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DIGITAL TWIN GENERATION OF CARAGA STATE UNIVERSITY'S HONORABLE ELISA R. OCHOA (H.E.R.O) LEARNING COMMONS USING UNMANNED AERIAL SYSTEMS (UAS)

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ABSTRACT: One of the new trends in digital transformation is the generation of digital twins. The term digital twin refers to a technique that combines data, models, and physical entities. The digital twin technology creates a virtual replication of a real-world entity. Digital twin technology and its applications are critical in enabling an innovative and inclusive urban planning process. The civilian use of Unmanned Aerial Systems (UAS) as remote sensing technology opens intriguing new possibilities including the generation of digital twins. This study employed remote sensing technology, particularly the use of an unmanned aerial vehicle (UAV), in creating a digital twin of the H.E.R.O. Learning Commons of Caraga State University. Aerial images of the study area were acquired using DJI Phantom 4 RTK-Rotary-Wing UAV. Three different sets of flight plan parameters were used during the aerial image acquisition to determine the best flight plan parameters for the digital twin generation. The acquired images are then processed using Agisoft Metashape software to complete the photogrammetric tasks and create a model for each set of parameters used. Spatial accuracy is assessed by computing the horizontal and vertical Root Mean Square Error (RMSE) of the digital twin generated. The RMSE of the three models is determined by comparing data collected on field observation and data measured in the generated models. The results show that the use of DJI Phantom 4 Pro-Rotary-Wing UAV in generating a digital twin of Caraga State University's H.E.R.O. Learning Commons is feasible. It also shows that the Set 1 Flight Plan Parameters with a 50-meter flying height and 80% forward and side overlap with 1.8 cm/pixel ground sampling distance (GSD) is the best among the three sets of flight plan parameters producing a horizontal accuracy of ± 0.65 m and vertical accuracy of ± 0.05 m.

1. INTRODUCTION

Structural modeling is frequently used to fully understand structural systems dynamics, assess structural safety, and design interventions in structures and the environment (Angjeliu et al., 2020). From the perspective of the construction field, the purpose of the Digital Twin model is to improve the existing construction process with its supporting semantics within the setting of cyber-physical synchronicity. It also means that the digital model will reflect the physical assets at any time (Boje et al., 2020). A three-dimensional (3D) model can represent the physical form of a city and visualize the physical features present in the environment. Other applications for 3D models have been further developed, including infrastructure planning, disaster response, and energy demand estimations (Shahat et al., 2021).

Although it is widely utilized in manufacturing as one of the enabling technologies of Industry 4.0, digital twin technology is a relatively new trend in the construction sector (Tagliabue et al., 2021), especially in educational buildings, historical sites, and big cities. Digital twins have become a business imperative, covering the entire life cycle of an advantage or process, and establishing the foundation for connected products and services. It allows data analysis and system monitoring to head off problems before they occur. These will prevent downtime, develop new opportunities in a cloud-based system, and event planning for the future by using simulations and thinking of a digital twin as a bridge between the physical and digital worlds (Monsone et al., 2019).

One of the main advantages of 3D modeling is Unmanned Aerial Vehicle (UAV) photogrammetry. It captures aerial images at different altitudes and different tilts in angle by integrating photogrammetry with computer vision. The Structure-from-Motion (SfM) algorithm generates a point cloud that represents the geometry of an object under investigation, the camera's orientation, and the positions from which the photographs were taken (Deng et al., 2021). Employing automated photogrammetry for image acquisition with a UAV and computer vision algorithms will save time on processing and improve the quality of the generated output models (Martínez-Carricondo et al., 2021).

In this study, the Unmanned Aerial System (UAS) photogrammetry approach generates a digital twin to provide useful digital information at Caraga State University's Hero Commons Library. The building is located at Caraga State University, Ampayon, Butuan City. The library is a three-floor building that can cater to a maximum of 2000 visitors. Three (3) photogrammetric parameters are used in this study to determine the best parameter for generating accurate digital twin models.

The researchers thoroughly discussed the methodology, which includes (i) the generation of digital twin models of the Caraga State University's H.E.R.O. Commons Library and (ii) the evaluation of the accuracy of the generated digital twin models.

2. METHODOLOGY

2.1 Generation of Digital Twin Models

Phantom 4 RTK, a Rotary-Wing UAV, was used to gather aerial images of the H.E.R.O. Commons Library building. It has an onboard GNSS that uses GPS and GLONASS for precise navigation. Also, it is equipped with vision systems on the vehicle's front, back, and bottom to recognize surfaces with a predetermined pattern and sufficient illumination and avoid obstructions within 0.2 to 7 meters. The Phantom 4 RTK has an RGB camera that contains a one-inch 20-megapixel (5472 x 3648) sensor and an aperture adjusted manually (from f/2.8 to f/11). Its lens features an 8.8 mm fixed focal length and an 84° horizontal FOV (Martínez-Carricondo et al., 2021).

The researchers utilized the typical UAS mapping workflow (Figure 1) introduced by the Land Management Bureau (LMB) of the Philippines through its LMB Technical Bulleting Number 2 Series of 2017 (LMB, 2017). The ground control points (GCPs) establishment and UAS image acquisition were strategically designed to acquire accurate datasets. The X, Y, and Z coordinates of established GCPs are referenced to the World Geodetic System 1984 (WGS84) Datum. The nature of the terrain and the potential obstructions and interference were identified through reconnaissance. Also, the locations of GCPs for quality control were planned and established. The flight of the UAV was planned, and the flight parameters were shown in Table 1.

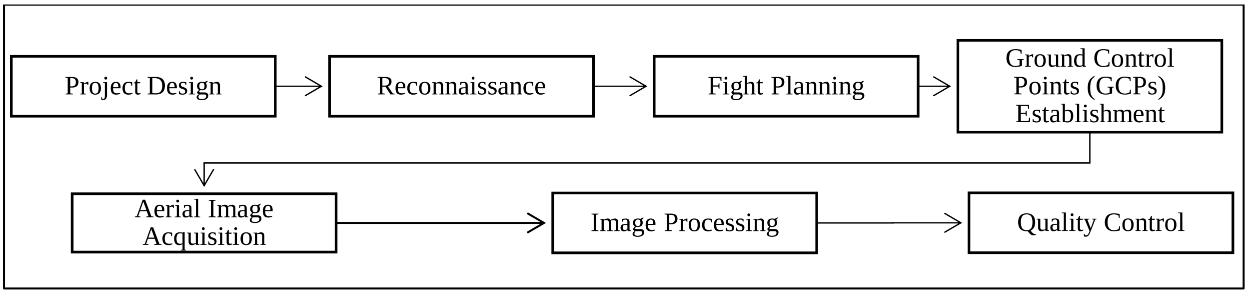

Figure 1. Workflow of the Digital Twin model generation

Table 1. Flight parameters of Phantom 4 RTK during the image acquisitions

Parameters	Flight 1	Flight 2	Flight 3
Flying Height	50 m	60 m	70 m
Forward Overlap	80%	85%	90%
Side Overlap	80%	85%	90%
No. of Images	623 images	622 images	1,304 images
Pixel Size (mm)	2.41 x 2.41	2.41x2.41	2.41x2.41
Focal Length (mm)	8.8	8.8	8.8
Speed of Aircraft	Max	Max	Max
Camera Angle	45°	45°	45°
GSD (cm/px)	1.8	2.27	2.66

The images of the first flight were acquired 50 meters from the ground with 80% overlaps. This flight acquired a total of 623 images with a ground sampling distance of 1.8 centimeters per pixel. Moreover, the images acquired by the second flight, with 60 meters flying altitude and 85% overlaps, have a total of 622 images with 2.27 centimeters per pixel GSD. On the other hand, flight three with 70 meters flying height and 90% overlaps acquired 1304 images with a GSD of 2.66 centimeters per pixel. All the images collected by these flights were acquired with 45 degrees gimbal angle.

The sets of images were individually processed using photogrammetric software, the Agisoft Metashape software (Agisoft LLC, Russia). The software assessed the camera's internal and exterior calibration parameters, including non-radial distortions, starting with the camera's focal length. These values were obtained from the EXIF data of the images. The utilization of the base station accurately acts as the base station for the coordinates of the acquired images.

2.1 Accuracy Assessment of Digital Twin Models

The generated digital twins were assessed based on the measured and collected GCPs within the vicinity of the study area. Using the formulas below, the vertical and horizontal Root Mean Square Errors (RMSEs) and accuracies of each model were calculated.

$$RMSE_{x} = \sqrt{\frac{\sum(X_{data}-X_{check})^2}{n}} \quad (1)$$

$$RMSE_{y} = \sqrt{\frac{\sum(Y_{data}-Y_{check})^2}{n}} \quad (2)$$

$$Accuracy_{r} = 2.4477 * 0.5 * (RMSE_x + RMSE_y) \quad (3)$$

$$RMSE_{z} = \sqrt{\frac{\sum(Z_{data}-Z_{check})^2}{n}} \quad (4)$$

$$Accuracy_{z} = 1.9600 * RMSE_z \quad (5)$$

In equation 1, 2, and 3 (FGDC NSSDA), n is the number of pairs where the location of the GCP on the ground was compared to the location of the GCPs in the 3D models. X_{data}, Y_{data}, Z_{data} are the X, Y, and Z coordinates of the 3D models, respectively. While X_{check}, Y_{check}, Z_{check}, are the X, Y, and Z coordinates of the GCPs on the ground. The RMSE was calculated in the horizontal and vertical dimensions. Equation 3 is used when approximating standard error when RMSEx is not equal to RMSE y (FGDC NSSDA). A lower RMSE value corresponds to a lower discrepancy, which means a better 3D model.

3. RESULTS AND DISCUSSION

3.1 Generation of Digital Twin Models

A digital twin model for each set of parameters is successfully generated as shown in Figure 2 to Figure 4. Shown in Figure 2 is the digital twin generated using the first set of flight plan parameters shown in Table 1. Based on the Digital Twins generated for Flight 1, it can be shown that the features of the CSU's H.E.R.O Learning Commons are much clearer and the gaps between the images are not evident.

Figure 2. Digital Twin Model Generated using the First Set of Flight Plan Parameters

The second set of flight plan parameters obtained images that are captured farther compared to the first set of flight plan parameters. However, due to its overlap which is much higher when compared to the first one, the model shows an area and a resolution that is similar to the first one. Figure 3 shows the model generated using the second set of flight plan parameters as shown in Table 1. There are apparent distorted areas that can be found when zooming in on the model, especially at the entrance of the library. Moreover, minimal gaps and hollow areas are evident in the model due to the higher-flying height in which other areas are covered.

Figure 3. Digital Twin Model Generated using the Second Set of Flight Plan Parameters

Having a high overlap and highest-flying height among the parameters (Table 1), the third set of flight plan parameters obtained a 3D Model that shows more visible ground features based on the images obtained. However, due to its higher flying height, more gaps and hollows on the model are evident. Figure 4 below shows the digital twin model of CSU's H.E.R.O Learning Commons generated using the third set of flight plan parameters.

Figure 4. Digital Twin Model Generated using the Third Set of Flight Plan Parameters

The models above are exported in the Agisoft Metashape using the 3D model exporter and is saved in the obj. format. This format is commonly used in generated 3D models and can be loaded on various online platforms for 3D viewers. The 3D models of this study are uploaded, saved, and published in the sketchfab for easy viewing. The links to the 3D models, which available in the sketchfab are: Digital Twin Model-First Parameter: https://sketchfab.com/3d-models/digital-twin-model-csu-library-50-meter-92544ce5b5c447118c2e48eeeaf43297, Digital Twin Model-Second Parameter: https://sketchfab.com/3d-models/digital-twin-model-csu-library-60-meter-e2366a0ff8ba4d0c8ea2b5d981237c6e, Digital Twin Model-Third Parameter: https://sketchfab.com/3d-models/digital-twin-model-csu-library-70-meter-5844c4a4b6da4928b232db4b53633bd6.

3.1 Quality Control of Digital Twin Models

To assess the accuracy of the data products, the researchers established five (5) natural GCPs. With the use of the total station, coordinates, and the height of the chosen GCPs are computed to calculate the spatial accuracy of the model. The table below shows the observed values that a total station computes during ground surveys, while the model gives the measured values during measurements. The measurements of these 3D models are calculated in the Agisoft Metashape Professional software (Agisoft LCC, Russia), shows the same software used during aerial image processing. Shown in Table 2 is the result of the observed and measured values of X, Y, and Z for every parameter.

Table 2. Measured Value and Observed Value of X (in m)

GCP	Observed X value	Model 1 Measured value	Model 2 Measured value	Model 3 Measured value
1	785523.3312	785523.8287	785523.8287	785523.8287
2	785502.4085	785502.2405	785502.2426	785502.2426
3	785479.0827	785479.0686	785479.0685	785479.0607
4	785450.5029	785450.2364	785449.9327	785450.2364
5	785450.8052	785450.6854	785450.6354	785450.6854

Table 3. Measured Value and Observed Value of Y

GCP	Observed X value	Model 1 Measured value	Model 2 Measured value	Model 3 Measured value
1	991189.9456	991189.9566	991189.9566	991189.9566
2	991173.8099	991174.1258	991173.8184	991173.8184
3	991165.9471	991165.9643	991165.9688	991165.0759
4	991180.7077	991180.2135	991179.5974	991180.7145
5	991158.6439	991158.6983	991158.6983	991158.6983

Table 4. Measured Value and Observed Value of Z

GCP	Observed X value	Model 1 Measured value	Model 2 Measured value	Model 3 Measured value
1	85.176	85.112	85.21	85.194
2	84.768	84.716	84.891	84.82
3	79.998	80.075	80.037	80.03
4	93.977	93.957	93.608	93.579
5	93.413	93.414	93.432	93.373

Table 5 to Table 7 show the difference between the Observed Value and Measured Value. Based on these tables, it can be noticed from the data listed that the value is precise, and the differences are in centimeter-level only. Furthermore, from the computed difference, the values of Root Mean Square Errors were tabulated in Table 9. Digital Model 1 has an RMSEx of 0.269m and RMSEy of 0.264m, making the horizontal accuracy of 0.652m. On the other hand, Digital Model 2 has an RMSEx of 0.355m, RMSEy of 0.497m, and horizontal accuracy of 1.043m. Lastly, Digital Model 3 has an RMSEx of 0.269m, RMSEy of 0.390m, and horizontal accuracy of 0.807.

Table 5. Difference X values

GCP	Difference with Model 1	Difference with Model 2	Difference with Model 3
1	-0.497467	0.497467	0.497467
2	0.168025	-0.165854	-0.165854
3	0.014139	-0.014170	-0.021986
4	0.266491	-0.570248	-0.266491
5	0.119792	-0.169792	-0.119792

Table 6. Difference in Y values

GCP	Difference with Model 1	Difference with Model 2	Difference with Model 3
1	0.011012	-0.011012	0.011012
2	0.315917	-0.008488	0.008488
3	0.017234	-0.021661	-0.871239
4	-0.494244	1.110278	0.006756
5	0.054363	-0.054363	0.054363

For vertical accuracy, the difference for every parameter is listed in Table 7. The RMSEz values were tabulated in Table 9, Digital Twin 1 has an RMSEz of 0.026 meters and an accuracy of 0.05096 meters, Digital Twin 2 has an RMSEz of 0.069 meters and vertical accuracy of 0.135 meters, and Digital Twin 3 has an RMSEz of 0.150 meters and vertical accuracy of 0.294 meters.

Table 7. Difference in Z values

GCP	Difference with Model 1	Difference with Model 2	Difference with Model 3
1	0.064	-0.034	-0.018
2	0.052	-0.123	-0.052
3	-0.077	-0.039	-0.032
4	0.020	0.369	0.398
5	-0.001	-0.019	0.040

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The accuracy of the 3D model based on the horizontal and vertical RMSE states that the lower the value, the more accurate the accuracy result is. Based on Table 8, the lowest value in horizontal and vertical accuracy is Digital Twin model 1. Thus, making the said parameter most accurate when compared to the two (2) other parameters based on accuracy results.

Table 8. Calculated RMSEs and accuracies

Model	$RMSE_x$ (in m)	$RMSE_y$ (in m)	Horizontal Accuracy (in m)	$RMSE_z$ (in m)	Vertical Accuracy (in m)
1	0.269	0.264	0.652	0.026	0.051
2	0.355	0.497	1.043	0.069	0.135
3	0.269	0.39	0.807	0.150	0.294

In addition to using GCPs to assess the generated digital twins, the actual distances on the ground with the distance measured at the Digital Twin (Table 9) were compared. Shown in Table 10 are their comparison, and it can be observed that model 1 has the lowest differences.

Table 9. Measured distances on the ground and Digital Twin models

Distance	Observed	Measured (Model 1)	Measured (Model 2)	Measured (Model 3)
	32.66	32.68	32.7	32.7
	16.87	16.85	16.9	16.8

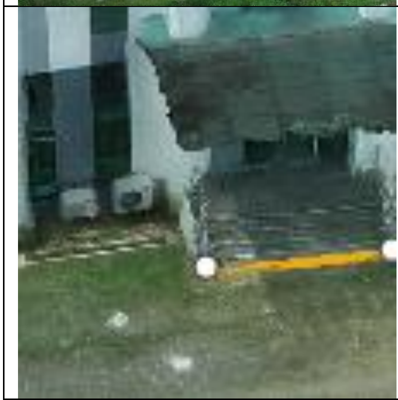
	10.15	10.13	10.2	10.1
	19.29	19.3	19.3	19.3
	5.02	5.04	5.06	5.03
	1.66	1.62	1.6	1.7
	2.47	2.48	2.56	2.42

Table 10. Computed differences of measured distances

Distance	Model 1 (in m)	Model 2 (in m)	Model 3 (in m)
1	0.02	0.04	0.04
2	0.02	0.03	0.07
3	0.02	0.05	0.05
4	0.01	0.01	0.01
5	0.02	0.04	0.01
6	0.04	0.06	0.04
7	0.01	0.09	0.05
TOTAL:	0.14	0.32	0.27

4. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusions

The generation of Digital Twin models using UAS of the library building was successful. With three different sets of parameters, the models showed their differences from each other. The Digital Twin model that was generated based on the first flight has a pixel size of 1.8 centimeters which has the highest spatial resolution compared to the two models which are 2.27 and 2.66 centimeters. With this resolution, it was visible that the same model produced the smallest RMSEs in both horizontal and vertical. The accuracy of the 3D model based on the horizontal and vertical RMSE states that the lower the value, the more accurate the accuracy result is. With 0.652 meters horizontal accuracy and 0.051 meters vertical accuracy, Digital Twin model 1 was apparently the best. This conclusion was supported by an additional assessment, which is comparing distances on the ground and the generated models. Model 1 has a total of 0.12 meters difference while model 2 and model 3 have 0.32 meters and 0.27 meters, respectively.

4.1 Recommendations

Due to the constraints brought about by the pandemic, the researchers were only able to conduct the study in a smaller area. Generating a digital twin with larger area of interest is recommended. In this study, it is also visible that flight parameters relatively affect the generated Digital Twin models. The researchers highly recommend furtherly exploring more flight parameter combinations. Also, it would be better if the gimbal angle should be considered in the optimization of flight plan parameters.

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