *ICES Journal of Marine Science*, 75(1), 1–8.

Darwin, N., Anuar, A. and Zainon, O. (2013) The Potential of Unmanned Aerial Vehicle for Large Scale Mapping of Coastal Area. *IOP Conference Series: Earth and Environmental Science*. 26 – 29 August. Kuching, Sarawak, 1 – 6.

Dash, J. P., Watt, M.S., Paul, T. H. S., Morgenroth, J. and PearseEarly, G.D. (2019) 'Detection of Invasive Exotic Trees Using UAV and Manned Aircraft Multispectral and LiDAR Data' , *Remote Sens,* 11(15), 1812.

DeeDee Whitaker (2015). *Satellite Imagery and Remote Sensing*. Available at https://slideplayer.com/slide/10692469/ (Accessed 4 June 2019)

Department of Civil and Aviation. (2008). *AIC 04/2008*. Putrajaya: DCA.

Department of Survey and Mapping Malaysia (2005) *BIL.10*. Kuala Lumpur: Department of Survey and Mapping Malaysia.

Department of Survey and Mapping Malaysia (2018) *MS ISO 9001:2015.6.* Kuala Lumpur: Department of Survey and Mapping Malaysia.

Digital Globe (2013). WorldView-3 Above and Beyond. Available at http://worldview3.digitalglobe.com/ (Accessed 5 June 2019)

Disa, N. M., Maarof, I., Latif, Z.A. and Samad, A.M. (2011) LiDAR : A Review on Generating Digital True Orthophoto. *2011 IEEE 7th International Colloquium on Signal Processing and Its Applications.* 4-6 March. Penang, Malaysia. 336 – 340.

Eisenbeiss, H., (2009) *UAV Photogrammetry*. PhD Thesis University of Technology Dresden.

Eisenbeiss, H. and Sauerbier, M. (2010) 'Investigation of UAV Systems And Flight Modes For Photogrammetric Applications', *Close Range Image Measurement Techniques*, 26(136), 400 – 421.

Eynard, J.D and Jenny, B. (2016) 'Illuminated and Shadowed Contour Lines : Improving Algorithms and Evaluating Effectiveness', *International Journal of Geographical Information Science*, 30(10), 1923 – 1943.

Franceschetti, G. and Lanari, R. (1999) *Synthetic Aperture Radar Processing*. Boca Raton, Florida: CRC Press.

Govorčin, M., Pribičević, B. and Đapo, A. (2014). Comparison and Analysis of Software Solutions for Creation of A Digital Terrain Model Using Unmanned Aerial Vehicles. *14th International Multidisciplinary Scientific GeoConference SGEM 2014.* 17 – 26 June. Sofia, Bulgaria, 67 – 71.

Graça, N., Mitishita, E. and Gonçalves, J. (2014) Photogrammetric Mapping Using Unmanned Aerial Vehicle. *ISPRS Technical Commission I Symposium - Sustaining Land Imaging: UAVs to Satellites*. 17 – 20 November. Colorado USA, 129 – 133.

Hendriatiningsih, S., Yusup, S.A., Haris R.A and Hernandi, A. (2014). UAV System with Terrestrial Geo-referencing For Small Area Mapping. *FIG Congress*. 16 – 21 June 2014. Kuala Lumpur, Malaysia, 1 – 13.

Hu, F., Gao, X.M., Li, G.Y. and Li, M. (2016) DEM Extraction From WorldView-3 Stereo Images and Accuracy Evaluation. *ISPRS Congress Commission 1, WG 1/4* , 12 – 19 July. Chezh Republic, 327 – 332.

International Civil Aviation Organization (2011). *328 AN/190*. Canada: International Civil Aviation Organization.

Jojo (2012). *Types of Drones – Explore the Different Models of UAV's*. Available at http://www.circuitstoday.com/types-of-drones (Accessed 18 December 2018)

Kakaes, K., Greenwood, F., Lippincott, M., Dosemagen, S., Meier, P. and Wich, S. (2015). *Drones And Aerial Observation: New Technologies For Property Rights, Human Rights, And Global Development*. Available at https://www.newamerica.org/international-security/events/drones-and-aerial-observation/ (Accessed 5 May 2019)

Liang, S.(2012) *Geometric Processing and Positioning Technique.* 1. USA: Elsevier Inc.

Liu X.F., Peng Z.R., Zhang L.Y. and Li L.(2012) 'Unmanned Aerial Vehicle Route Planning For Traffic Information Collection', *Jiaotong Yunshu Xitong Gongcheng Yu Xinxi/J. Transport. Syst .Eng. Inform. Technology*, Vol.12(1), 91-97.

Ma, Z., Wu, X., Yan, L. and Xu, Z. (2017) Geometric Positioning for Satellite Imagery Without Ground Control Points by Exploiting Repeated Observation. *Sensors*, Vol. 17 (2), 240 – 257.

Mohamad, E., Ait M'Hand A., Aloui R. (2005). Digital True Orthophoto Generation. *Semaine Professionnelle de la Fédération Internationale des*. 16 – 21 April. Caire, Egypt. 4 – 11.

Nicolas, J.M. and Tupin, F. (2016). *Microwave Remote Sensing of Land Surface*. 1. France: ISTE Press.

Niethammer, U., Rothmund, S., Schwaderer, U., Zeman, J. and Joswig, M. (2011) Open Source Image-Processing Tools For Low-Cost UAV-Based Landslide Investigations. *ISPRS Zurich 2011 Workshop*. 14 – 16 September. Zurich, Switzerland. 161 - 166.

Nikolakopoulos, K. and Kyriou, A. (2016). DSM generation using multiple radar data for relief change detection in North Peloponnese. *Fourth International Conference on Remote Sensing and Geoinformation of the Environment*. 4 – 8 April. Paphos, Cyprus, 23 – 28.

O'neil-Dunne, J. (2015). UAS Photogrammetric Point Clouds: A Substitute for LIDAR?. *LIDAR Magazine*, 5/5, 2 – 5.

Perez, M., Aguera, F. and Carvajal, F.(2011). Digital Camera Calibration Using Images Taken From Unmanned Aerial Vehicle. *Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-1/C22*. 14 – 16 September. Zurich, Switzerland, 167 – 171.

Perko, R., Raggam, H., Gutjahr, K.H. and Schard, M. (2015) Advanced DTM Generation from Very High Resolution Satellite Stereo Images. *ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences. Vol.2*. 25 – 27 March. Munich, Germany, 165 -172.

Radzi, F.M. (2015) *Accuracy Assessment Of Ebee UAV Image Using Onboard And Ground Control Point Processing*. Master Thesis. Universiti Teknologi Mara Shah Alam.

Rusli, N., Pa'suya, M.F. and Talib, N. (2016) A comparative accuracy of Google Earth height with MyGeoid, EGM96 and MSL. *8th IGRSM International Conference and Exhibition on Geospatial & Remote Sensing*. 13-14 April. Kuala Lumpur, Malaysia. 1 – 6.

Saip S.N. (2016) *Conventional Aircraft vs UAV for Updating Topographic Map in JUPEM*. Master thesis. Universiti Putra Malaysia, Selangor.

Samad, A. M., Kamarulzaman, N., Hamdani, M. A., Mastor, T. A. and Hashim K. A. (2013) The potential of Unmanned Aerial Vehicle (UAV) for civilian and mapping application. *2013 IEEE 3rd International Conference on System Engineering and Technology*. 19-20 August. Selangor, Malaysia. 313-318,

Shin, P., Sankey, T., Moore, M.M and Thode, A.E. (2018) *Evaluating Unmanned Aerial Images for Estimating Forest Canopy Fuels in a Ponderosa Pine Stand*, Remote Sensing, 10(8), 1266 – 1288.

Snitch, T. (2013). *Entrepreneurial Approaches to Protecting Highly Endangered Wildlife: Saving Rhinos with Math, Drones and Satellites*. Available at http://cmns.umd.edu/news-events/events/839 (Accessed 16 June 2019)

Skrzypietz, T (2012). *Unmanned Aircraft Systems for Civilian Missions. Brandenburg Institute for Society and Security*. Available at https://www.bigs-potsdam.org/images/Policy%20Paper/PolicyPaper-No.1_Civil-Use-of UAS_Bildschirmversion%20interaktiv.pdf (Accessed 3 March 2019)

Tampubolon, W. and Reinhardt, W. (2014). UAV Data Processing For Large Scale Topographical Mapping. *ISPRS Technical Commission V Symposium*. 23 – 25 June. Riva del Garda, Italy, 565 – 572.

Wegmuller, U., Strozzi, T., Werner, C. and Wiesmann, A. (2002) SAR Interferometry for Topographic Mapping and Surface Deformaton Monitoring. *Photogrammetric Journal of Finland*, 18(1), 24 – 32.

Yusoff, A.R., Mohd Ariff, M.F., M. Idris, K., Majid, Z. and Chong, A.K. (2017). Camera Calibration Accuracy At Different UAV Flying Heights. *Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W3.* 1-3 March. Nafplio, Greece, 595 – 600.