Application of Unmanned Aerial Vehicle and Ground Control Point for Mapping and Road Geometric Review

The Case Study from Pandu to Kima Atas Street

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ABSTRACT

Technology implementation, particularly the use of Unmanned Aerial Vehicles (UAVs) and photogrammetry, is being employed in road works for regional and road planning. The current study deploys aerial photographs and data processing along with software, like Agisoft Metashape, PCI Geomatica, Global Mapper, and Autocad Civil 3D as an efficient and effective way to generate digital maps and perform geometric road reviews. The accuracy test of CE90 performed for horizontal accuracy was 0.003 m and the LE90 carried out for vertical accuracy was 0.006 m. This accuracy level is valuable for road planning, ensuring that the data utilized for decision-making are reliable and precise. The study focused on Wori Street spanning from Pandu to Kima Atas Street Manado, covering the section from Sta. 0+000 to Sta. 5+225, which is a collector road with a designated speed of 50 km/h. Among the 16 bends analyzed, 11 met highways' standards for the collector road class, certifying compliance with safety guidelines. Furthermore, the existing road slope conforms to standard requirements, remaining below 8%. This adherence to safety criteria is vital for the design and operation of safe roads.

Keywords-UAV; GCP; road geometry

I. INTRODUCTION

Road infrastructure plays a very important role in the development and growth of a region. It enables greater mobility and accessibility for people, goods, and services. Well-constructed roads facilitate smooth transportation, connecting remote areas with urban centers and supporting economic activity. Additionally, good accessibility ensures easy access to essential services, including hospitals, schools, and other public facilities. Therefore, the road network should be planned and constructed before or at least simultaneously with the new capital's development. Understanding the future growth direction of the new capital area is of utmost importance in order to develop effective road network planning [1]. Topographic mapping serves as the initial step in road planning and design. The information obtained from topographic mapping is invaluable for planners, as it enables them to design roads that are well-suited to the local environmental conditions. Road geometric mapping and analysis are essential for evaluating the feasibility and suitability of a road alignment, taking into account the existing environmental and land conditions. Moreover, mapping aids in estimating the budget and resource requirements for road construction.

Regional infrastructure development, particularly roads, necessitates essential graphical and geographical map data, which can be obtained through aerial photographs. One effective method to acquire aerial photos is by utilizing photogrammetry with drones or UAVs. Helicopter Unmanned Aerial Vehicles (HUAVs) are versatile and capable of performing various maneuvers, including vertical take-offs and landings, which make them suitable for numerous applications [2]. The technology of photogrammetric mapping and surveying has significantly advanced in data collection and processing, particularly with the use of UAVs [3]. In indoor environments, a UAV is capable of scanning a wide area with high accuracy in a short period of time [4]. Photogrammetry serves as a mapping tool that enables the exploration of large areas relatively quickly, making drones an efficient, cost-effective, and safe alternative for mapping regions compared to conventional methods [5-9]. These methods involve ground/field surveying using instruments like theodolites and total stations [10], or aerial photography deploying airborne platforms like helicopters [11, 12] or airplanes [5, 12, 13].

Discerning geometric qualities through geometric accuracy and product resolution makes UAVs suitable for compiling topographical maps, cadastral maps, and engineering survey maps. UAVs can acquire data at high spatial resolutions, with complete control over the temporality required for the desired application [14]. The versatility of the UAV, both in terms of flight characteristics and onboard sensors, makes it possible to generate relevant geodata for a wide range of landfill monitoring activities. Utilizing UAV technology demonstrates the potential for haul road monitoring. The results show that orthophotos and digital elevation models can assess road smoothness conditions and check road design suitability [15]. Employing road geometry and dimensions in drone navigation is an adequate and a not limited to ground applications approach [16]. Nowadays, the relationship between road geometry and traffic accident cases is processed through maps of accident-prone locations using a comprehensive Geographic Information System (GIS) technology [17]. Integration and analysis of various thematic maps and image data carried out in a GIS environment has been proved to be efficient for the delineation of suitable zones for landfill sites [18]. Putting into service the developed GIS, enables users to access information regarding the geographical coordinates of a particular location, as well as details about its facilities [19].

The results of the measurements performed through the employment of photogrammetric techniques by drones can be in the form of Digital Surface Model (DSM) data and Digital Terrain Model (DTM). UAVs equipped with low-cost digital cameras and improved photogrammetric methods for digital mapping are becoming increasingly available [20]. UAVs can capture ground data from a specific height and provide reliable accuracy for road planning. The maximum accuracy for horizontal and vertical measurements is 0.3 m and 0.2 m, respectively, for a 1:1000 scale map in class 1 category [21]. The analysis includes planning and assessing the accuracy of the road design. DTM is utilized for road design to check the accuracy of the designed road and validate the use of UAVs in road construction [7]. A UAV with high flexibility, low cost, and easy maneuverability is an attractive option for monitoring road conditions [22]. Illumination geometry and flight altitude could influence the retrieval of reflectance values from individual images obtained with UAS. Taking photos deploying a drone at a maximum permitted flying height of up to 100 m is better because the photos' overlap is around 70-80% [23]. Additional geo-processing techniques that can reconstruct curved elements and smooth segments can enhance the fundamental geometry of the road [24]. Evaluation of road geometry using UAV can be carried out for two elements of road geometry in the form of horizontal alignment and vertical alignment of the road.

Several studies have observed the effect of road geometry design on vehicles and the safety performance of automatic vehicles on geometric road features. The results show that automatic driving has a higher probability of a hazardous incident on curved sections than on straight sections [25]. However, the main factor causing accidents is the driver, and the characteristics of the road environment contribute to a risky driving behavior [26]. In [27], the main effect of road slope and its interaction with other variables on rural roads was studied, where the interaction between vehicle classification (passenger cars or heavy vehicles) and the slope is a significant parameter. Geometric design of highways relates to the dimensions and layout of visible features of the road, such as horizontal and vertical alignment and visibility. The road geometry design must provide efficiency in traffic operations with maximum safety at a reasonable level [28], as one component of sustainable transportation is safety [29]. Straightening sharp horizontal curves, as a part of road safety countermeasures, could reduce the number of rollovers [30]. The use of UAVs for road mapping and road geometry review has several limitations that need to be considered. UAVs have constraints on flight range and duration as their batteries have limited capacity, which in turn limits the range and survey time that can be carried out in a single flying mission. Moreover, unfavorable weather conditions can cause delays in mapping and affect the accuracy of the collected data. Some areas may have specific restrictions on flying heights, or requirements for obtaining special permits prior to flying. By understanding and addressing these limitations and challenges, the use of UAVs can significantly improve efficiency and accuracy in road infrastructure development.

The innovations resulting from this study include the incorporation of high accuracy Global Navigation Satellite System (GNSS) technology. GNSS is a global navigation system comprising a network of satellites orbiting the earth along with ground control stations. The importance of the GNSS is increasing significantly across different services as a crucial positioning technology [31]. By utilizing signals from multiple GNSS satellites, a GNSS receiver can precisely determine position and time. In mapping and surveying applications, GNSS with Real-Time Kinematic (RTK) technology enhances accuracy by providing correction to GNSS data using signals from reference stations. The combination of high-precision GNSS technology and 3D modeling ameliorates the overall accuracy and reliability of mapping and surveying processes, leading to improved data quality and better-informed decision-making in various applications.

II. RESEARCH METHOD

The location study focuses on the Wori Street section, Pandu Village, extended to the Adipura Raya Street section, Kima Atas Village, Mapanget District, covering a distance of 5 km. The chosen method for data collection is photogrammetry, using the DJI Mavic 2 Pro UAV as the data acquisition medium in April 2024. The camera model utilized is the L1D 20c (10.26 mm) with a resolution of 5472×3648, a focal length of 10.26 mm, and a pixel size of 2.41×2.41 µm. Data processing involves implementing Agisoft Metashape and PCI Geomatica to process the aerial imagery and create topographic maps and contour maps. Subsequently, the horizontal and vertical alignment of roads is reviewed employing Global Mapper and Autocad Civil 3D. The accuracy of the collected data will be tested deploying a GPS Geodetic tool as a GCP [21]. Additionally, the horizontal alignment and vertical alignment will be reviewed in accordance with the guidelines [32]. The drone's flight parameters include a side overlap and forward overlap patches set at 80%. The flying height is adjusted in coordination with the airport authority PT. Angkasa Pura and set at 61.9 m.

III. RESULT AND DISCUSSION

A. *Road Mapping*

GCP measurements were conducted using the Sinognss T300 Geodetic GPS tool. GCP measurements are essential for accurate aerial photo data acquisition. For this study, 6 GCP points were distributed along the road, with a distance of approximately 1 km between each GCP. The GCP recording utilized the Network Transport RTCM via Internet Protocol - Real Time Kinematic (NTRIP-RTK) method, enabling real-time observation of positions or direct coordinate recording in the field. The recorded GPS Geodetic data present northing, easting, and altitude coordinates, all connected to the WGS 84/UTM coordinate system zone 51 N and corrected via Continuously Operating Reference Station managed by the Geospatial Information Agency (CORS GIA), located at Sam Ratulangi International Airport. The GCP data recording results are provided in Table I.

TABLE I. GCP RECORDING COORDINATES

Name	Easting (m)	Northing (m)	Altitude(m)
GCP001	708563.667	173311.843	131.455
GCP002	709171.167	173234.09	135.098
GCP003	710214.444	173350.747	127.738
GCP004	711132.335	173844.303	119.818
GCP005	711733.426	173614.278	107.877
GCP006	712166.938	172303.351	134.284

B. *Orthophoto Processing*

The first step in the orthophoto processing is the alignment of photos. The acquired aerial photos are combined to form a single large photo. In this study area, drone flight once complete can undergo data processing for photo alignment (Table II).

TABLE II. ALIGNMENT IMAGE RESULTS

Name	Result
Number of images	2,549
GSD	1.62 cm/pix
Coverage area	0.705 km^2
Tie point	2,189,594

The orthophoto presentation displays aerial photography images that have undergone geometric correction for images with accurate scale and alignment with the existing map or layout to be produced (Figure 1).

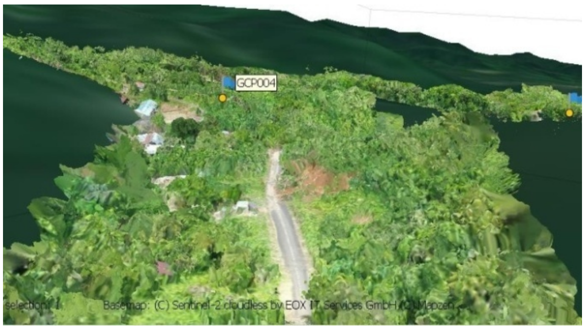

Fig. 1. Orthophoto results.

C. *Horizontal and Vertical Accuracy*

The formulas for calculating horizontal and vertical geometric accuracy analysis, based on [21] regarding the technical guidelines for basic map accuracy, are:

$$RMSEr = \sqrt{\frac{\sum[(X_{data} - X_{check})^2 + (Y_{data} - Y_{check})^2]}{n}} \quad (1)$$

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

where *RMSEr* is the Root Mean Square Error at *x* and *y* positions (horizontal), *RMSEz* is the Root Mean Square Error at z position (vertical) , *n* is the total number of checks on the map, *X* is the coordinate value on the X-axis, *Y* is the coordinate value on the Y-axis, and *Z* coordinate value on the Z-axis.

Additionally, Circular Error 90% (*CE90*) and Linear Error 90% (*LE90*) values can be calculated based on the United States National Map Accuracy Standards (US NMAS) standard [21]:

$$CE90 = 1.5175 \times RMSEr \quad (3)$$

$$LE90 = 1.6499 \times RMSEz \quad (4)$$

Considering the data processing results, observed in Table III, the *RMSEr* value is calculated to be 0.00225 m. According to the US NMAS formula:

$$CE90 = 1.5175 \times 0.00225 = 0.003 \text{ m}$$

Therefore, the horizontal accuracy value obtained for the planimetric coordinate accuracy test from the results of aerial photo mapping is 0.003 m.

TABLE III. 90% ACCURACY CALCULATION RESULTS IN THE HORIZONTAL ACCURACY TEST

Point name	**X map**	**X check**	**dx**	**dx^2**	**Y map**	**Y check**	**dy**	**dy^2**	**dx^2 + dy^2**
GCP001	708563.666	708563.667	0.0010	0.0000010	173311.842	173311.843	0.0013	0.0000017	0.0000026
GCP002	709171.167	709171.167	-0.0005	0.0000002	173234.090	173234.090	-0.0003	0.0000001	0.0000003
GCP003	710214.45	710214.44	-0.0026	0.0000068	173350.747	173350.747	0.0001	0.0000000	0.0000068
GCP004	711132.335	711132.335	0.0001	0.0000000	173844.303	173844.303	0.0002	0.0000000	0.0000000
GCP005	711733.426	711733.426	0.0004	0.0000002	173614.282	173614.278	-0.0041	0.0000166	0.0000168
GCP006	712166.937	712166.938	0.0012	0.0000015	172303.350	172303.351	0.0015	0.0000022	0.0000037
Sum									0.00003
Average									0.00001
RMSEr									0.00225
Horizontal Accuracy 90%									0.003

Moving on to the vertical accuracy test, the data processing results, illustrated in Table IV, yield an *RMSEz* value of 0.00383 m. According to US NMAS formula:

$$LE90 = 1.6499 \times 0.00383 = 0.006 \text{ m}$$

Thus, a value of 0.006 m is obtained for the vertical accuracy.

TABLE IV. 90% ACCURACY CALCULATION RESULTS IN THE VERTICAL ACCURACY TEST

Point name	**Z map**	**Z check**	**dz**	**dz^2**
GCP001	131.455	131.455	0.0001	0.0000000
GCP002	135.092	135.098	0.0063	0.0000400
GCP003	127.737	127.738	0.0005	0.0000003
GCP004	119.812	119.818	0.0062	0.0000380
GCP005	107.874	107.877	0.0026	0.0000068
GCP006	134.282	134.284	0.0018	0.0000031
Sum				0.00009
Average				0.00001
RMSEz				0.00383
Vertical Accuracy 90%				0.006

Table V presents the results of the horizontal and vertical accuracy tests for map accuracy, compliant with the 1:1000 scale [21]. The road falls under class 1, which has a maximum accuracy requirement of 0.3 m for horizontal accuracy and 0.2 m for vertical accuracy.

TABLE V. CE90 AND LE90 TESTS FOR 1:1000 SCALE MAP ACCURACY

Accuracy	**CE90 and LE90 Test Results (m)**	**Accuracy Map Scale 1:1000**		
		Class 1 (m)	**Class 2 (m)**	**Class 3 (m)**
Horizontal	0.003	0.3	0.6	0.9
vertical	0.006	0.2	0.3	0.4

Concerning the analysis results mentioned earlier, including data acquisition, orthophoto generation, GCP accuracy analysis, and map layout, Figure 2 provides an overview of the entire process.

D. *Road Geometric Review*

Regarding the road classification and functions, Wori Street, extending from Pandu Village to Adipura Raya Street, in Kima Atas Village, Mapanget District is classified as a collector road, which serves transportation with medium-distance travel characteristics, maintaining a moderate average speed ranging from 50 to 60 km/h.

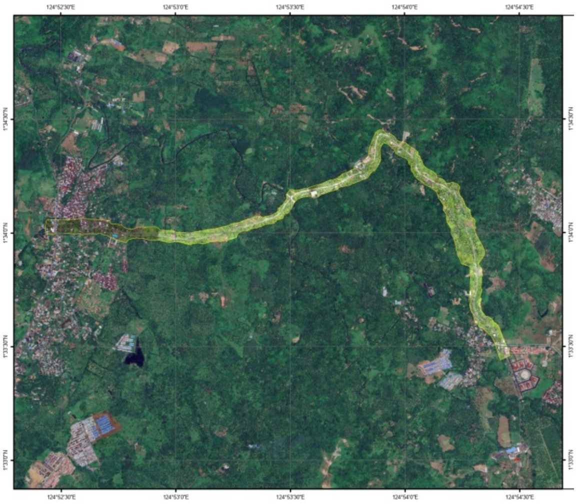

Fig. 2. Road layout.

TABLE VI. PI COORDINATES

Point	**COORDINATES**	
	X	**Y**
A	708554.1337	173310.5633
B	708951.8352	173300.6012
C	709160.4398	173235.6447
D	709421.7916	173231.3535
E	709703.1318	173186.1441
F	710357.6986	173398.7402
G	710482.5085	173583.7004
H	710820.5366	173646.1649
I	711063.6106	173770.1334
J	711133.8020	173841.2879
K	711149.7152	174120.7713
L	711459.7763	173859.1925
M	711483.6427	173740.0272
N	711757.4695	173600.7939
O	711994.1722	172967.8538
P	711915.8446	172627.1656
Q	712109.0529	172464.2665
R	712195.0120	172239.4040

The Point of Intersection coordinates along the road in the study area can be seen in Table VI.

E. *Horizontal Alignment Review*

The review of the horizontal alignment for the existing road, Wori Street, ranging from Pandu Village to Adipura Raya Street in Kima Atas Village, Mapanget District, revealed a total of 16 bends. Among these bends, there are seven types of Spiral-Spiral (S-S) curves and nine types of Spiral-Circle-Spiral (S-C-S) curves. Upon calculation, it was found that five curves do not meet the standard requirements. For a collector road with a design speed of 50 km/h, the minimum radius requirement is *Rmin* = 90 m. The five curves that fall short of this standard are bends numbered 8, 9, 10, 11, and 12. Their radius values are below the minimum specified value of 90 m. The results of these calculations are presented in Table VII. This indicates that these five curves need to be redesigned or adjusted to meet the minimum radius requirement for safe and efficient travel on the road.

TABLE VII. CALCULATION RESULTS

Type of curve	**PI**	**Δ** (°)	***Vd*** **(km/h)**	***e*** **(%)**	***Rd*** **(m)**	***θs*** **(°)**	***Ys*** **(m)**	***Xs*** **(m)**	***K*** **(m)**	***P*** **(m)**	***Lc*** **(m)**	***Ts*** **(m)**	***Es*** **(m)**
S-S	1	15.86	50	8	150	7.93	1.92	41.44	20.75	0.48	5.49	41.71	1.93
S-S	2	16.35	50	8	175	7.93	2.38	49.85	24.96	0.60	15.88	50.19	2.40
S-S	3	8.18	50	8	300	4.10	1.02	42.85	21.43	0.26	17.80	42.92	1.02
S-C-S	4	27.12	50	8	500	13.56	18.67	235.35	118.12	4.73	218.87	239.86	19.21
S-S	5	37.99	50	8	90	18.99	6.60	59.03	29.73	1.69	16.60	61.30	6.98
S-C-S	6	45.52	50	8	120	22.76	12.62	93.83	47.41	3.28	55.11	99.13	13.69
S-C-S	7	16.55	50	8	300	8.28	4.17	86.49	43.30	1.05	61.43	87.09	4.22
S-C-S	8	18.37	50	8	50	9.18	0.87	15.99	8.01	0.22	23.90	16.13	0.87
S-S	9	41.35	50	8	50	20.68	4.34	35.62	17.96	1.12	3.92	37.25	4.63
S-C-S	10	126.89	50	8	40	63.45	32.70	77.73	41.94	10.58	53.37	143.16	73.15
S-S	11	38.52	50	8	70	19.26	5.27	46.53	23.44	1.36	9.01	48.75	5.59
S-C-S	12	45.52	50	8	75	25.86	10.19	66.33	33.61	2.68	99.88	71.26	11.32
S-C-S	13	42.54	50	8	130	21.27	11.95	95.20	48.03	3.09	57.30	99.85	12.82
S-C-S	14	33.45	50	8	300	16.72	17.04	173.66	87.32	4.35	149.59	178.79	17.80
S-C-S	15	62.81	50	8	110	31.40	22.03	116.97	59.65	5.92	79.27	130.42	25.82
S-S	16	28.94	50	8	90	14.47	3.83	45.18	22.68	0.97	2.43	46.16	3.95

F. Vertical Alignment Review

Vertical alignment is a crucial aspect of road design, as it involves determining the height and elevation changes along the road, typically expressed as the slope of the road related to the horizontal line. This slope can be measured as the difference in height between two points, such as the reduction of the final stationary elevation and the initial stationary elevation. For the specific case in the study area, it has been found that the road generally complies with the standard requirements. The existing slope of the road is below 8% except at Sta.1+800 and Sta. 1+900, as shown in Table IX, which overall meets the standard guidelines for the maximum slope allowed [32] (Table VIII). Maintaining slopes within the acceptable range is important for ensuring safe and efficient transportation on the road. A slope below 8% typically provides a comfortable and manageable driving experience for vehicles traveling along the road. It also helps prevent potential issues related to steep gradients, such as vehicle stability concerns.

TABLE VIII. MAXIMUM SLOPE

Specifications for the provision of road infrastructure	**Maximum Slope (%)**		
	Flat terrain	**Hill field**	**Mountain terrain**
Freeway	4	5	6
Highway	5	6	10
Medium Road	6	7	10
Small Road	6	8	12

TABLE IX. EXISTING ROAD SLOPE

Station	**Slope Existing (%)**	**Station**	**Slope Existing (%)**	**Station**	**Slope Existing (%)**	**Station**	**Slope Existing (%)**	**Station**	**Slope Existing (%)**
0+000	3.61	1+100	4.93	2+200	0.65	3+300	0.30	4+400	3.66
0+100	2.88	1+200	3.06	2+300	0.27	3+400	7.66	4+500	1.28
0+200	4.71	1+300	2.27	2+400	1.37	3+500	0.29	4+600	5.38
0+300	1.38	1+400	5.05	2+500	4.46	3+600	0.23	4+700	4.43
0+400	5.63	1+500	2.46	2+600	3.53	3+700	1.16	4+800	5.63
0+500	3.60	1+600	4.55	2+700	7.52	3+800	3.42	4+900	7.26
0+600	0.13	1+700	4.23	2+800	2.34	3+900	6.42	5+000	7.72
0+700	3.49	1+800	8.99	2+900	6.72	4+000	2.13	5+100	5.92
0+800	3.39	1+900	14.73	3+000	0.97	4+100	2.59	5+200	6.66
0+900	2.34	2+000	0.51	3+100	5.68	4+200	1.70	5+225	6.11
1+000	2.85	2+100	3.20	3+200	3.73	4+300	2.08		

IV. CONCLUSION

The utilization of Unmanned Aerial Vehicle (UAV) technology has demonstrated its potential to bring innovation and efficiency to surveying and mapping road infrastructure. The use of UAVs in road mapping has been shown to produce accurate data in a more efficient manner, both in terms of time and cost. By integrating UAVs with Global Navigation Satellite System (GNSS) technology, the data collected can achieve high accuracy, leading to more precise and detailed road maps and geometric road reviews.

This study successfully generated orthophoto map using a UAV, covering a 5-km area. The analysis of horizontal accuracy (*CE90*) and vertical accuracy (*LE90*) of the base map indicates that the position errors do not exceed the specified accuracy values with a 90% confidence level.

The road alignment review revealed that the Wori Street section, spanning from Pandu Village to Adipura Raya Street in Kima Atas Village, Mapanget District, represents a collector road with a speed limit of 50 km/h. Among the sixteen bends on this road section, eleven of them meet the Indonesian Highway standard. Additionally, the existing road slope adheres to the slope requirements, staying below 8%.

Overall, the employment of UAVs for road mapping and road geometric review significantly contributes to optimizing the use of this technology, improving efficiency, accuracy, and sustainability in road infrastructure mapping and surveying.

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