VERY HIGH RESOLUTION SATELLITE IMAGERY UTILIZATION STANDARD FOR LARGE SCALE TOPOGRAPHIC MAPPING

(Standar Pemanfaatan Citra Satelit Resolusi Tinggi untuk Pemetaan Skala Besar)

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ABSTRACT

Due to its large area Large Scale Topographic Mapping (LSTM) for Indonesia requires acceleration strategies that must be innovative enough to take into account the production efficiency. Satellite-based technologies are still a preferable choice especially in conjunction with the security clearance and weather. Standards for the Very High-Resolution Satellite Imagery (VHRS) utilization are essential, especially in a situation where there are so many available sensors and processing methods implemented. Hence, the selection of a proper geometric correction method is fundamental in order to utilize the VHRS imagery as one source of geospatial data especially for LSTM production and updating purposes. For CSRT geometric correction, an orthorectification process is required, where this process requires input data from the Ground Control Point (TKT) and the Digital Elevation Model (DEM). Therefore, the Least Square Adjustment (LSA) method is implemented to be able to include 8-9 GCPs per-scene (orbital and sensor parameters) and the DEM with a maximum resolution 4 times of the VHRS imagery's Ground Sampling Distance (GSD) in the process of producing VHRS orthoimages. In addition, the role of orbital and sensor parameters is also essential for the geometric correction because its relation to the Direct Georeferencing (DG) of each pixel by Rigorous Sensor Model (RSM) approach. However, in the situation where the reliable orbital and sensor parameters are not available, the Rational Function Model (RFM) can be used as an alternative solution for the geometric correction of VHRS imagery. This paper discusses the VHRS utilization with a comprehensive approach that can be implemented in a local coordinate system i.e. the Indonesian Geospatial Reference System for the production of the reliable VHRS imageries.

Keywords: VHRS, standard, GCP, DEM, orthorectification

ABSTRAK

Pemetaan skala besar di Indonesia membutuhkan strategi akselerasi yang inovatif dengan tetap mempertimbangkan faktor efisiensi biaya. Teknologi satelit penginderaan jauh tetap menjadi pilihan yang diperhitungkan, terutama terkait dengan aspek perizinan dan cuaca. Standar pemanfaatan Citra Satelit Resolusi Tinggi (CSRT) menjadi sangat fundamental, terutama dalam situasi dimana begitu banyak sensor dan metode pemrosesan yang bervariasi diterapkan. Penetapan ketentuan metode koreksi geometrik yang sesuai menjadi sangat fundamental guna memanfaatkan CSRT sebagai salah satu sumber untuk pemetaan dan pemutakhiran peta skala besar. Untuk koreksi geometrik CSRT dibutuhkan proses ortorektifikasi, dimana proses ini membutuhkan data masukan Titik Kontrol Tanah (TKT) dan Digital Elevation Model (DEM). Penerapan Perataan Kuadrat Terkecil (PKT) dengan menggunakan GCP sebanyak 8-9 unit per-scene (parameter orbit dan sensor) dan DEM dengan Ground Sampling Distance (GSD) maksimal 4 kali GSD CSRT menjadi syarat mutlak dalam proses produksi CSRT. Selain itu, peranan parameter orbit dan sensor CSRT menjadi sangat esensial dalam proses koreksi geometrik karena terkait langsung dengan proses Direct Georeferencing (DG) setiap piksel yang dihasilkan melalui pendekatan Rigorous Sensor Model (RSM). Dalam situasi parameter orbit dan sensor yang akurat dan memadai tidak tersedia, maka model Rational Function Model (RFM) dapat dipilih sebagai solusi alternative dalam proses koreksi geometrik CSRT. Tulisan ini mengkaji standar pemanfaatan CSRT dengan menggunakan pendekatan komprehensif yang akan diimplementasikan pada sistem koordinat lokal yaitu Sistem Referensi Geospasial Indonesia (SRGI) untuk menghasilkan CSRT dengan tingkat akurasi geometrik terbaik.

***Kata kunci**: CSRT, standar, TKT, DEM, ortorektifikasi*

INTRODUCTION

Recent legislation act reflecting governmental concern about geospatial information in 2011 presented some initiatives in order to accelerate the development of infrastructure in Indonesia. Thus, the geospatial-based analysis as an integrated phase of the development and planning requires reliable geospatial data sources as an input. Paragraph number 27 section 2 of the above-mentioned legislation (RI, 2011) requires the standard for geospatial data acquisition including reference system (a); type, definition, criteria and data format (b). Therefore, the international standard e.g. International Organization for Standardization (ISO), International Society for Photogrammetry and Remote Sensing (ISPRS), etc. is crucial and essential for the context of geospatial data production. The reliable geospatial data source will enable more accurate analysis in what so called Decision Support System (DSS).

For a land area 5 times of Germany, Large Scale Topographic Mapping (LSTM) in Indonesia requires acceleration measures that must be innovative enough to take into account the production efficiency especially for the base geospatial data provision as its main source. Satellite-based technologies are still a preferable solution especially in conjunction with the security clearance and weather situation as the main constraints hampering the geospatial data acquisition. In addition, the role of VHRS imageries can be seen distinctively in an emergency situation e.g. disaster, pandemics, etc where geospatial analysis must be done as soon as possible in order to provide proper decision. Indeed, the massive development of space remote sensing technologies enhances both spatial and spectral resolution to provide the spatial data infrastructure. TerraSAR Add On DEM-X (TanDEM-X) radar data is one instance which can be potentially used in many applications.

Major advantages using satellite-based radar data are relatively weather independence and free security clearance procedure. However, using radar data for LSTM is still constrained especially for object interpretation and accuracy matter. In order to overcome this drawback, the integration between radar and optical imagery is assumed as a potential solution.

Especially in a situation where there are so many available technologies and infrastructures on the market, both the standard of product and process are required. The efficiency of the approach also must be investigated in order to fulfill the objectives and requirements of the stakeholders. Defining a robust and reliable standard, mechanism, and procedure to derive the geospatial data source is a main key for the successful of the LSTM.

METHOD

The main focus of this section is to study the achievable geometric accuracy of the optical satellite-based monitoring data as well as the available geometric correction method. The incorporation of the radar sensor TerraSAR-X adds on Digital Elevation Model-X Band (TanDEM-X) as well as the GCP requirements is also briefly discussed. In particular, the orthorectification in the VHRS data processing based on reliable GCP and DEM is deeply discussed. Subsequently the standard of process will be explained in the next section and a new approach referring to the more precise national reference datum has been implemented i.e. Geospatial Reference System of Indonesia (SRGI). For this purpose, the high-resolution DEM well-adjusted to the SRGI is the pre-requisite since all the GCP has been measured in the same reference system.

Geometric correction method is an important part of the VHRS data processing. The intrinsic objective of the image data processing is to include the reliable geospatial reference system in the image data content. With respect to the level of detail (GSD less than 1 m), VHRS imageries require precise geometric corrections which must be done by orthorectification (Belfiore & Parente, 2016).

Prominent improvement of the recent SPOT-6/7 compared to the previous SPOT-5 is the fundamental geolocation accuracy of the sensors. The newest version of Attitude and Determination and Control Subsystem (ADCS) increases the actual geo-referencing performance measured on SPOT-6 image primary products (see Table 1), i.e. without use of GCP is better than 20 m Circular Error 90% (CE90). Generally, as implicated from **Table 1**, the achievable VHRS accuracy are still more than 10 times spatial resolution (GSD) and still insufficient for supporting the LSTM data production though.

Table 1. VHRS imagery specifications.

Aspect	Worldview	SPOT6/7	Pléiades Neo
Orbit	617 km	832 km	620 km
GSD	0.31 m	1.5 m	0.3 m
Accuracy (CE90)	3.5 m (without GCP)	20 m (without GCP)	5 m
Spectral	8 bands	4 bands	4 bands
Coverage size	13.1 km (swath at nadir)	60x120 km	14 km (swath at nadir)

Source: Airbus (2020)

Currently, the improvement of geospatial data acquisition by using space borne platforms is developed rapidly to provide an unprecedented data resolution of optical satellite imagery. This achievement triggers the massive utilization of VHRS imageries around the globe i.e. web-based imageries application (Goudarzi & Landry, 2017). The communities have widely used aforementioned interesting VHRS data as an important source to address their geospatial awareness demand. For this purpose, orthorectification as a specific task is mandatory in the standard of VHRS data processing, which can produce high quality imageries.

The usage of optical sensor-based imagery for topographic mapping has been investigated since latest 1990's by focusing on automatic DEM extraction and orthoimage generation. Al-Rousan et al., 1997 found that satellite-based data can be used to perform small scale topographic mapping up to scale of 1:100,000. This approach has been tested using SPOT Level 1B data and verified by comparison with current 1:250,000 topographic map at that time. From this point, the role of current topographic maps derived from photogrammetric acquisition had an important role as a reference data to validate the result from satellite imageries.

Onboard ephemeris and attitude of satellite geolocation based on Rational Polynomial Coefficients (RPCs) is the most common and generic method to provide georeferenced satellite imageries without any GCP and/or DEM. However, high resolution is not always correlated with good geometric accuracy. As included in **Table 2**, the geometric accuracies of VHRS images processed by RPCs are within 5-80 meter of Circular Error 90% (CE90) though GSD is less than 2.5 m.

In order to improve the geometric accuracy, it is mandatory to remove bias and systematic errors contended by the RPCs. Indeed, some approaches to compensate aforementioned bias and systematic errors do exist for example by using the local polynomial modeling (Shen et al., 2017) or DEM (Alidoost et al., 2015). On the other hand, other example of VHRS imagery widely used is WorldView imagery product which has accuracies depending on the processing scheme as published by Digital Globe, 2016. This product can be delivered on the basis of Area of Interest (AOI) scheme by using square kilometer as a unit price. Even though the WorldView panchromatic imagery has a 0.46 m resolution, the absolute accuracy for CE 90% is within the range of 4.2 m to 25.4 m or almost 10 times resolution to the utmost i.e. orthorectified without any GCP (**Table 3**).

Another example of VHRS data is SPOT 6/7 satellite imageries (see **Table 4**), that provide a geospatial data intended for civil and military mapping as well for disaster monitoring. These products are also well coordinated with radar data acquisition i.e. TerraSAR-X and TanDEM-X under the same project management at least until 2024 and afterwards. Thus, it shows the strong collaboration between radar and optical satellite data especially in a situation where the geometric accuracy and high resolution must be achieved simultaneously.

As reported in Astrium (2013), the technical specifications about the geometric modeling are included and described in details to support further advance investigations related with the image product. In addition, the integration between optical and radar data can complement each other such as by pan-sharpening (fusion) the TerraSAR-X radar data with SPOT5 optical data (Klonus & Ehlers, 2008).

Table 2. VHRS stereo optical satellites.

Satellite	Processing	Geometric quality (m)		
		Accuracy (CE90)	RMSE	GSD
IKONOS	RPC	15	9.9	0.81
QuickBird		23	15.2	0.62
Orbview-3		25	16.5	2.3
Worldview-1		5	3.3	0.5
Worldview-2		5	3.3	0.46
GeoEye-1		5	3.3	0.41
Pleiades 1B		5	3.3	0.7
Cartosat-1		15	9.9	1
KOMPSAT-2		80	52.7	1
SPOT-6		35	23.1	1.5

Source: Jacobsen (2013; Astrium (2013)

Table 3. WorldView product level.

Product type	Processing	Absolute accuracy (m)		Geographic coverage
		Accuracy (CE90)	RMSE	
System-Ready (Basic)	Radiometric and sensor corrected	5	2.3	Worldwide
System-Ready (Basic stereo)		5	2.3	
View-Ready (Standard)		5	2.3	
View-Ready (Ortho ready standard)		5	2.3	
View-Ready (Ortho ready stereo)		5	3.3	
Map-Ready 1:5,000 (Ortho)		4.2	2.0	Worldwide, need a fine DEM
Map-Ready 1:12,000 (Ortho)		10.2	4.8	
Map-Ready 1:50,000 (Ortho)		25.4	11.8	

Source: Digital Globe (2016)

Table 4. SPOT6 product level.

Product level	Processing	Absolute accuracy (m)		Geometry
		Accuracy (CE90)	GSD	
Primary product	Radiometric and Sensor corrected	5	1.5	Sensor
Standard ortho	Radiometric, Sensor corrected and Ortho corrected	10		Map projection with standard GCPs and DEM
Tailored ortho		On demand		Map projection with customized GCPs and DEM

Source: Astrium (2013)

A more advanced approach is applied by the investigation of stereo pair data from optical sensor imageries. The satellites jitter effect was introduced as a significant systematic error in the image orientation model (Jacobsen, 2018). Even though this error can be located in the order of 0.1-0.4 pixels, it is rather only validation with available high-resolution DSM/DTM. In other words, the high accuracy only can be achieved by stereo pair data with a support from high resolution (accuracy) DEM. The calibration procedure as implemented by using GCP data only is not suitable for this stereo pair data because the aforementioned errors could differ from one part to another part of the image/scene.

RESULTS AND DISCUSSIONS

As discussed in previous section comprehensively, the geometric correction by using RPCs and/or orbital and sensors parameters yields insufficient absolute planimetric accuracy (CE90) required by the LSTM specifications. In addition, it makes no sense if the produced VHRS imagery in decimeter GSD has geometric accuracy only in the fraction of 5 meter or even more. Moreover, the investigation by Abdullah (2013), stated that the digital orthophoto (orthoimage) shall ideally have planimetric accuracy not more than 2 times pixel size i.e. class III standard.

As investigated in Tampubolon (2020), the geospatial information in topographic maps as a basic reference is mandatory to support many development activities especially for regional planning. From this point, the national government of Indonesia encourages rapid mapping activities in a scale of 1:5,000 by local communities. This so called "village mapping" (Regulation of Head of BIG No. 3/2016) requires VHRS orthorectified imageries (CSRT) as a primary data source produced not only with high resolution but also high accuracy. Therefore, the synchronized national orthorectification program is the only solution by taking into account the GCPs and fine DEM data (Astrium, 2013; Digital Globe, 2016).

The standard for geometric correction of VHRS imagery has been defined in the context of LSTM requirements (see **Figure 1**). It starts from the implementation of Rigorous Sensor Model in the primary data in order to get the geolocation from space without any field/ground data. The primary data is the imagery which has been processed by radiometric correction. In the above mentioned RSM model, Least Square Adjustment (LSA) is applied by taking into account three basic inputs:

1. Orbital and sensor parameters
2. GCP data (with the accuracy less than or equal 0.5 GSD)
3. DEM (with resolution less than or equal 4 times GSD)

Manual selection of both GCP and ICP is a subject to the error in the orthorectification as well as for the accuracy assessments. Thus, proper GCPs and ICPs were selected in well-distributed and good locations such as road intersections or building corners or badminton fields (see **Figure 1**).

For evaluation purposes, the geometric accuracy of this proposed orthorectification workflow has been incorporated into the workflow (**Figure 2**). Hence, it is required by the workflow to have RMSE less than 1 pixel. At the end, the accuracy assessment (CE90) is performed by using representative ICPs from the Area of Interest (AOI). This assessment validates the expected planimetric accuracy vis-a-vis accuracy assessment results.

Noticeably, it is necessary that the VHRS orthorectified imagery in a resolution < 4 m as a geospatial data source must comply with 1:5,000 LSTM specifications required by the detailed spatial planning regulation. The objective of the proposed standard for geometric correction (**Figure 1**) hence is to get the achievable LSTM planimetric accuracy of VHRS data based on various GCP configurations and DEM inputs in the orthorectification tasks.

Figure 1. GCP measurement with GNSS and its identification on VHRS imagery.

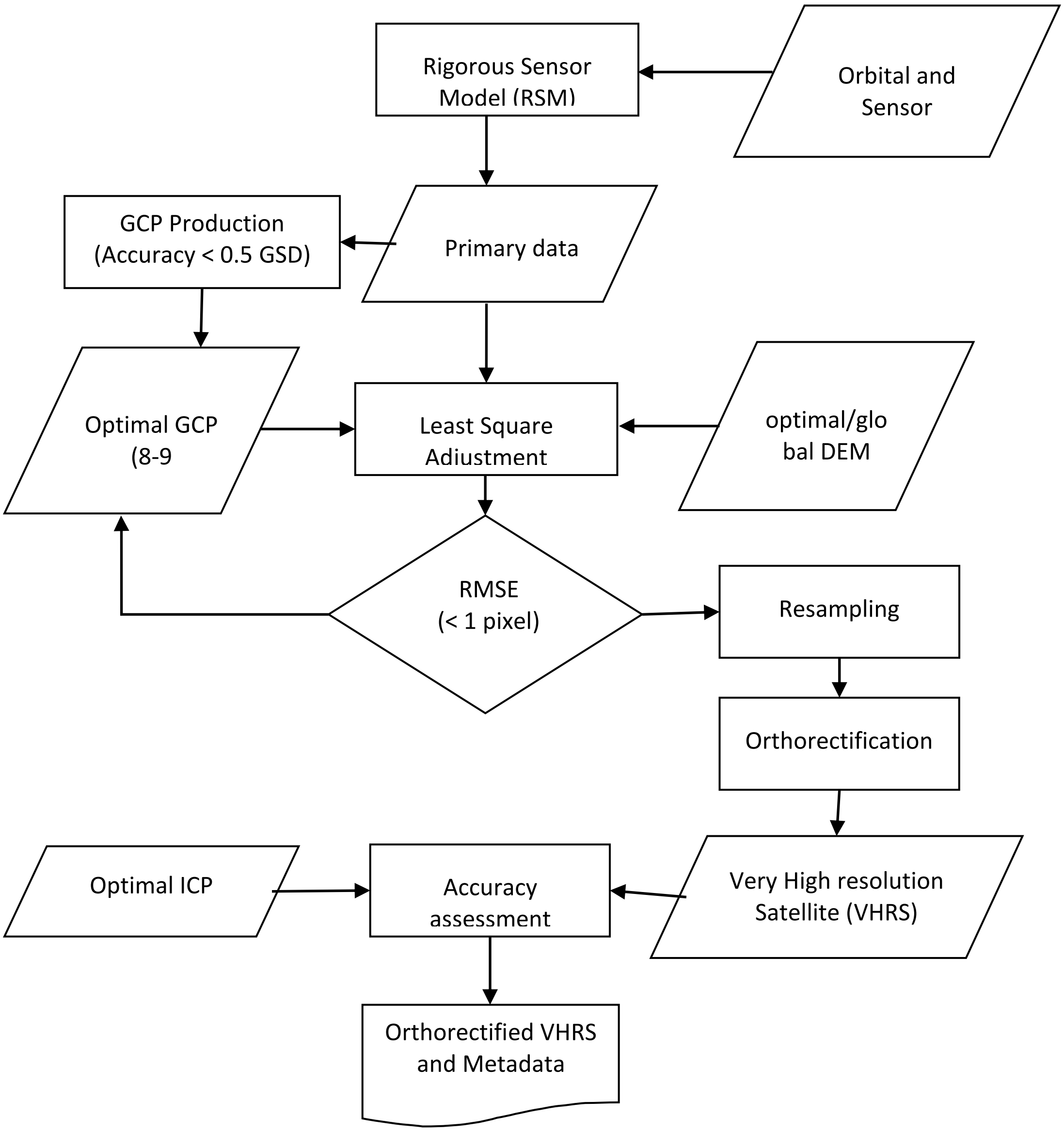

Figure 2. VHRS geometric correction workflow.

CONLUSIONS

VHRS imagery utilization for LSTM requires proper standard of process in order to achieve more accurate georeferencing results. Thus, orthorectification is an essential part for the geometric correction of VHRS imagery. In this case, GCP and DEM are the mandatory inputs for the orthorectification purposes. As it is not possible to achieve good geometric accuracy without adequate GCPs and DEM, the LSA method is applied by using 8-9 GCPs per-scene (orbital and sensor parameters) and the DEM with a maximum resolution 4 times of the VHRS imagery's GSD for the production of VHRS orthoimageries.

Finally, this kind of standard operational and procedure is capable to detect possible errors from GCP measurements as well as misinterpretation of picking the correct objects in the image. Without VHRS orthorectification by using GCPs and DEMs, the compilation of each detected object on image will not be synchronized with SRGI. Noticeably, this paper has presented the significant geometrical improvement of VHRS imagery by the implementation of the national orthorectification mechanism.

ACKNOWLEDGEMENTS

We would like to acknowledge Geospatial Information Agency of Indonesia (BIG), Working Group of Geoinformatics-UniBw Muenchen (AGIS) and German Aerospace Center (DLR) for providing the relevant VHRS datasets (QuickBird, TanDEM-X StripMap) as well as an access to the GPS/GNSS reference station (CORS) during the GCP measurements in Borobudur Temple, Indonesia and processing software license (PCI Geomatics).

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