EVALUATING THE QUALITY OF DIGITAL DATASETS IN TERMS OF AVIATION SAFETY DERIVED FROM STEREO SATELLITE IMAGERY IN SARAWAK, MALAYSIA'S AIRPORTS

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ABSTRACT:

High-resolution satellite imagery offers new possibilities in geospatial data acquisition, particularly in 3D city modeling, topographic mapping, and aviation safety. This study evaluates the quality of digital datasets generated from satellite imagery for five airports in Sarawak, as part of the eTOD (Electronic Terrain and Obstacle Data) project conducted by the Civil Aviation Authority of Malaysia (CAAM). The airports under examination include Miri Airport (WBGR), Bintulu Airport (WBGB), Mukah Airport (WBGK), Sibu Airport (WBGS), and Kuching Airport (WBGG). A comprehensive assessment was conducted to evaluate accuracy and reliability by combining stereo satellite imagery with on-site validation. The study yielded digital datasets of exceptionally high accuracy and reliability. The overall error rate remained below 3%, with a mean error value of 0.96 meters across all five airports. Notably, it has been observed that using satellite images as the only data source creates difficulties in detecting Power Transmission Lines and Poles that require precise detection. A multifaceted approach was adopted to increase the detection accuracy, involving site verification measurements, incorporation of external source data (Sarawak Energy Company), and manual interpretation.

In conclusion, this study underscores the significant potential of very high-resolution satellite imagery for creating precise and reliable digital datasets for aviation safety. Additionally, the study's emphasis on detecting Power Transmission Lines highlights the need for advanced methods to improve accuracy in challenging scenarios. These findings not only contribute to enhancing aviation safety but also provide valuable insights into the utilization of satellite imagery for similar applications worldwide.

1. INTRODUCTION

Aviation safety is the set of measures and practices aimed at preventing accidents and ensuring air travel safety. It emphasizes the identification of potential dangers and the evaluation of associated risks. Within the aviation safety domain, Obstacle data in aviation refers to information about physical objects and obstructions near or around airports and flight paths that could pose a risk to aircraft during take-off, landing, or while in flight. These obstacles include buildings, towers, trees, terrain features, and other structures that may interfere with safe aircraft operations. Collecting, and maintaining obstacle data with high accuracy is essential for ensuring aviation safety. It plays a significant role in aviation safety by helping aviation professionals identify potential hazards and plan flight operations to avoid obstacles and ensure the safety of passengers and aircraft.

Digital datasets in aviation refer to the collection, storage, and analysis of digital data relevant to various aspects of the aviation industry. This data can encompass a wide range of areas such as flight, safety, real-time monitoring, innovation, and research data. The Digital Obstacle Dataset (DOD) in aviation is a critical component for ensuring flight safety and aiding in navigation. It primarily consists of information about various obstacles that aircraft might encounter during flight. These obstacles can range from natural terrain features to man-made structures. It is a compilation of data regarding physical obstacles that are significant to aviation. This includes buildings, towers, wind turbines, tall trees, and geographical features like mountains or hills. The primary purpose of the DOD is to aid in flight planning and to ensure that flight paths are safe and free from potential hazards. The data for the DOD is gathered from various sources, including satellite imagery, ground surveys, and reports from government agencies or private entities. In some cases, data is also sourced from public infrastructure projects, like the construction of new buildings or communication towers. This study is primarily focused on collecting digital terrain and obstacle datasets derived from very high-resolution (VHR) satellite imagery, which is pivotal for advancing aviation safety. Another key aspect of the research involves a meticulous evaluation of the quality of these digital datasets through the incorporation of external source data within a Geographic Information System (GIS) environment and complemented by on-site verifications. This evaluation and verification process is being undertaken as part of the eTOD project, conducted by the Civil Aviation Authority of Malaysia (CAAM). One of the project's goals is to assess the quality of digital datasets created from high-resolution satellite images, identify potential obstacles, and perform comprehensive analyses to contribute to the overall improvement of aviation safety.

2. STUDY AREA

The study area covers five airports situated in the Sarawak Region of Malaysia along with the critical surfaces of these airports determined by ICAO for aviation safety. Airports examined include Miri Airport (WBGR), Bintulu Airport (WBGB), Mukah Airport (WBGK), Sibu Airport (WBGS) and

Kuching Airport (WBGG). Obstacle data was collected for each airport's critical surfaces for aviation safety (Figure 1) denoting obstacle data collection surfaces. Each airport, spanning an area between239-455km²,(WBGR-318km²,WBGB-320km², WBGK-239km², WBGS-428km², WBGG-455km²), collectively covers a total area of 1760 km². The region exhibits a tropical climate, characterized by a predominant vegetation of palm trees.

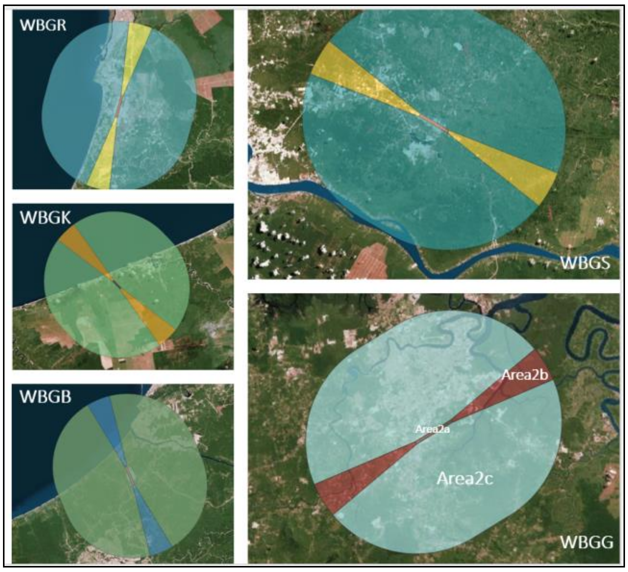

Figure 1. Study Area: SARAWAK Region Airports and the critical surfaces (Area-2abc) of these airports determined by ICAO for aviation safety.

3. METHODOLOGY

The methodology starts by identifying study areas – obstacle data collection surfaces defined by ICAO. Employing satellite images from stereo image pairs with Ground Sampling Distance (GSD) of 30 cm and 50 cm, the approach involves detailed 3D object detection and drawing constituting the process of Digital Obstacle Data Collection. Subsequently, the methodology progresses with satellite image block adjustment and advances to the creation of Digital Terrain Models (DTM) and Digital Surface Models (DSM) for complex terrain representation. Following the 3D surface analysis, the generation of an orthophoto is initiated. This is followed by creating 3D objects and the integration into Geographic Information Systems (GIS). Figure 2 shows a schematic of the general methodology followed during this project for acquiring 3D obstacle data using satellite imagery and measuring data quality. Detailed descriptions of each sub-section are provided in the following sections.

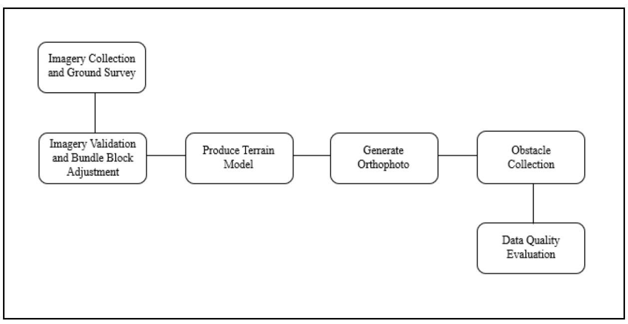

Figure 2. Methodology schema used in this study.

3.1 Satellite Imagery Block Adjustment

In the world of modern aviation, cutting-edge satellite systems provide detailed insights into the Earth's surface, airside situations, and essential navigation tools, significantly enhancing the safety and efficiency of air travel. For this study, stereo satellite images were obtained by assigning five different satellites from two alternative providers, Maxar and Airbus. Airbus supplied satellites Pleiades (with a resolution of 50 cm), Pleiades Neo 3 (with a resolution of 30 cm), and Pleiades Neo 4 (also with a resolution of 30 cm), which operate at an orbital altitude ranging from 620-620-624 km. Satellites GeoEYE-1 (resolution of 50 cm), WorldView-2 (resolution of 50 cm), and WorldView-3 (resolution of 30 cm), operating at an orbital altitude between 617 and 681-70 km, were provided by Maxar.

By checking whether there was a cloud and its compatibility with the project area, the stereo images were combined for processing using the photogrammetric method. For a comprehensive understanding, the following table (Table 1) provides detailed information about the satellite images and their respective providers utilized in this study.

Table 1: Satellite Images Resolutions of SARAWAK Region's Airports

ICAO CODE	RESOLUTION		BAND COMBINATION	INCLUDED FILES
	30 cm	50 cm		
WBGR (Miri Airport)		x	Pan-sharpened Color	3-Band, 1-File RGB
WBGB(BintuluAirport)	x		Pan-sharpened Color	3-Band, 1-File RGB
WBGK(MukahAirport)		x	Pan-sharpened Color	3-Band, 1-File RGB
WBGS (Sibu Airport)		x	Pan-sharpened Color	3-Band, 1-File RGB
WBGG(Kuching Airport)		x	Pan-sharpened Color	3-Band, 1-File RGB

In the process of using satellite imagery in this study, Bundle block adjustments were performed using GCPs (Ground Control Points) data to improve the position of the image blocks. The strategic distribution of GCPs across the project area established on suitable surfaces, was imperative for their effective utilization in Block Adjustment. Ground surveying methods, such as Real-time kinematic positioning (RTK) and Static Global navigation satellite system (GNSS) positioning techniques, were employed for GCP measurement. After network adjustment and various data processing procedures, the measured GCPs were prepared for utilization in subsequent stages of the project. Real-time kinematic and static observation techniques were used by field teams. In addition, efforts were made to minimize error sources such as multipath and signal obstacles to achieve higher accuracy. Within the scope of the project, references in the Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) and the Virtual Reference System (VRS) for certain regions were used. The accuracy calculation of GCPs served as a critical metric, evaluating how effectively their location on an image or map aligned with real-world coordinates. Satellite images from Pléiades, Pléiades Neo 3, Pléiades Neo 4, Geoeye, WorldView-2, and WorldView-3 were meticulously adjusted using GCPs measured in the field. The alignment of a group of overlapping satellite images through the Block Adjustment Method was a pivotal step, enhancing their spatial accuracy and consistency. Both automatic and manual Tie Points were established during the Block Adjustment process. Following the matching of images, certain tie points were eliminated through statistical and manual analyses. After all, images were matched, some tie points were eliminated through statistical and manual analyses. In the context of the project, block adjustment played a pivotal role in elevating the accuracy, consistency, and precise georeferencing of satellite images. By aligning and adjusting multiple images as a block, it effectively minimized geometric discrepancies and enhanced the quality of the final output.

3.2 Digital Terrain and Surface Model Generation – DTM, DSM

DSM and DTM serve as crucial data sources in the aviation industry. DSMs essential for flight path planning and the creation of climb/descent profiles for aircraft. They contribute significantly to the aviation sector's navigation, mapping, air traffic management, and flight simulation endeavours. These models are considered an important data source in the aviation industry and help to improve flight safety and efficiency. In the creation of DTM and DSM, mathematical models were established and associated with the terrain. Following these steps, the images were cleared and ready for the DSM generation phase, which is one of the finished products for 3D obstacle detection.

A highly detailed digital elevation model (DEM) of the study area was created using advanced image-matching algorithms. Refinements were applied to the acquired Digital Surface Model (DSM) data by associating it with the land structure and its surroundings. To generate DTM, a meticulous process was undertaken to eliminate non-ground elements, such as buildings, vegetation, and vehicles, present in the DSM (filtering process). To improve the accuracy of DTM, additional point elevations (3D Points) and break lines (3D Lines) were measured at certain intervals in the stereo-evaluating step. Figure 3 shows the example of DSM-DTM data produced at a remarkable 1-meter spatial resolution illustrating the precision achieved in representing the study area's topography.

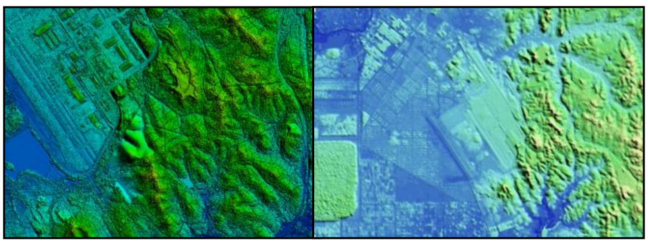

Figure 3. Example of Produced DSM (left) - DTM (right) for Obstacle Detection

3.3 Generation of 3D Obstacle Datasets in a GIS Environment: Integration of Orthophoto Production, Aviation Safety Surfaces Analysis, and Photogrammetric Evaluation

Following the meticulous completion of block adjustment and terrain modeling from the stereo satellite imagery, orthophotos were methodically generated to facilitate comprehensive visualization. This foundational step laid the groundwork for subsequent phases, encompassing 3D obstacle detection, aviation safety surfaces analysis for identifying areas that may be potential obstacles, and a photogrammetric evaluation. All stages are detailed in this section.

3.3.1 Orthophoto Creation: Orthophotos, integral to geospatial analysis, are meticulously produced through the processing of satellite or aerial images, incorporating corrections to eliminate distortions arising from terrain relief, camera or sensor tilt, and perspective variations. This significant step accurately represents the Earth's surface for subsequent stages. Upon the completion of the Digital Surface Model (DSM) and Digital Terrain Model (DTM) processing, orthophotos were systematically generated for object detection and 3D drawing. The inclusion of DTM in this process facilitated an accurate representation of the terrain in three dimensions, particularly emphasizing the bare soil surface. The ortho-mosaic outputs were derived from orthorectified satellite images after the work that requires manual labor, paying attention to the seam line transitions of each orthophoto. The final outputs were produced as 3-band RGB image with a spatial resolution of 0.3 and 0.5 meters and a radiometric resolution of 32 bits.

A thorough review of the orthophotos was conducted to identify and rectify any residual artifacts or inconsistencies. Particular attention was given to addressing cloudy areas, one of the challenges in the study area. To mitigate the impact of cloud cover, diligent efforts were made to complement these areas with data from cloudless images whenever available. Any necessary adjustments or edits were made to meet the desired quality standards.

3.3.2 Surface Analysis for Identification of Obstacle Areas: For each airport, critical surfaces defined by ICAO for aviation safety were created. Surface analysis was carried out to decide possible areas where obstacle detection would be performed. The surface analysis involves mathematical and statistical analyses of height data. A new grid value was calculated (or another grid value) layer by combining and/or comparing numeric values such as elevation-slope etc. from the DSM layer and aviation safety surfaces. Areas that penetrate on these specified surfaces were created and identified as possible obstacle data collection areas. After all these processes, the geometry of the resulting vector data is arranged. Output vector data are considered as reference limits for obstacle data collection areas. With using Stereo Model, 3D obstacle data were identified and digitized. Photogrammetric Stereo Evaluation technique which provides high accuracy and precision, was selected as an ideal method for this project in terms of obstacle collection. Figure 4 illustrates critical surfaces (as defined by ICAO for aviation) and DSM layers used in surface analysis on the left side. On the right side, the figure depicts a potential obstacle detection area arising from surface analysis.

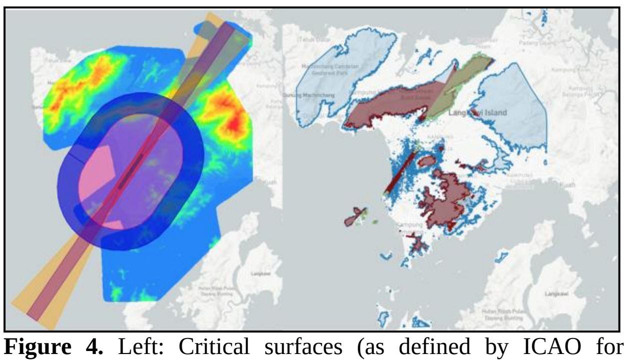

Figure 4. Left: Critical surfaces (as defined by ICAO for aviation) and DSM layers used in surface analysis. Right: Potential obstacle detection area resulting from surface analysis.

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3.3.3 Photogrammetric Stereo Evaluation: The Photogrammetric Stereo Evaluation technique which provides high accuracy and precision, was selected as an ideal method for this project in terms of obstacle collection. The purpose of this methodology is to digitize and compile topographic data for vertical obstacles using photogrammetric evaluation of satellite imagery. The meticulous process of photogrammetric stereo evaluation involves utilizing digital stereo aerial or satellite image pairs processed through specialized software designed for stereo vision. Hardware compatibility with this software is extremely important and highlights the need for experienced operators. The execution of this stage is carried out by adhering to a drawing method that is created following national and international aviation priorities and emphasizes its critical nature. In this process, the three-dimensional coordinates of each point are determined by considering the shooting angles and distances between the photos. These coordinates can be visualized as three-dimensional maps, models, or point clouds later using computer programs. The choice of geometry structure (point-line polygon) for the stereo photogrammetry drawing is methodically determined in the feature capture guide, aligning with the obstacle's footprint and real-world characteristics.

During this process; as a first step, surface analysis was performed to find obstacle areas on certain surfaces. The surface analysis involves mathematical and statistical analyses of height data. As a result of this analysis, a vector polygon area was obtained. These areas will be used to detect and collect obstacle data in 3D space by using photogrammetric stereo models.

3.3.4 Digital Obstacle Data Collection: After drawing 3D obstacles with their vertical information (height and elevation) in a CAD environment, a structured dataset of Coordinate Reference Systems and Coordinate Transformations was generated. The horizontal and vertical reference systems were specified with the World Geodetic System - 1984 (WGS84) set as the horizontal reference system and the mean sea level (AMSL) datum based on the Earth Gravitational Model -1996 (EGM-96) was set as the vertical reference system for this project. Data collection adhered to criteria in the reference documents ensuring analysis within a data sensitivity below 3 m. The data were collected to meet the numerical requirements specified in the reference documents (EUROCONTROL eTOD Manuel Ed. 3.0, ED-98C, ED-119C, PANS-AIM DOC 10066).

After designing the database structure according to aviation obstacle data standards in a GIS environment, GIS transformation/integration was conducted following for main process. GIS Integration four main processes were followed. The first process involved creating a feature database structure and defining the minimum required set of attributes in the GIS environment. The second process included a mathematical transformation for attribute values. The third process verified the dataset and in the final step, all obstacle datasets were evaluated for data quality. Metadata was created for all geographic datasets. After completing the stereo-digitizing process, data cleanup, standardization, and attribute data implementation were performed, resulting in products containing 3D Digital Obstacle Data.

After generating the 3D obstacle data, a comparison with external sources for data accuracy and quality, and a comparison of random samples of the data with the results of measurements in the field were performed. The next section describes the methods and results of this data quality and reliability analysis.

Figure 5 depicts 3D obstacle data generated through stereo photogrammetry within the GIS environment.

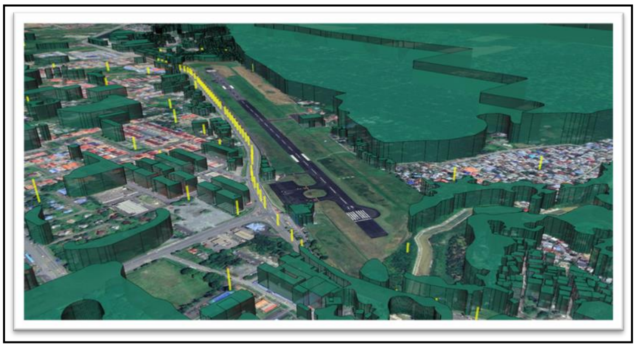

Figure 5. 3D Obstacle data created from Stereo Photogrammetry & GIS Environment

4. EVALUATION OF 3D DATASET FOR FIVE AIRPORTS IN SARAWAK IN TERMS OF AVIATION SAFETY (SITE VERIFICATION & OTHER OUTSOURCES)

A comparison was made from different sources (geographically) to check data validation and quality. Fundamental methods employed included the accuracy assessment of Ground Control Points (GCP), on-site verification, cross-referencing with published external sources (AIP - Aeronautical Information Publication, and Sarawak Energy), and alignment with measurements from on-site verification.

The initial quality evaluation focused on GCP's accuracy. This involved examining the accuracy of the geometric model across the entire dataset through GCP accuracy calculation with a 90% confidence level. This methodology is based on comparisons of stereo measurements and Site/Ground measurements of GCP Points. Vertical and horizontal accuracy levels ranged from 0 to 1.36 meters, primarily below 1 meter, with a 90% confidence level in GCP measurements.

The second evaluation method was AIP – Aeronautical Information Publication data comparison. The obstacles identified by using remote sensing and the AIP (Aeronautical Information Publication) obstacles published by the government were compared and analysed in terms of geographic location, elevation, height, and obstacle status. The GAP analysis is one of the output products of the project methodology was used during this comparison, according to stereo measurement results of obstacles and published AIP obstacles.

The other evaluation method was Site/Ground Verification. Site Verification is a widely used term in multiple disciplines, referring to information that is deemed factual and reliable, obtained through direct observation and measurement (i.e., empirical evidence), as opposed to information derived through inference. Stereo images, as one of the principal applications of remote sensing methods, were utilized to detect 3D obstacle datasets, which encompass electronic terrain and obstacle data. Site verification study of 3D Digital Obstacle Data involves the acquisition of data from stereo satellite imageries, which are then processed and analysed to identify and classify obstacle features. During Site Verification analysis, sample data was meticulously chosen to ensure the precision of obstacle data extracted from satellite images. The selection process entailed the consideration of aviation safety criteria and the even distribution of points, with critical areas taking precedence based on multiple factors such as aircraft movement in the airside and on the ground, Balked Landing Procedures, and runway expansion. During this study, site measurements were meticulously performed using a combination of a Total Station and GNSS observation technique. To acquire GNSS data, the highly accurate CHC i80 GNSS Receiver was utilized, while the Total Station survey was conducted using the CHCNAV CTS-112R4. The use of these cutting-edge instruments ensured the precision and reliability of the data collected. The methodology of Site verification studies on WBGR, WBGB, WBGK, WBGS, and WBGG airports involves two key steps: selection of field verification points and determination of measurement methods. The first step is to extract all obstacles of 5 airports from the GIS system. The primary step entails identifying critical areas relevant to flight operations. Since obstacles within these areas present the biggest threat to aviation safety, where criterion holds utmost significance.

The external source data (SARAWAK ENERGY) dataset was used as a final evaluation method for this study. Figure 6 shows the comparison of the Transmission Line Tower data detected by remote sensing methodology using satellite imagery with the data provided by Sarawak energy and its relationship with aviation safety surfaces. The data were analyzed both spatially (x-y value) and in terms of elevation (z-value) and gaps and differences were identified. Red cylinders show the position and height of the Power Transmission Line (PTL) Towers detected from satellite images and yellow cylinders show the position and height of the Power Transmission Line taken from Sarawak Energy Company. The results show that while the location of PTLs can be detected 90% of the time from satellite imagery (undetected PTLs were observed in densely forested areas and areas between high-rise buildings), there is a discrepancy in heights with Sarawak energy data.

4.1 Calculation of error rates according to the differences between elevation (z values & geographic location (x-y value) from 3 Sources (Site verification & other outsources)

In this part of our study, a spatial analysis of the 3D Obstacle dataset obtained from satellite imagery using remote sensing technology was performed by comparing it with the site verification measurement. Evaluation of the x-y-z value of obstacle obtained from the satellite image and obtained from site verification analysis to see the data accuracy level. The evaluation was made by comparing both the spatial (x-y value) and elevation (z value) analysis. In terms of spatial analysis, 96% accuracy was achieved for the geographical location of an obstacle detected from satellite imagery. In 70 sample obstacle measurements at 5 airports, the x-y position differences between stereo photogrammetry and site measurements were less than 1-meter for 67 samples, and errors up to 3-meter were observed for tall buildings and tall structures such as power poles, towers, etc.

In terms of aviation safety, the error rate up to 5 meters horizontally (x-y direction) in the geographical location of the obstacle provides a 90% confidence level. As a result, it is observed that the accuracy and reliability of spatial information in aviation obstacle detection from satellite imagery is quite high.

In aviation safety, the accuracy of the height-elevation information is as important as the location of an obstacle. In aviation, the procedure designs planned for the safe landing and take-off of airplanes are planned based on the z-value of obstacle data, and the reliability and low error rate in z-values are vital to prevent the risk of accidents. In the next stage of the analysis, the accuracy and reliability of the z-values in the data obtained using satellite imagery were evaluated with site verification and other sources.

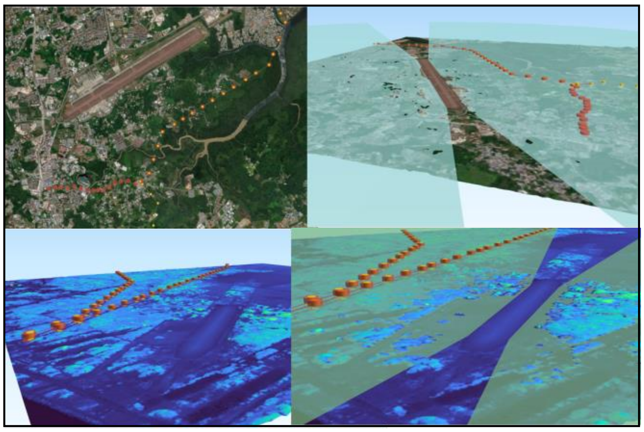

Figure 6. Z Value Comparison for PTL Tower in GIS. Red cylinders represent satellite-detected heights, and yellow cylinders represent heights from Sarawak Energy Company.

In the comparison of elevation values (AMSL) for 70 sample obstacle points across 5 airports (WBGR-WBGB-WBGK-WBGS-WBGG) between site verification and stereo photogrammetry measurements. It was found that 65 of 70 sample obstacles had matching measurement points, with elevation differences staying below the 3-meter tolerance level. For the remaining 5 sample obstacles that exceeded the 3-meter tolerance level on elevation, a closer examination revealed that these differences mainly occurred in high-rise buildings, trees, and transmission line towers.

The evaluation result shows that rig-transmission line tower obstacles can be challenging in 30-50 cm resolution stereo measurement. As a solution to this situation, an error rate analysis was performed using SARAWAK region power line location and elevation data from outsourced data (SARAWAK Energy). The transmission line tower dataset from SARAWAK Energy was digitized in a GIS environment and then z-values were compared with stereo photogrammetry measured data. A comparison of the z value of the obstacle obtained from the satellite image and obtained from site verification analysis & SARAWAK Energy Data were evaluated to understand the challenges and efficiency of the satellite imagery - remote sensing method in obstacle detection.

4.2 Results

Site Verification comparison results demonstrate a high level of accuracy and reliability, with an overall error rate of less than 3% and a mean error value of 0.96 meters for airports with WBGB, WBGG, WBGK, WBGR, and WBGS having mean error values of 0.65, 1.09, 0.72, 0.94 and 1.40 m, respectively indicating that the validated data is reliable for aviation safety purposes (Table 2). Considering the GCP accuracy values below 1-meter, results below the 3-meter tolerance level of 93% were observed in detecting obstacles from satellite imagery, especially for building structures. It has been observed that remote sensing method with satellite imagery provides data with high accuracy and reliability in large structures such as buildings. Despite these promising results, the study also highlights some challenges in using stereo satellite imageries for measuring Radio Tower and Transmission Line Tower obstacles, due to the high error rate associated with the 30-50 cm GSD resolution. Moreover, atmospheric conditions such as haze and fog can affect the accuracy of stereo measurements, emphasizing the need for additional data from ground or 3D sources to enhance aviation safety.

Table2: SiteVerification- Stereo Photogrammetry Measurement Comparison in 5 Airports on the SARAWAK Region

	OVERALL	**WBGB**	**WBGG**	**WBGK**	**WBGR**	**WBGS**
Measure Compared	70	7	22	9	22	10
Below-3m ToleranceLevel	65 (93%)	7	20	9	21	8
Above3m ToleranceLevel	5 (7%)	0	2	0	1	2
Average Error	**0.95**	**0.65**	**1.08**	**0.72**	**0.9**	**1.4**

Since the error rates of the Transmission Line Tower detections made using satellite images obtained according to the field verification results were higher, these data were analyzed in detail by supporting these data with external sources and because of the analysis made in the GIS environment, the accuracy rate was increased by making the necessary mathematical calculations and the data quality was increased.

Table 3: SARAWAK Energy Data - Stereo Photogrammetry Data COMPARISON (AGL) in 3 Airports on SARAWAK Region

SARAWAK Energy Data - Stereo Photogrammetry Data COMPARISON (AGL)					
	OVERALL	**%**	**WBGB**	**WBGG**	**WBGK**
Measure Compared	142		56	38	48
Below 3m ToleranceLevel	108	76%	47	30	31
Above 3m ToleranceLevel	34	24%	9	8	17
Average Error	**2.43**		**1.78**	**2.17**	**3.34**

To improve the issue of the challenges on Transmission Line Towers, the Sarawak energy dataset was evaluated for 3 airports (WBGB-WBGG-WBGK). Transmission line towers at WBGR - WBGS airports did not penetrate aviation safety surfaces, because of this data were not evaluated from stereo photogrammetry. For 3 airports (WBGB-WBGG-WBGK), SARAWAK Energy data and stereo photogrammetry measurements were compared for 142 transmission line tower data. The 108 of 142 comparison results show that the value error rate was below the 3-meter tolerance level. On the other hand, 34 of 142 comparison results were above the 3m tolerance level. The average error of the z value was examined at 2.43 meters (Table 3).

In the overall analysis of z values, satellite imagery sometimes yields values higher or lower than those in the SARAWAK Energy dataset and site verification dataset. The average error rate for data with errors exceeding a 3-meter tolerance level in z values is around 7-8 meters. To ensure aviation safety, a 10-meter safety buffer was applied to power lines measured by stereo photogrammetry.

4.2.1 Hybrid Solution by Using Outsource Data: The data provided by Sarawak Energy was compared with the data obtained by satellite imagery using remote sensing in terms of spatial and elevation in a GIS environment. As a result of this comparison, electricity poles and lines that could not be detected in the satellite image were detected in some areas. In terms of the height of the data in these areas, the heights of DSM-DTM and SARAWAK Energy data were compared, and the ambient height values were taken and added to the dataset.

In the satellite image, missing or incorrect detection of elongated structures such as electricity poles was observed. It is obvious that this methodology needs to be confirmed and supported by other external source data. In the comparison, missing power lines were detected 1.5-2km south of the runway at WBGG airport. The heights in these areas were then compared using DSM-DTM and missing data were added to the dataset. Figure 6 shows that yellow dots represent the transmission line towers detected from satellite images and red dots represent the data taken from SARAWAK Energy. Unidentified transmission line towers are critical to aviation safety. In the case of WBGG, the lines located in the bulk landing area, where aircraft pass through when they cannot land, could not be identified from satellite imagery. This data is of critical importance as it increases the risk of accidents during flight. Data that could not be detected from satellite imagery were analyzed and their heights were calculated by DSM-DTM evaluation and safety surface piercing and obstruction data were analyzed and their heights were calculated and added to the dataset. With this multiple comparisons and holistic evaluation method, the deficiencies/inadequacies in 3D obstacle detection with satellite imagery were eliminated with the support of external resources, and the data quality was improved.

5. CONCLUSION AND DISCUSSION

The primary objective of this study was to employ remote sensing techniques for the identification of 3D obstacles from satellite imagery while assessing the accuracy and reliability of the acquired data. Despite these promising results of the accuracy values in the GCP evaluation being below 1 meter, the study also highlights some challenges in using stereo satellite imageries for measuring Radio Tower and Transmission Line Tower obstacles, due to the high error rate associated with the 30-50 cm GSD resolution. Despite achieving reliability is 90% and above for structures such as buildings through the stereo evaluation method, the study reveals a notable challenge in detecting thin obstacles like power lines with relatively high error rates. Stereo satellite imagery emerges as a valuable tool for the identification and classification of terrain and obstacles especially for fine structures like radio towers, transmission line towers, and power poles, determining of z-values (height) can be affected by a variety of factors, including atmospheric conditions such as haze and fog, as well as factors such as radiometric resolution, spectral reflectance, and parallax. These influencing factors significantly affect the accuracy of stereo measurements, especially for thin and long obstacles such as power lines in forested areas. When the samples with erroneous heights in PTL Towers were analysed, it was observed that the error rate was higher in densely forested areas. It is concluded that the use of satellite imagery with a geometric resolution of 3m in the formation of DTM - DSM in these areas cannot exhibit accurate sampling results. As a result, higher altitude stereo measurements were considered to stay on the safe side from an aviation perspective. However, it is important to note that a detailed aviation study needs to be conducted using a methodology other than stereo imagery especially for critical structures such as mast-infrastructure-transmission line towers that create critical obstacles. Additionally, the study emphasizes the dynamic nature of obstacles such as trees, towers, and equipment, necessitating regular updates and measurements from external sources. Regular checks and evaluations are crucial to mitigate potential risks to aviation safety posed by these structures.

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