Integration of Aerial Photography, Airborne LiDAR, and Airborne IFSAR for Mapping in Malaysia

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Abstract. Aerial mapping is now widely used for plenty of applications especially in generating digital terrain models. In this Industrial Revolution 4.0 era, the digital product is integrated with each other to add a new value-added into industries. Therefore, the aim of this paper is to deliberate the integration process between aerial photography, airborne LiDAR, and airborne IFSAR for enhancing the airborne IFSAR quality and come out with new value-added aerial mapping products. The aerial photography was used to enhance the ORI IFSAR imagery through the image fusion method and LiDAR DTM was used to enhance the accuracy of IFSAR DTM through the DTM fusion method. For image fusion, the result shows that colorized ORI imagery (CORI) was generated. On the other hand, terrain profiling analysis was conducted to validate the result of DTM fusion based on using LiDAR DTM as a benchmark. The result shows that the fused DTM accuracy is nearest to LiDAR DTM compared to IFSAR DTM. This result also shows that new value-added aerial mapping products can be generated from this integration process.

1. Introduction

The development of spatial databases and data information management is crucial in this modern era. There is a cumulative demand for integrated spatial data to assist in decision making and development policies for both public and private sectors [1]. As part of the Industrial Revolution 4.0 (IR4.0) core, data integration activities are happening rapidly to meet the needs of stakeholders and national development [2]. Simultaneously, the mapping industries are actively integrating mapping data to improve existing data sources as stimulated by United Nations through the 12th goal of Sustainable Development Goals (SDGs) which to ensure sustainable consumption and production patterns [3].

Department of Survey and Mapping Malaysia (JUPEM) as mapping data providers in Malaysia have implemented the principle capture once used by many for more than 20 years [4]. Most data sources for mapping activities are obtained from an airborne platform such as aerial photography, Light Detection and Ranging (LiDAR) and Interferometric Synthetic Aperture Radar (IFSAR). For example, for Sabah state only, the airborne LiDAR acquisition has covered 1,463 square kilometers of Kota Belud, Sabah, Malaysia meanwhile airborne IFSAR acquisition consists of 37,000 square kilometers of Coastal Sabah and the Spratly Islands in Sabah. Despite two different sensors used to capture the data, it has a similar goal which is to generate 3D elevation terrain data based on project requirements [4]. As a national
mapping agency, the department has undertaken various modernization programs to improve the quality of its services and products. This paper sets out to aim of this paper is to deliberate the integration process between aerial photography, airborne LiDAR, and airborne IFSAR to enhance the airborne IFSAR quality and come out with new value-added aerial mapping products.

2. Characteristics Aerial Photography, Airborne LiDAR, and Airborne IFSAR

2.1. Aerial Photography
Aerial photography is one of the fundamental platforms using a passive optical sensor and being conducted for many years to collect the mapping information. The aerial photography principle is based on triangulation where the nadir photograph should be taken at least from two different locations or known as stereo pair [5]. Overlapping images either end-lap or side-lap are intersected in order to capture the 3D coordinates for the earth's surface. The angular field of view playing important role in the aerial photograph. There were three (3) types of angular views which are normal angle (70 to 50 degree), wide-angle (75 to 100 degree), and ultra wide-angle (100 to 130 degree) [6]. These angular fields of view are used based on the project requirement which is basically reflected from the side-lap requirement. The stereo-plotter was used to process the captured photographs where plenty of photographs involves because of the overlapping concept. Aerial photography data acquisition is limited to weather conditions but can cover much wider areas and suitable for the topography mapping application [7].

2.2. Airborne LiDAR
Light Detection and Ranging or LiDAR is one of the platforms that widely used to capture mapping information. LiDAR application is based on an active surface measurement technique that using an active sensor that emits Near-Infrared (NIR) (905-nm wavelength) to identify the spatial location of features on the earth's surface with high-density point data [8]. The vertical and horizontal positioning of an object can be measured through the identification of the time of pulse reflection and returning to the sensor based on the formula [9] as in Equation 1.

\[ D = r \times t / 2 \]  

- \( D \) = distance from the sensor to target object x 108 m/s
- \( R \) = rate of light speed
- \( t \) = the time taken for the pulse to return to the sensor
- \( 2 \) = process of light going and returning to the sensor

![Figure 1. Airborne LiDAR fundamental mechanisms](image)

There were some fundamental mechanisms used in airborne LiDAR acquisition that led to the identification of 3D terrain information including (i) the time difference between laser and beam reversal, (ii) the transmitted laser beam angle, and (iii) the detector location [10] as in Figure 1. The acquisition target (imagery and point cloud) is focusing on nadir acquisition with a typical incidence angle up to ±20 degrees. Currently, there is a hybrid sensor developed with the addition of an oblique camera to expand the imagery acquisition area for building facade coverage and generation of true-
orthophoto such as the CityMapper sensor by Leica Geosystem [11]. Unfortunately, airborne LiDAR is weather dependent, and area coverage is limited which only suitable for the corridor mapping application.

2.3. Airborne IFSAR
Interferometric Synthetic Aperture Radar or IFSAR is another platform that can be used to capture the mapping information. In order to operate, airborne IFSAR are not depending on the Sun’s radiation because it employs an active sensor that emits its microwave signal and receives the echoes to identify the spatial location of features on the earth’s surface [13]. The transmission time delay determines the different depths of the imaged terrain. The usual active wavelengths are X-band (2.40 to 3.75 cm wavelength) and P-band (30 to 100 cm wavelength) and both active wavelengths have different penetration abilities. The transmission of X-band signals can only reach the surface of features while the P-band signals can penetrate more before reflected to the sensor [14]. This is because the P-band signals have longer wavelengths compared to X-band signals. The acquisition target is focusing on the side-looking acquisition with typical incidence angles ranging from 30 to 60 degrees [14]. Airborne IFSAR data acquisition is not limited to weather conditions and suitable for the topography mapping application.

3. Airborne Data Acquisition Procedure and Product in Malaysia

3.1. Airborne Data Acquisition Procedure
There are some standard of procedures (SOP) that need to be complied with to conduct the data acquisition activity for the airborne platform in Malaysia. The SOPs for airborne data acquisition can be divided into two (2) main categories which are permit and flight planning. For permit application, there are three (3) permit need to be applied which are (i) flying permit from the Civil Aviation Authority Of Malaysia (CAAM), (ii) acquisition permit from the Department of Survey and Mapping Malaysia (JUPEM) and (iii) frequency permit from Malaysian Communications and Multimedia Commission (SKMM). On the other hand, for flight planning, there are four (4) main components that need to identify such as (i) number or ground control, (ii) flying height, (iii) strip overlap, and (iv) time. The details of the procedure for airborne aerial photography, airborne LiDAR, and airborne IFSAR as in Table 1.

| Table 1. Airborne data acquisition procedure in Malaysia |
|--------------------------------------------------------|
| **SOP** | **Airborne Aerial Photography** | **Airborne LiDAR** | **Airborne IFSAR** |
|________|________________|________________|________________|
| **Permit** | Flying permit | Required | Required | Required |
| Acquisition permit | Required | Required | Required | Required |
| Frequency permit | Not required | Not required | Not required | Not required |
| **Ground control** | 5-10 | 10-20 | 1-5 |
| Flying height | 4000 - 5000 feet | 1300 - 1500 feet | 27,000 - 38,000 feet |
| Flying speed | 100 - 120 knots | 90 - 100 knots | 200 - 400 knots |
| **Flight plan** | Overlap | Based on the project requirement | Multiple overlapping signal returns |
| Side lap | 60 - 70% | Based on the project requirement | Multiple overlapping signal returns |
| Flying time | 3 - 4 hours | 6 - 8 hours | 0.5 - 1 hour |

3.2. Airborne Product Specification
Each of the airborne data acquisition performed has a different form of the product but has the same goal which is for mapping purposes. For example, the main product of aerial photography comprises aerial imagery or orthophoto while the main product from airborne LiDAR acquisition comprises two (2) components which are (i) orthophoto (intensity imagery) and point cloud data (point with vertical
and horizontal value) [14]. On the other hand, the main product from airborne IFSAR acquisition comprises of Orthorectified Radar Image (ORI) [14]. From the main product, three (3) terrain products were generated which are digital surface model (DSM), digital terrain model (DTM), and contour [14]. Each terrain product has different accuracy and resolution reflected from the main product accuracy. The product specification is in Table 2.

**Table 2. Airborne product specification**

| Airborne Product | Aerial Photography | Airborne LiDAR | Airborne IFSAR |
|------------------|--------------------|----------------|----------------|
| Main product     | Orthophoto Resolution - 10cm | Intensity image Resolution - 10cm | Orthorectified Radar Image (ORI) Resolution - 10cm |
| Terrain product  | DSM Resolution - 50cm Accuracy - 15cm | DSM Resolution - 50cm Accuracy - 15cm | DSM Resolution - 500cm Accuracy – 100cm |
|                  | DTM Resolution - 50cm Accuracy - 15cm | DTM Resolution - 50cm Accuracy - 15cm | DTM Resolution - 500cm Accuracy – 100cm |
|                  | Contour Accuracy – map scale | Contour Accuracy – map scale | Contour Accuracy – map scale |
4. Integration Methodology
The integration process is important to enhance existing data product quality from the limitation instrument [2]. It the integration output also helps to fit the utilization specification on various application either profile or semantic visualization. There is some data integration process conducted in JUPEM that involves blending data collected from various sources creating a more accurate and useful end product. The integration process improves both the content and the accuracy of the resultant products relative to the original products. Integration between different aerial data can be conducted on two (2) spatial structures which are image fusion and DTM fusion.

4.1. Image Fusion
The process of image fusion involved the integration between low resolutions ORI IFSAR imagery with high-resolution Airborne Aerial Photography. The ORI is in intensity value (black and white) while the aerial photography is in Red Green Blue (RGB) value [5]. The process flow can be seen in Figure 2.

![Image Fusion Process Flow](image1)

**Figure 2.** Image fusion process flow

The process started with the image alignment process which involves relative georeferencing of both imageries where the elements of projection and vertical datum being synchronized. The mosaicking process takes part to make sure the image orientation on the right scale and place after the georeferencing process is completed. After that, the Ehlers fusion (EHL) algorithm was selected to make sure the image fusion fit its purpose and intensity matching was conducted to transform the RGB value into ORI. The component substitution also takes part if there are any different features between both imageries so that the features transformation can be implemented into the final output. Lastly, resampling can be done to generate Colorized ORI (CORI) imagery that is generated based on ORI IFSAR imagery with an aerial photography fusion process.

4.2. DTM Fusion
The process of DTM fusion involved the enhancing of low accuracy IFSAR DTM by anchoring to high accuracy LiDAR DTM. The IFSAR DTM accuracy is ±100cm while the LiDAR DTM accuracy is ±15cm. The DTM fusion process flow can be seen in Figure 3.

The process started with the addition and reproject of both DTM where the elements of projection and vertical datum being synchronized. The resampling process takes part after reproject to make sure the DTM has controlled pixel size, vertical value, and horizontal value. After that, the blending distance was conducted to make sure the fused DTM has a seamline appearance minimize for the quality check. Lastly, resampling can be done to generate fused DTM based on IFSAR and LiDAR DTM products.
5. Integration Result and Analysis

5.1. Image Fusion Result

As explained before, the main objective of image fusion is to enhance the ORI IFSAR by transferring the aerial photography color value to generate CORI imagery. This is because colorized imagery is widely used as a base map compared to imagery with intensity value (black-white). Even though the image accuracy is not as good as aerial photography, but it can be used for small scale mapping purposes. Example of image fusion product as in Figure 4.

5.2. DTM Fusion Result

The main objective of DTM fusion is to enhance the IFSAR DTM by integrating the LiDAR DTM accuracy. A study case at Kota Belut, Sabah has been conducted to analyze the DTM fusion product. The geomorphological quality different between input DTM (IFSAR DTM and LiDAR DTM) with output DTM (fused DTM) can as in Figure 5.

Based on all three (3) DTMs, a terrain profiling analysis was conducted to validate the elevation changes where the DTM LiDAR becomes a benchmark of accurate elevation. Four (4) profile areas were identified along the selected profile line including a residential area, water body (river), bush area, and mountainous terrain. The terrain profiling result and the elevation different as in Figure 6.
Figure 5. Geomorphological quality different between (a) IFSAR DTM (b) LiDAR DTM and (c) fused DTM

Figure 6. Terrain profiling result

The terrain profiling values can be referred on Table 3. The vertical elevation of fused DTM for residential area, water body (river), and the bush area seems to show a slight difference from DTM LiDAR (the accuracy indicator) but the elevation value is nearest to DTM LiDAR compared to DTM IFSAR. For mountainous terrain areas, the elevation difference is more significant due to instability.
terrain changes and canopy factors. The 3D distance from start to endpoint shows that the distance difference between DTM LiDAR and fused DTM is the lowest (18 meters) compared to DTM IFSAR (25 meters). The maximum path slope also started at the same distance from the starting point (1,333 meters from starting point) between DTM LiDAR and fused DTM shows that the fused DTM data is more suitable to conduct for geomorphology analysis compared to DTM IFSAR. This difference also shows that the objective of DTM fusion is to enhance the IFSAR DTM by integrating the LiDAR DTM accuracy is accomplished.

| Profile detail | IFSAR DTM | LiDAR DTM | Fused DTM |
|----------------|-----------|-----------|-----------|
| **Start position** | Latitude: 6° 25' 22.6424" N | Longitude: 116° 31' 19.6979" E | |
| **End position** | Latitude: 6° 25' 50.1559" N | Longitude: 116° 31' 56.4130" E | |
| **Straight line distance** | 1,410 m | 1,410 m | 1,410 m |
| **3D Distance** | 19.17° | 49.11° | 34.85° |
| **Max path slope** | 1,072 m along path | 1,333 m along path | 1,333 m along path |
| **Total climbing** | 119.8 m over 936.59 m on surface | 151.7 m over 909.53 m on surface | 104.6 m over 937.89 m on surface |
| **Total descending** | 25.0 m over 491.21 m on surface | 53.2 m over 536.62 m on surface | 13.4 m over 482.83 m on surface |

6. Conclusion
This paper has shown that aerial mapping products such as aerial photography, airborne LiDAR, and airborne IFSAR are widely used and can enhance each other through integration procedures. Each of the data can complement each other and generate a new value-added product. It opens a new dimension for data utilization where the quality of the integrated product can give benefits to various mapping fields especially in Malaysia. It is undeniable that there is plenty of room for improvements either through theoretical models or the airborne mapping sensor itself. Therefore, the users need to be cultivated more to aid the improvement of the integration process for greater use of the data.

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