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Accuracy Assessment of DEM from UAV and TanDEM-X Imagery

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***Abstract*—** Digital Elevation Model (DEM) is now becoming a common method for modelling the earth surface for various purposes. It is becoming more so with the widespread use of Unmanned Aerial Vehicle (UAV) for data capture. With a similar purpose to the use of UAV, TanDEM-X satellite images are also able to capture the information about the earth surface. It would therefore be interesting to compare the accuracies of both methods and that became the aim of this paper. The DEM from UAV was generated using Agisoft PhotoScan software. Using ArcGIS, the study made the comparison based on the elevation data extracted from verification points and structure of Triangulation Irregular Network (TIN). The result showed that the DEM extracted using UAV had a better accuracy compared to TanDEM-X product. Expectedly, both are positively correlated with $R^2 = 0.7992$ and therefore both can be used with reliable accuracy.

Keywords— UAV, TanDEM-X, DEM, elevation accuracy, correlation, RMSE

I. Introduction

Digital Elevation Model (DEM) plays an important role in analyzing and monitoring the surface of earth and DEM quality has a lot of impact depending on applications. Lately, there are quite a number of benefits gained from using unmanned aerial vehicle (UAV) for acquiring DEM data such as fast image capturing and processing as well as high spatial resolution. Hence its wide range of remote sensing applications [1]. Extracting data, however, requires field-measured ground control points using Global Positioning System (GPS) and subsequent applications of different corrections.

Light Detection and Ranging (LiDAR) is currently the most common remote sensing technology used in generating DEM. The DEM obtained from LiDAR are already georeferenced that the position of the sensor is determined using GPS and IMU data. However, with the rapid development in technology, TanDEM-X imagery is notably becoming one of the new fascinations of global DEM that can provide a high-quality DEM. Real Time Kinematic–Global Positioning System (RTK-GPS) method can be used for Global Navigation Satellite System (GNSS) data field acquisition [2]. The Root Mean Square Error (RMSE) for TanDEM-X imagery has demonstrated the feasibility of an interferometric radar mission with close formation flight and innovative SAR technologies which delivers an important contribution for the conception and design of future SAR missions [3].

Acquiring data using UAV like drones is one of the best method because the costs are affordable and nowadays plenty of organizations own their own drone. There are many capabilities of and benefits from UAV such as forestry management planning, urban planning, archeology and flood modelling. Integration of UAV and TanDEM-X on the other hand allows for high quality results in 3D data processing. While satellite images are able to collect data in obtaining temporal resolution and atmosphere, UAV are flexible in capturing data where all the settings can be customized based on one's preference. The integration of UAV and TanDEM-X is able to produce a high quality in analyzing terrain mapping using new technologies and demonstration in various applications.

Those general applications include scientific applications, operational applications, military applications and others. These application needs DEM in order to investigate and solving problems related to the elevation of the earth. For instance, in solving disaster management, transportation, land cover classification and remote sensing where it able to improve the significant in the analysis of result and its development. With these kind of applications, it will be able to improve the importance of DEM in producing a high-quality output.

For scientific applications, mainly DEM applied is related to the topographic aspects for the earth's surface such as water flow, soil movement and forest fires. This application is applied along with the movement of water information besides DEM data. DEM data will be used as well as GIS application in correcting the images, relief and thematic information. Thus, it will provide an output where the terrain and thematic information are correlate to each other in performing analysis such as geomorphology and landscape analysis. Furthermore, in calculating the water runoff and it's soil moisture, the surface points must undergo using interpolate method from GIS software, thus able the DEM with a good resolution [4].

Operational applications in DEM is mainly related in geo-information analysis. DEM data is used for regional planning and also for infrastructure development planning. In addition, this application is mostly involving the government services and management operations where DEM is used in replacing the printed maps and instead producing an application for updating geo-information and governmental issues.

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Furthermore, for operational applications, DEM is also used in analysis in risks and hazard for security services where terrain information is involved.

Moreover, DEM is also used for military applications where height information as well as land cover classification are needed in order to obtain the orientation of the scene and also road to identify the access way. The more accurate DEM data, therefore it gives advantage over military team in conducting their mission. Not only DEM that is applied for military application, somehow, with the aid of remote sensing also able to provide and improve the accuracy of data since accuracy plays important role in military aspects. A 3D polygon models is made from DEM in order to extract the terrain information and giving the output of global texture from the geo-specific image so that a stimulator will be able to operate and also provide a high quality of accuracy for military mission [5].

Therefore, this study analyzed the DEM accuracy of UAV and TanDEM-X imagery in applying applications where DEM data is needed such as flood modelling and landslide detection. Obtaining data via UAV also would ease in so many ways including cost and time as well as TanDEM-X where it able to gives the best elevation data. The final result will help in solving problems of uncertainty and reliability of the accuracy for both data to be apply on DEM applications in the future.

II. Methodology

A. *Study Area, Tools & Instruments*

The study area is located at Universiti Teknologi MARA Perlis (UiTM) Perlis Branch. The university itself is located in the state of Perlis, Malaysia with its coordinates 6.4490˚N, 100.2786˚E. This university is located within the town of Arau and is 9.5 kilometer from Kangar the Capital. The size of the study area is approximately 0.252km^2. Fig. 1 shows location of the study area for this study.

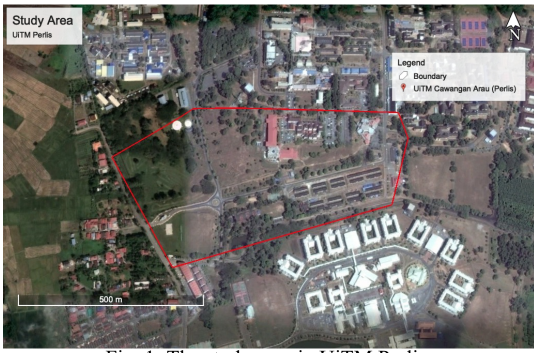

Fig. 1: The study area in UiTM Perlis
Source: Google Earth

B. *Data Acquisition*

Four types of data were collected for this study which are UAV images, ground control points (GCP) data, Continuously Operating Reference Station (CORS) and TanDEM-X images. For UAV data, the instrument used was DJI Phantom 3 Advanced drone to capture the image of the study area. A flight mission and weather checking were carried out before flying. For GCP points acquisition, the data were collected using GPS instrument which was Topcon GR-5. The requirements for establishing GCP points must be at least 6 points and verification of the GCP points would be established using approximately 20 points.

The flight mission was carried out using DJI GS Pro where altitude and the size of study area were customized using the application. This application also provides features such as number of flight line, number of photos and the speed of the UAV. The planning was done 4 days before flight mission. Fig. 2 shows the interface of DJI GS Pro during planning phase. The altitude of the mission was 100 meters with 60% overlap. The total number of images taken on 13th March 2018 for the whole study area were 224 images.

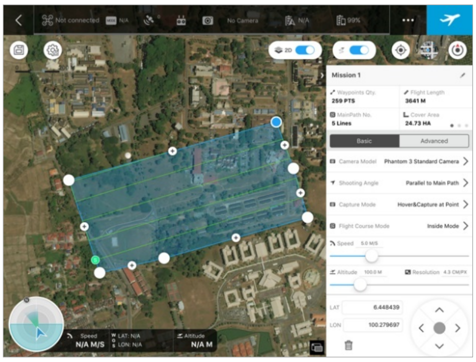

Fig. 2: Interface from DJI GS Pro

All GCP points need to be planned properly and must be well distributed in order to yield better accuracy. For this research, there were 6 GCP and 27 VP measured for ground control network purposes. All points were measured and observed in GDM2000/RSO Geocentric coordinates system. The method used to observe GCP was by using static method. The observation time for GCP was 30 minutes. Meanwhile, for VP, the data were observed using RTK-VRS method in order to control the network of GCPs. The positions of the ground to be obtained included longitude, latitude and elevation information. Not much option was available for selection of GCPs as vegetation covered most of the study area. Fig. 3 shows the GCP distribution of the study area.

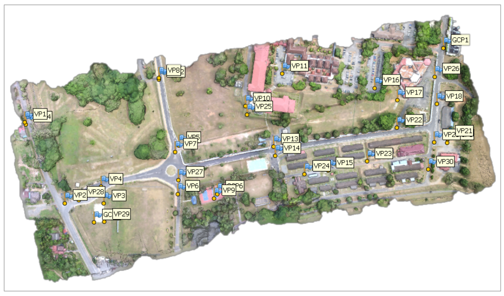

Fig. 3: GCP and VP distribution

C. *TanDEM-X imagery*

TanDEM-X images were obtained through a proposal submission sent to European Space Agency (ESA) to their website https://earth.esa.int/aos/terrasarx. The proposal prepared as per their requirement which include the title, description of proposal, summary of data requirements and acceptance of ESA terms and condition for data use. In applying for TanDEM-X data (Fig. 4), the submission need to be done in 3rd Party page at the website. The result of the application would normally be known within two weeks. The data received is in adf format where the file can then be converted into TIFF file format. The coordinate system of the raw TanDEM-X data is in WGS84.

Fig. 4: TanDEM-X raw elevation data for Perlis

D. Data Processing

Data processing is described into two sections which are UAV and TanDEM-X respectively. The first processing step was GCP points data processing. The main processing for UAV images focused on steps such as placing the markers and building dense point cloud to generate the DEM and Orthophoto for the final output. Placing the makers was a step where all GCP points would be placed and the coordinates system would be customized in the setting. The coordinate system were set in GDM2000.

On the other hand, for TanDEM-X image, the processing started with adding VP points and extracting the elevation information to compare with UAV elevation values. Contour were constructed from the DEM layer, followed by TIN structure. The quality of DEM defines by a few parameters such as absolute height accuracy, relative vertical height accuracy and data coverage which shows the validity of pixels in final DEM [6]. The TIN and slope values from TanDEM-X image were then to be compared with UAV points.

All the GPS data obtained were given in ellipsoid height that needed to undergo few calculation processes in order to get the orthometric height. Firstly, geoidal height needed to be obtained using Surfer 13 software. All the GCP and VP data were added in Surfer 13 Software to get the fitted geoid data. The fitted geoid data generated from each GCP and VP were saved. Next, all the data needed to undergo few calculations to gain the orthometric height using Microsoft Excel. Equation 1 below shows the formula involved in obtaining the orthometric height.

$$H = h - N \tag{1}$$

where

H: Orthometric height
N: Geoidal height
h: Ellipsoidal height

III. Results and Discussion

A. Accuracy Assessment of DEM elevation from UAV

The result obtained from $RMSE_r$ for northing and easting are 0.042 and 0.096 respectively. Meanwhile, $RMSE_r$ for the horizontal accuracy at 95% confidence level is 0.182m (Table 1). Meanwhile, for vertical accuracy (Table 2), the $RMSE_z$ is 0.084m which is also within tolerance of NSSDA Vertical Accuracy, at 95% confidence interval which is 0.570m.

Table *1*: RMSE Accuracy of Horizontal Position

	Northing (m)	**Easting (m)**	**ASPRS 2014 tolerance**
RMSE (m)	0.042	0.096	0.750
NSSDA Horizontal Accuracy, 95% Confidence Level	0.182		1.836

Table *2*: RMSE Accuracy of Vertical Position

	Elevation (m)	**ASPRS 2014 tolerance**
$RMSE_z$ (m)	0.084	0.500
NSSDA Vertical Accuracy, 95% Confidence Level	0.570	0.980

Performing camera calibration through parameter optimization enables one to rectify the lens distortion and the camera position during processing. Furthermore, camera optimization is important to avoid huge errors during points marking. Thus, whenever the points are removed, it is highly recommended to optimize the camera. The selection of parameter is important especially when generating elevation related elements such as mesh and texture before DEM and orthomosaic is carried out. In order to obtain high horizontal accuracy values, the control of ground control points being marked and the parameters used in processing are important.

B. Accuracy Assessment of DEM elevation between UAV and TanDEM-X

An accuracy assessment of VP for TanDEM-X image was carried out to identify the accuracy level as well as the vertical accuracy of TanDEM-X. Table 3 shows the result of the horizontal position accuracy. The tolerance values are obtained from the ASPRS (2014) guidelines.

Table *3*: RMSE Accuracy of Horizontal Position

	Northing (m)	**Easting (m)**	**ASPRS 2014 tolerance**
RMSE (m)	0.044	0.099	0.750
NSSDA Horizontal Accuracy, 95% Confidence Level	0.187		1.836

TABLE *4*: RMSE ACCURACY OF VERTICAL POSITION

	Elevation (m)	**ASPRS 2014 tolerance**
$RMSE_Z$ (m)	1.482	0.12
NSSDA Accuracy Z, 95% Confidence Level	2.386	0.14

According to vertical accuracy for elevation data set from Table 4, the tolerance for $RMSE_Z$ and NSSDA Accuracy Z, 95% confidence level for urban terrain are 0.12m and 0.14m respectively. The elevation data from TanDEM-X, the RMSE value has exceeded the tolerance value range with 2.386 for Z confidence level and 1.482 for $RMSE_Z$. The accuracy is defined as the average vertical error of interpolated points with DEM grid. The altitude and sensor may affect the accuracy of the RMSE. Furthermore, the spatial resolution of TanDEM-X does affect the interpolation of elevation during value extraction. The errors of true data and derived data may affect the $RMSE_Z$ values.

C. Comparison of TIN Elevation between UAV and TanDEM-X

According to APRS (2014) guidelines, vertical accuracy of point-based elevation datasets should be compared using TIN elevations. The results of TIN elevation are shown in Fig.4. TIN was created based on the contours generated beforehand with 1-meter interval.

Based on the elevation of TIN from both data, there are ±4-meter difference for the highest value of the TIN elevation and ±3-meter difference for the low elevation value. The flat triangles created from TIN formed when there are three nodes with the same elevation values where UAV have higher value of TIN elevation, which is 35.6 meter, compared to the TanDEM-X imagery with 31.8 meter. The TIN surface from UAV has better and higher elevation which might have been caused by the features existing on the surface. Based on the perspective view of the TIN structure, the yellow colored elevation has major difference where it covered more area in UAV compared to TanDEM-X. This may have been caused by the interpolation of soft edges generated through the TIN tools in ArcGIS in generating elevation from the VP measurement. TIN is able to give better DEM accuracy compared to automated DEM generation.

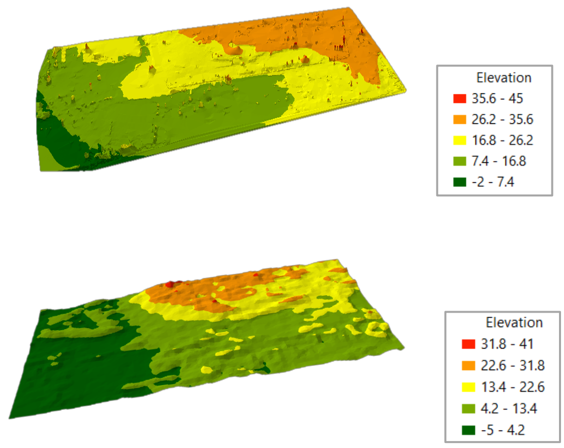

Fig. 4: TIN structure from UAV (top) and TanDEM-X (bottom)

D. Evaluation of DEM from UAV and TanDEM-X

The comparison of DEM elevation generated from UAV and TanDEM-X were done based on the high and low values of the DEM. Based on Fig. 5 below the high value for TanDEM-X and UAV are 41.312 meter and 45.0158 meter respectively, resulting in the highest difference between the two DEMs of ±4 meters.

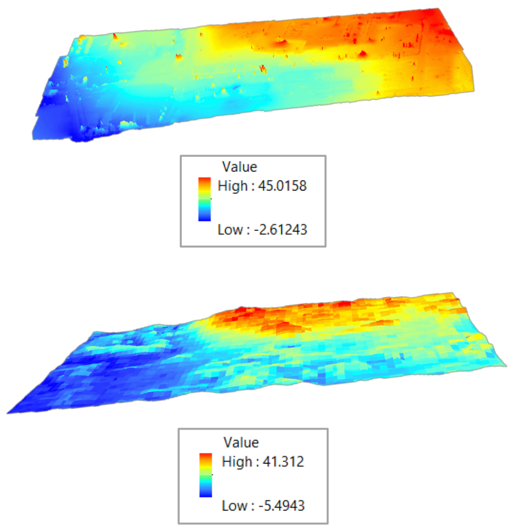

Fig. 5 DEM of UAV (top) and TanDEM-X (bottom)

The difference may have been caused by the difference in sensor and altitude when capturing data. Satellite image is mostly about surface capture through scanning while UAV is using a multispectral image with altitude that can be customized. In addition, the DEM data from UAV is believed to include some of the surface features that may affect the elevation. For the low value, TanDEM-X has the lowest value of -5.494m compared with UAV low value of -2.6109m where the values differ by ±3 meters. The result does not differ much as lower values represents the ground and other surface such as natural drains. In addition, the different processes with the corresponding error sources may affect the maximum residual where error exists during transformation and conversion.

E. Correlation of DEM elevation between UAV and TanDEM-X

The graph in Fig. 6 below shows the elevation values of TanDEM-X on Y-axis and the elevation values of UAV on X-axis with a regression line drawn. The result shows that the scatter graph is strongly positively correlated with the value of $R^2 = 0.7992$. It can therefore be concluded that both methods of generating DEM would produce similar results.

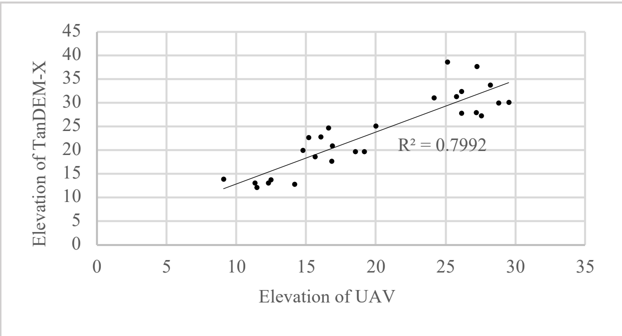

Fig. 6: Correlation between UAV and TanDEM-X

IV. CONCLUSION

This simple study reveals that the methods of generating DEM using UAV-flown instrument and using TanDEM-X satellite images produce results that have some differences. The differences of 3 to 4 meters would or would not matter depending on the purpose of generating the DEM. Both methods have their advantages and disadvantages taking into accounts factors such as costs, coverage area, time required, processing involved, etc. However, it is foreseen that the prospect of further customization and improvement of techniques may tip the balance in favor of UAV-generated DEM.

REFERENCES

[1] G. D. Jin, L. X. Gu, and L. Bin Lu, "Study on technique of 3D imaging based DEM and massive orthograph," *Proc. - 2009 Int. Conf. Comput. Model. Simulation, ICCMS 2009*, vol. 2, pp. 223–227, 2009.

[2] S. Lee and J. Ryu, "High-Accuracy Tidal Flat Digital Elevation Model Construction Using TanDEM-X Science Phase Data," *Appl. Earth Obs. Remote Sens.*, vol. 10, no. 6, pp. 2713–2724, 2017.

[3] D. B. Tridon, M. Bachmann, M. Martone, D. Schulze, and M. Zink, "The Future of TanDEM-X : Final DEM and Beyond," *Proc. EUSAR 2016 11th Eur. Conf. Synth. Aperture Radar*, pp. 541–545, 2016.

[4] T. S. T. A. Ń. Czyk and A. B. Ł. A, "Application of Digital Elevation Model (DEM) for description of soil microtopography changes in laboratory experiments," *Ann. Warsaw Univ. Life Sci.*, vol. 48, no. 48, pp. 377–388, 2016.

[5] M. Van Persie, H. H. S. Noorbergen, a C. Van Den Broek, and R. J. Dekker, "Use of Remote Sensing Imagery for Fast Generation of Military Maps and Simulator Databases Use of Remote Sensing Imagery for Fast Generation of Military Maps and Simulator Databases," *Natl. Aerosp. Labarotary NLR, Netherlands*, vol. XXXIII, pp. 573–581, 2000.

[6] C. Wecklich, D. Borla-tridon, C. Gonz, M. Martone, T. Kraus, M. Bachmann, P. Rizzoli, and M. Zink, "TanDEM-X Mission Status and Final DEM Performance," *Ger. Aerosp. Cent.*, pp. 1–8, 2017.