Analysis of Geo-Positioning Accuracy Using Stereo Pairs of Wordview-1 and Pleiades-1B Imagery

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ABSTRACT
It is important to analyze geo-positioning accuracy using high-resolution satellite imageries in order to acquire accurate geo-spatial information. This paper investigates geo-positioning accuracy of combinations with four imageries covering the same region from two different types of satellite platforms and sensors: Worldview-1 and Pleiades-1B. For the analysis, seven combinations are constituted from four imageries: two homo-type stereo pairs, four hetero-type stereo pairs and one stereo of all four imageries. We first assessed the bias of vendor-provided rational polynomial coefficients (RPCs) for each imagery. And then, we compared and analyzed the geo-positioning accuracy achieved by using conventional space interception without ground control points (GCPs) and that achieved by using RPC block adjustment model with five GCPs for seven different combinations separately. This study demonstrates that the use of different types of satellite stereo pairs can achieve meaningful geo-positioning accuracy for inaccessible regions difficult to measure actual ground coordinates by comparing without and with GCPs.

1. INTRODUCTION

Since the launch of IKONOS satellite in 1999, commercial high-resolution satellite imagery has been widely used because of its advantages such as high resolution, short revisit time, and wide coverage. Stereo satellite imagery is used as the primary source for generation of geo-spatial information, since it can determine three-dimensional ground position using space intersection method without global positioning system (GPS) surveying on the actual spot. In particular, in generating geo-spatial information for the hard-to-access regions where ground control points (GCPs) are difficult to be obtained, the accuracy by stereo satellite imagery itself is an important factor that affects the quality of the outputs.
Satellite imagery vendors provide an in-track stereo pair acquired by the same satellite sensor. In-track stereo pair is taken on the same orbit during short time period, and has good geometry for accurate geo-positioning. However, there are some difficulties on its availability such as weather conditions, acquisition expense, busy acquisition schedule and urgency of data needs. For more practical and wide application of high-resolution satellite imageries, geo-positioning using stereo imageries obtained from different satellite sensors has been suggested. Rational polynomial coefficients (RPCs) included in satellite imagery facilitate geo-positioning using different types of satellite imageries. They support fast, simple transformation between 3D object space coordinates and 2D image space coordinates regardless of sensor type.
There have been few studies regarding geo-positioning using different types of satellite imageries with RPCs. Li et al (2007) investigated the geo-positioning accuracy using IKONOS and QuickBird satellite imageries, Choi et al. (2012) investigated it using GeoEye-1 and Worldview-2 satellite imageries, and Jeong et al. (2015) also investigated it using IKONOS, QuickBird, and KOMPSAT-1.
We analyzed the geo-positioning accuracy of stereo pairs with four imageries covering the same area from two different types of satellites: Worldview-1 and Pleiades-HR 1B in-track stereo imagery. In this study, we defined two kinds of stereo pairs. One is homo-type stereo pairs obtained by the same satellite sensor, and the other is hetero-type stereo pairs that are combinations of imageries obtained by different satellite sensors at different time. We constituted seven stereo combinations from four imageries, which are two homo-type stereo pairs, four hetero-type stereo pairs and one stereo of all four imageries. With respect to each combination, the geo-positioning results using space intersection without GCPs and those using RPC block adjustment with GCPs were compared. This study demonstrates to determine relatively accurate three-dimensional ground position using hetero-type stereo imageries, and confirms the potential of geo-positioning for inaccessible regions that are difficult to collect GCPs by GPS surveying.

2. DATASETS

The in-track stereo pair images of Worldview-1 and Pleiades-HR 1B taken in Pohang, South Korea and the corresponding RPCs provided by each satellite image vendor were used for the experiment. In the case of Pleiades, the imagery includes two kinds of RPC models. One is direct model RPC to determine image coordinates from ground object coordinates, and the other is inverse model RPC to determine ground object coordinates from image coordinates. In this experiment, we used inverse model RPC for Pleiades satellite imagery. Table 1 represents the properties of used satellite imageries and imagery ID given to distinguish each imagery.

Table 1. Properties of used satellite imageries

Satellite	**Worldview-1**		**Pleiades-HR 1B**	
Imagery ID	**WV01**	**WV02**	**PL01**	**PL02**
Product Level	Stereo 1B		Primary	
Band	P	P	P	P
Acquisition Date (GMT)	2014.04.22 02:00	2014.04.22 02:01	2013.11.07 02:08	2013.11.07 02:07
Angle(Along / Across)	7.5°/ 17.7°	-21.4°/ 14.5°	13.7°/ 18.8°	-13.1°/ 23.7°
Ground sample distance (column/row)	0.543	0.599	0.76/0.80	0.78/0.85

In order to evaluate the accuracy, twenty-one ground points commonly distributed in all four images are collected by GPS surveying. Among them, one center point and four points located in the boundary regions are used as control points for RPC block adjustment, and the other sixteen points are used as check points. Figure 1 shows the ground coverage of imageries and distribution of the GCPs.

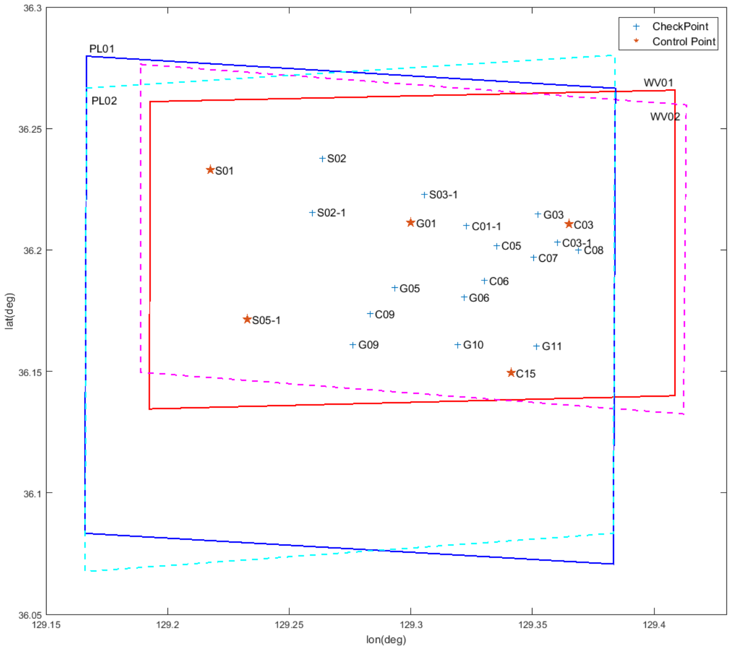

Figure 1. Image coverage and Distribution of GCPs

3. EXPERIMENTS AND RESULTS

The seven combinations were constituted from four satellite imageries for this experiment. We implemented geo-positioning with or without GCPs and assessed accuracy for each combination. The seven combinations consist of two kinds of homo-type stereo pair, four kinds of hetero-type stereo pair, and one combination of all four imageries. In each combination, derived ground coordinates of sixteen check points are compared with the coordinates obtained by GPS, respectively. The geo-positioning accuracy of each combination is measured by root mean squared error (RMSE), circular error (CE), and linear error (LE) of three-dimensional ground coordinates. The calculations of CE and LE used in this experiment is presented in NATO (2010).

3.1 Bias in Vendor-provided RPCs

Figure 2 shows the vectors of differences between the calculated image coordinates via the vendor-provided RPCs and image coordinates of GCPs. The vector magnitudes are plotted in a relative length of four imageries. Table 2 shows means, standard deviations, and root mean squares (RMSs) of errors in both line and sample directions of image coordinates. Pleiades imageries with larger ground sample distance (GSD), as shown in Table 1, have relatively larger errors than Worldview-1 imageries. It can be seen that all points in the same imagery have the same error direction, that is bias. RPCs are outputs of rational function model (RFM) derived by re-parameterization of physical sensor model, and thus errors in physical sensor model such as sensor orientation give rise to biased errors in the RPCs.

Table 2. Image coordinates biases in pixels

	Mean		Standard Deviation		RMS	
	Line	Sample	Line	Sample	Line	Sample
WV01	-0.94	-3.93	0.65	0.19	1.14	3.93
WV02	-0.44	-0.69	0.52	0.24	0.67	0.73
PL01	-2.36	5.28	0.54	0.27	2.42	5.29
PL02	-3.71	9.22	0.47	0.36	3.74	9.23

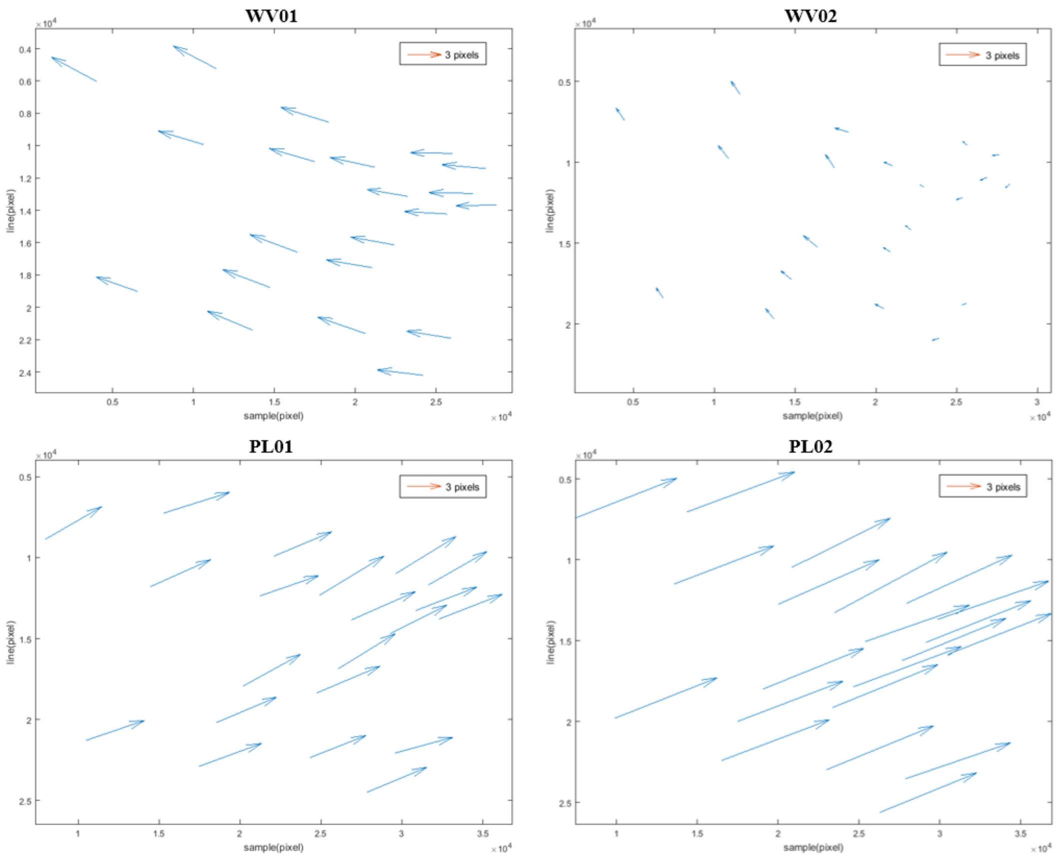

Figure 2. Image coordinates bias vectors by the vendor-provided RPC

3.2 Accuracy of Space Intersection without GCPs

The ground coordinates were determined using the conventional intersection algorithm based on least square estimation without any RPC bias compensation processing using GCPs. The geo-positioning results of seven combinations that we constituted are described in Table 3 and Figure 3.

Table 3. Geo-positioning accuracy of space intersection without GCPs

	Convergent Angle	RMSE (m)			CE90(m)	LE90(m)
		N	E	h		
WV01-WV02	31.24°	0.46	1.21	0.57	1.84	0.97
WV01-PL01	18.51°	0.76	1.12	2.37	2.14	4.25
WV01-PL02	8.46°	4.55	12.16	36.16	14.28	40.05
WV02-PL01	13.57°	3.92	1.20	9.14	4.95	11.04
WV02-PL02	38.96°	1.80	0.85	5.30	2.40	6.21
PL01-PL02	25.65°	1.78	2.74	3.96	3.77	4.82
WV01-WV02-PL01-PL02	-	1.33	0.29	3.55	1.73	4.12

It is said that convergent angle of stereo pair is the one of important factor in determining accuracy, and the angle between 30 and 60 degrees are ideal (GEOIMAGE, 2010). WV01-PL02 pair which has the largest convergent angle difference from this scope can be seen the worst accuracy in all directions. It showed the effects of the stereo geometry on the geo-positioning accuracy.

As shown in Figure 3, all seven combinations have bias patterns of error in all axis. There are no significant differences in accuracy between homo-type stereo pairs and hetero-type stereo pairs except WV01-PL02 pair. The accuracy of WV01-PL01 hetero-type pair is better than that of PL01-PL02 homo-type stereo pair. This is because the stereo model is constructed via the RPCs regardless of physical sensor model whether homo-type or hetero-type pair. The result that the accuracy of hetero-type stereo pairs is as accurate as that of homo-type stereo pairs follows the previous studies using GeoEye-1 and Worldview-2 imageries (Choi et al, 2012) and using IKONOS and QuickBird imageries (Li et al., 2007).

The combination of all four imageries has generally better accuracy than stereo-pairs of two images, and it can be seen that this result comes from the characteristic of least square estimation method which minimizes the errors by using intersection points. This result confirms the research findings that a proper use of multiple satellite images can be effective for geo-positioning (Fraser et al., 2006; Choi et al., 2012).

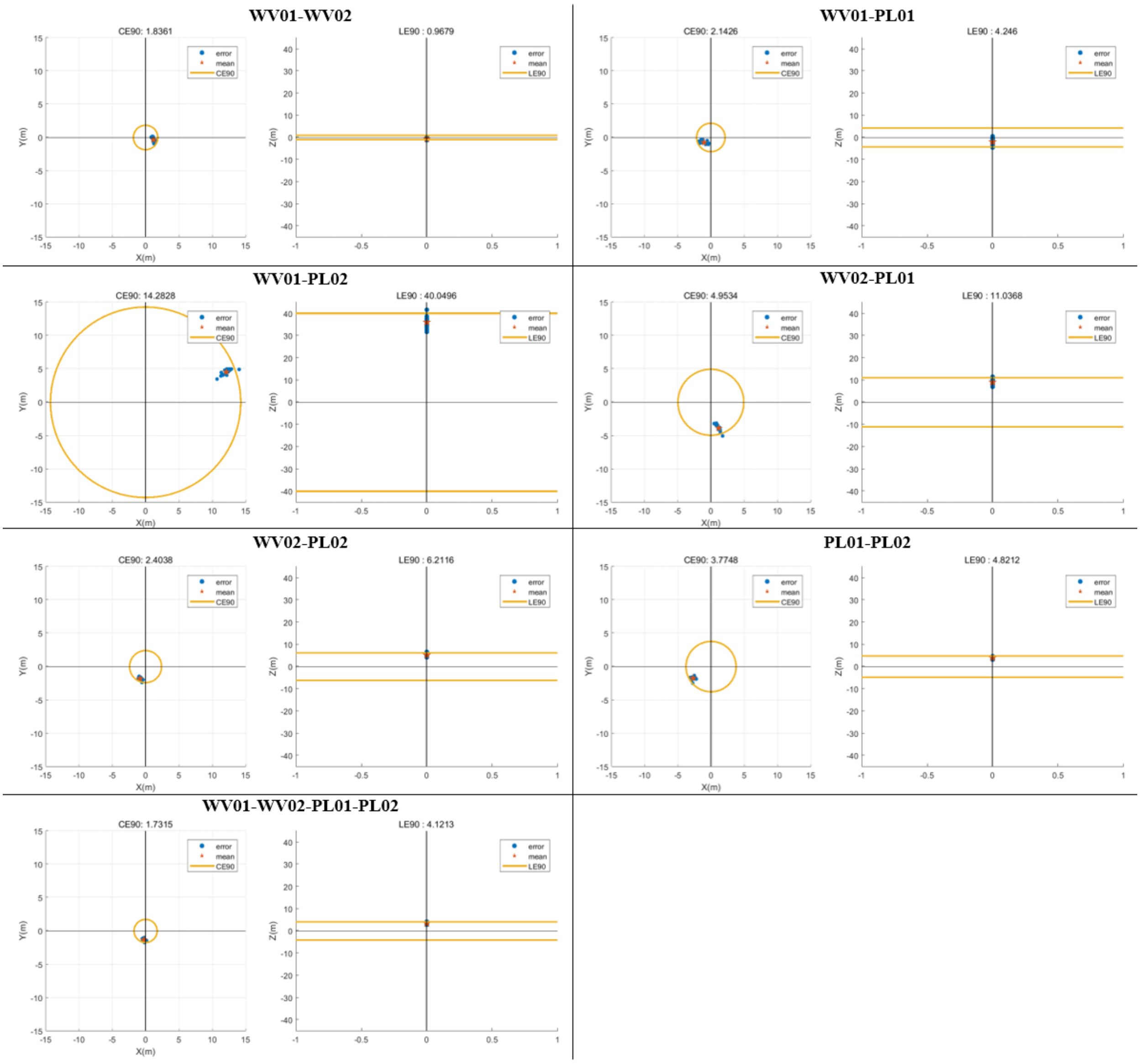

Figure 3. Circular error and linear error of space intersection without GCPs

3.3 Accuracy of Block Adjustment with GCPs

With respect to seven combinations, RPC block adjustment was performed using five control points and the accuracy was assessed. The used RPC block adjustment model for the experiment is proposed in Grodecki and Dial (2003).

The results are shown in Table 4 and Figure 4. In any case of all seven combinations regardless of homo-type or hetero-type stereo pairs, the errors were reduced from that of intersection method which does not use GCPs, and the bias became randomized.

Whether we perform bias-compensated RPC block adjustment or not, relative accuracy still varies depending on the combinations of imageries. According to the results in Table 3 and Table 4, WV01-WV02 pair has the best accuracy in both geo-positioning using space intersection without GCPs and block adjustment modeling with GCPs. Likewise, WV01-PL02 pair has the worst accuracy regardless of the geo-positioning method. From these results, it can be said that convergent angle plays an essential role in improving accuracy of geo-positioning.

Table 4. Geo-positioning accuracy of block adjustment models

	Convergent Angle	RMSE (m)			CE90(m)	LE90(m)
		N	E	h		
WV01-WV02	31.24°	0.24	0.15	0.27	0.67	0.49
WV01-PL01	18.51°	0.29	0.38	1.05	1.09	1.94
WV01-PL02	8.46°	0.34	0.68	1.88	1.68	3.61
WV02-PL01	13.57°	0.52	0.27	0.80	1.31	1.37
WV02-PL02	38.96°	0.44	0.23	0.47	1.07	0.90
PL01-PL02	25.65°	0.25	0.23	0.61	0.81	1.20
WV01-WV02-PL01-PL02	-	0.60	0.19	0.37	1.10	0.72

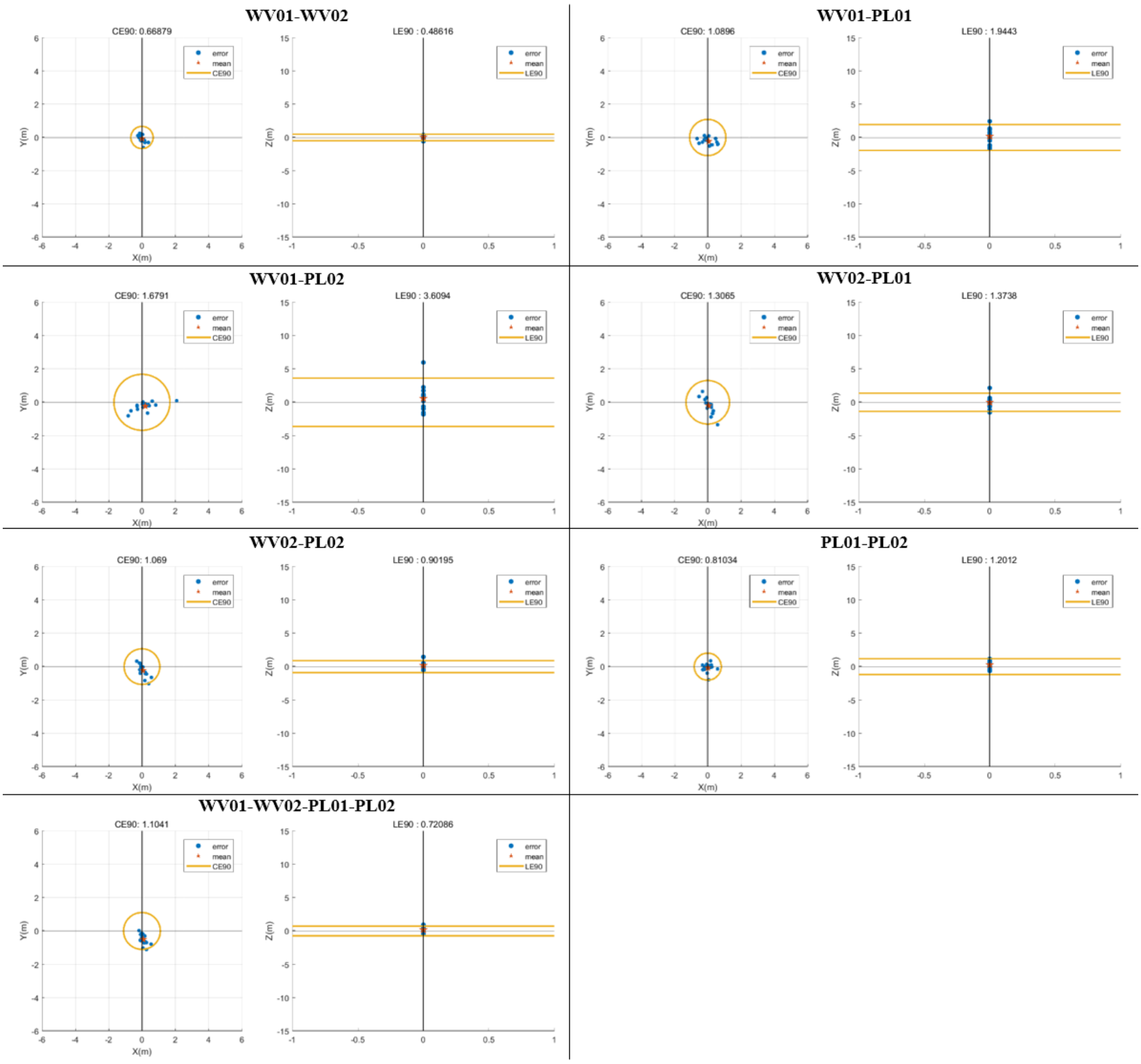

Figure 4. Circular error and linear error of block adjustment models

4. CONCLUSION

We investigated the geo-positioning accuracy of different combinations from four imageries acquired by Worldview-1 and Pleiades HR-1B satellites. Firstly, the bias of vendor-provided RPCs for each satellite imagery in itself was assessed. Secondly, the geo-positioning using the space intersection based on least square estimation without any GCPs was performed, and the accuracy of that was evaluated. Thirdly, we confirmed the effect of bias-compensation with GCPs using RPC block adjustment model, and compared the its accuracy with the accuracy achieved by using intersection method without GCPs. Finally, the following conclusions can be drawn.

- The combinations of high-resolution Worldview-1 and Pleiades HR-1B imageries have the potential that can do three-dimensional geo-positioning for inaccessible regions difficult to collect GCPs by GPS surveying.
- In case there is no GCPs, integrating multiple imageries can improve the geo-positioning accuracy.
- The hetero-type stereo pairs can be an effective alternative of homo-type stereo pairs for geo-positioning using a proper combination.
- While the bias in the vendor-provided RPCs is remained after space intersection, RPC block adjustment model removes the bias.
- Regarding geo-positioning methods that are space intersection and block adjustment model, the relative order for accuracy depends on the combination of imageries, that is stereo geometry created by imageries, regardless of bias-compensation using GCPs.

Furthermore, in order to verify validity of this study in practical cases, an analysis of various factors such as stereo angles in geo-positioning accuracy should be performed by using lots of varied satellite imageries.

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