Three-dimensional Line Mapping from Airborne Digital Photogrammetry for Detail Spatial Planning

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Abstract. Government regulation mentioned that detail spatial planning has to use detailed map data, which mean detail thematic information with high accuracy in term of geometric aspect. Three-dimensional (3D) representation of city infrastructures needs to fulfil due to the spatial planning office application to organize their city, for example building permit purpose. This kind of data is very useful for another spatial analysis and application as well, such as smart city and digital twin. The utilization of digital technology to streamline a long-standing business workflow is an issue in various fields in recent years, including geospatial technology for city planning. Currently, the development of large format digital camera and photogrammetric workflow has experienced rapid progress. City infrastructures such as building, sewerages, roads, electricity poles, etc. is possible to be extracted accurately including their position, shape and dimension with this mapping technique. This paper presents the creation of high accuracy three-dimensional line map derived from digital photogrammetric workflow for Bandung City as a study area. This area has ramps characterized in the southern part and hilly terrain in the northern part where height discrepancies between those two areas is more than five hundred meters. It is a challenge to meet high accuracy spatial data for the whole areas with this condition. Validation of positional accuracy was carried out using hundreds pre-marking independent check points (ICP) including well identified geographic features as an addition. The result show that almost all city infrastructures on the terrain can be identified and positional accuracy in centimeter level can be obtained by this technique.

Keywords: 3D, photogrammetry, spatial planning

1. Introduction

The City of Bandung, like other provincial capitals in Indonesia, is experiencing rapid economic growth, which attract citizen who live in the surrounding area to come to work, study and other daily activity. This situation led to the construction of new buildings and facilities that cause changes in land use functions. To avoid negative impact and make it as a better place to live, the government issue rules for city planning. UU No. 25 of 2004 concerning the National Development Planning System states that all development activities must be planned based on both spatial and non-spatial data as well as other accurate and accountable information. Article 14 paragraph 3 letter c, UU No. 26 of 2007 clearly states the need of Large-Scale Geospatial Information, especially for the purposes of preparing the detailed spatial planning and strategic areas. This UU coupled with local regulations and other government policy...
packages, emphasizes the importance of a good spatial data in the development planning process, which is valid thematic information with high accuracy on geometric aspect according to its level. There are several levels of spatial planning and each level use a map at different scales, started from the Regional Spatial Plan on the national level use map at 1:1.000.000 scale, up to the Building and Environmental Spatial Planning (BESP) in the city level use map at 1:1.000 scale. For BESP purposes, large-scale map in the three-dimensional (3D) form is required due to some policy decision is based on the height information on the infrastructures object. As an example, for a building permit, it needs building height information, number of floors and building footprint. The geometrical digital representation of a building and other geographical object on the earth’s surface for the spatial planning and management purpose is suitable to use vector format (point and line) due to it more versatile, flexible and relatively easy to use compare with raster data. This kind of data useful many spatial analysis and modelling application such as, smart-city and digital-twin city.

There are two mapping techniques that can be used to produce large-scale 3D line maps, laser scanning and photogrammetry [1]. The laser scanning provides a point cloud that informs 3D point position of reflecting object on the earth surface. A line object representation is interpolated from this data and its quality depend on how much points representing the object. The successful of this approach also affected by object size, shape complexity and a distance between an object. It will be difficult to construct proper line following the object edge when the following condition is occurs, the object size is small and close each other with unstandardized object shape. This characteristic is existing in many Indonesian cities. The photogrammetry output is oriented images, provide stereo-pair that can derive 3D line map based on stereo plotting. The object with relative high complexity shape can be extracted, including point for terrain representation. Another product of this second technique is orthophoto, which cannot be obtained from the first technique. For vast area, airborne platform is more efficient and effective in the operational consideration perspective. Based on the photogrammetry advantages and the size of the project area, Bandung City Government decided to use Airborne Digital Photogrammetry Technique with Large Format Camera to produce 3D line map at 1:1.000 scale. This paper presents the creation of 3D line map from airborne digital photogrammetry technique that is used for detail spatial planning in Bandung City.

2. Data and Methods

2.1 Study Area

Bandung is the capital city of West Java Province and the third largest city in Indonesia after Jakarta and Surabaya, located at 6° 50' 38" - 6° 58' 50" South Latitude and 107° 33' 34" - 107° 43' 50" East Longitude. It’s surrounded by mountains, which make a morphology of the area is looks alike a giant bowl. The altitude of southern area is approximately 675 m above sea level and continues to increase in height up to 2084 m at the Tangkuban Perahu mountain in the northern part. There are two rivers that go through the city that is Citarum and Cikapundung. According to the Bandung City Regional Regulation number 06 of 2006, there is 30 sub-district and 151 urban villages within the Bandung City Government (see Figure 1). With total 11 million inhabitants who live in total area 167.3 km², make Bandung as a highly populated city.

2.2 Data Acquisition

The data acquisition can be divided into two main activities, ground-based and airborne-based. The ground-based activity part consists of base-station observation and GCP/ICP measurement. The project uses five base-station, one located in the middle of project area and the four remaining at the perimeter. The observation uses static mode and record the data as long as the aircraft flown for data collection. There are 150 points of GCP/ICP which each point measured using radial methods that connect to four different benchmark references. The distribution of GCP/ICP can be seen in Figure 2 and 3. As addition, there are 57 points of well define object, such as corner of tennis court etc, for accuracy test. The distribution of accuracy test location can be seen Figure 4. All these points measurement use static
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The airborne-based activity part collects digital aerial photo, position (GNSS data) and orientation (IMU data) of the camera exposure. The project area covers by aerial photos taken from DMC II 230 Large Format Digital Camera System equipped with a Gyro Stabilizing System, which adjust camera z axis to remain stable in a perpendicular position to earth’s surface and flying direction. This camera was designed to meet highest geometric accuracy standards requirements for geometric accuracy [2]. The large single monolithic frame sensor is the base for high accuracy. The aircraft flown following the flight plan in two different flying height to produce digital photo at the 8 cm GSD. The camera resolution is 230 megapixels with digital photo radiometric resolution of 14 bits. The area divided into three blocks as illustrated in Figure 4, the letters in a different colour are an exposure position of aerial photo and ground control points. The cyan letter is block 1, yellow letter is block 2 and red letters is block 3, while the ground control points are represented by green letters. The forward overlap and side overlap are 65% and 30% respectively. Lever arm and boresight misalignment data is calculated before project flight mission started. The UTM zone 48 S is coordinate system uses in this project.

Figure 1. Bandung City Area

Figure 2. GCP/ICP distribution

Figure 3. Accuracy test point distribution
2.3 Data Processing

In general, the three-dimensional (3D) line map creation from airborne digital photogrammetry following a workflow shown in Figure 5. The activities can group into five stages that is preparation, data acquisition, data processing, stereo-compilation (feature extraction) and accuracy assessment. It starts with preparation stage, which includes system and equipment, flight plan, standard specification, administration matter, etc. On-board dual frequencies GNSS receivers and the IMU are used to provide camera movement information throughout the photographic mission. The base-station observation data used to improve recorded position by using the differential approach. Lever arm offsets of the GNSS antenna center to the camera sensor and boresight misalignment of IMU and camera sensor is measured and calculated to obtained correction value applied in trajectory processing. The output of this process is exterior orientation (EO) which is stamped to each photograph.
Afterward, Aerial Triangulation is performed. Aerial triangulation is a mathematical process to determine the correct position and orientation of aerial photos during camera exposure in the air. The EO produce from previous step were improved in this section. This information used to transform the coordinates of all objects in the photo into the desired coordinate system so the object features can be depicted into the map in the correct position. The workflow of Aerial Triangulation process shown in Figure 6. In the Aerial Triangulation process conducted tie point identification and registration of one frame photo to another photo in an overlap area based on the object feature. This binding process between photos is called tie point (photos between strips) and pass point (photos in one strip) observation process. It could be done in automatic mode by applying the image matching method. The distribution of tie points and pass points is made evenly over the overlapping areas. After checking and correcting the generated tie points and pass points, the process continues to register GCP. Then, the block bundle adjustment is performed that provides statistical reports. This information is analyzed and determines whether the process need to be finalized or repeated. Refer to national standard, the statistical threshold for geometric accuracy of 1:1.000 map scale is 0.2 m and each block processed separately. The final block bundle adjustment shown in Table 1.

![Figure 6. The workflow of Aerial Triangulation process](image)
Table 1. Aerial Triangulation statistic report

|                | Block 1       | Block 2       | Block 3       |
|----------------|---------------|---------------|---------------|
| Number of control points | 126           | 29            | 10            |
| Number of photos | 1099          | 282           | 136           |
| Number of image points | 188190        | 58346         | 32060         |
| Sigma           | 1.6 um        | 2.2 um        | 1.6 um        |
| X RMS Control   | 0.04          | 0.053         | 0.046         |
| Y RMS Control   | 0.027         | 0.033         | 0.037         |
| Z RMS Control   | 0.047         | 0.062         | 0.017         |
| Max Ground Residual | 0.141        | 0.133         | 0.107         |

2.4 Stereo-compilation (feature extraction)

The stereo-compilation process started with a creation of the stereo-model. The input for this step is aerial photograph pairs with interior orientation information from the camera calibration report and adjusted exterior orientation from the aerial triangulation result. An object digital representation in vector format is carried out by digitizing the object features on the earth's surface in three-dimensional form through stereo views. Based on UU No. 4 tahun 2011, the base map consists of 8 elements, that is coastline, hypsography, water boundaries, topographical names, territorial boundaries, transportation and utilities, buildings and public facilities, and land cover. These elements, then classified into more detail name which describe its function, as an example, buildings have several derivation names such as dwelling houses, market, museum, sport center, etc. This also applies to the other seven elements. The element code and name are in accordance with the Indonesian Geographical Elements Catalogue version 4.0 of 2015. If there are elements that do not have an equivalent in the list yet, it decided as new code and name to the list. There are hundreds of feature code used to accommodate the city infrastructure objects. As example, feature code GI01100080 is puskemas, GI01100101 is hospital, etc.

On this stereo-compilation stage, the following things are a concern. All feature elements recorded in 3D vector format, in the form of point and line elements of territorial boundaries, hypsography, hydrography, transportation and utilities, buildings and public facilities, and land cover. Line elements that intersect and form topological nodes, have a vertex with the same height. The water element is completed first and then followed by (sequentially) other object features, such as breakline hypsographic elements, mass point hypsographic elements, and then other planimetric elements (transportation and utilities, land cover, buildings and public facilities). The floating-mark position at the time of stereo-compilation placed correctly, it is not floating or digging. As an example, in the corner of the roof while digitizing the building and on the terrain surface while digitizing land cover boundary.

The digitization of the building roof is carried out according to their shape and for its representation used Level of Detail (LoD) building specification introduces by Biljecki et al. [3]. For this project, there are three types is selected, that is LoD 1.3, LoD 2.0 and LoD 2.2. Each building is classified into one of these three categories based on following criteria; type of building, the distance between the building and the building purpose. Buildings included in LoD 1.3 are buildings located in areas with an irregular distribution of houses, a high level of density, generally the distance between houses is close. Figure 7.a., illustrates a building object with a level of detail 1.3. Buildings included in LoD 2.0 are buildings located in areas with a regular and planned distribution pattern, relatively uniform shape and size of houses, and sparse distances between houses. Figure 7.b., illustrates a building object with a level of detail 2.0. Buildings included in LoD 2.2 are buildings of cultural heritage objects or those that located in campus areas, office complexes, city landmarks and beside the main road corridor of Bandung City. Figure 7.c., illustrates building objects with a level of detail 2.2.
The mass point, spot height, breakline and line/point feature that digitize on the terrain surface or on the ground, such as road line, water line, land cover boundary etc., is used for digital terrain model (DTM). This data is an input for contour generation and orthophoto production. There is no certain distance between the mass points, the important thing is the points can represent the terrain of the earth’s surface accurately and not too close to the river or breakline because it makes contour not smooth. The mass point obtained from automatic image matching method and manual registration. The breaklines are elevation lines used to delimit the high relief and low relief, for example, slope top and slope bottom. The left and right embankments of rivers and irrigation as well as on the edges of road, faults, excavations and depressions should be drawn as breaklines, especially in hilly areas. In flat areas, it is not necessary to make a breaklines. The contour line is generated from the digital terrain model at 0.5 m interval.

3. Results and Discussion

3.1 Three-dimensional (3D) Line Map

The three-dimensional (3D) line map from stereo-compilation result shown in Figure 8. and the building roof construction line based on three different Level of Detail (LoD) shown in Figure 9.
3.2 Accuracy Assessment

The accuracy assessment based on point position and is done by comparing the coordinates of well-defined objects on the orthophoto with GPS measurements on the field as shown in Figure 10. There are 57 locations distributed throughout the city of Bandung as shown in Figure 3. The orthophoto is a photo/image based on an orthographic projection, rather than the perspective projection of a regular frame photograph, and planimetrically correct so it can be used as a map. The orthophoto of Bandung City shown in Figure 11. The accuracy assessment statistical result shown in Table 2.

### Table 2. Accuracy assessment statistical report

|                | Easting (m) | Northing (m) |
|----------------|-------------|--------------|
| Mean           | 0.0747      | 0.1110       |
| Median         | 0.0703      | 0.1023       |
| Standard Deviation | 0.0508    | 0.0753       |

**Figure 9.** The building roof construction line of LoD 1.3 (a., d.), LoD 2.0 (b., c.) and LoD 2.2 (c., f.)

**Figure 10.** Accuracy assessment point

**Figure 11.** Orthophoto of Bandung City
4. Conclusion

Based on the accuracy assessment, statistical report shows that the orthophoto, as an end product, provide mean value less than 0.2 m and standard deviation less than 0.1 m, this value within national standard tolerance for 1:1,000 map scale. The input data used for orthophoto generation, which obtained from previous steps, are inner orientation values from the camera calibration report, digital photos, adjusted exterior orientation values from aerial triangulation process and digital terrain model from stereo-compilation. If the end product provides the geometrical accuracy value within the tolerance, then the data used as an input will have the same quality or even better. The airborne digital photogrammetry technique can extract more complex object shape and produces comprehensive product output, combination of vector and raster format, which is three-dimensional (3D) line map, digital terrain model and orthophoto at high geometric accuracy.

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6. References

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