ACCURACY AND APPLICABILITY OF IMAGE REGISTRATION METHODS FOR CHANGE DETECTION IN RESTRICTED ACCESS AREAS

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ABSTRACT: For countering nuclear proliferation, satellite imagery has been used to monitor suspicious nuclear activities. Since high-resolution optical imagery is available due to the improvement of satellite sensor capabilities, small-scale structures and activities on multi-temporal satellite imagery have been investigated in a few decades. In analysing satellite images of nuclear-related sites, the concern remains that there are spacious sites required to examine carefully. This led to an automated process for examination, and consequentially, a series of temporal images has to be correctly registered prior to algorithm-based change detection. The angle of satellite sensors produces perspective (tilt) images, demanding high-resolution elevation model, which is hardly achievable for restricted access area. As a prerequisite of algorithm-based change detection, this work assesses the accuracy of image-to-image registration with a data set of multi-temporal satellite images in North Korea. A feature-based matching method, the speeded-up robust features (SURF) model, is applied, and location of matching points for registration is discussed according to the target of interest.

1. INTRODUCTION

With the development of remote sensing technologies, satellite imagery has been widely applied to various categories such as environmental biology, geology, national defence, nuclear nonproliferation, etc. In the field of the nuclear nonproliferation, commercial satellite imagery is used as an open-source to verify the correctness and completeness of the member states' declaration according to the treaty on the nonproliferation of nuclear weapons (NPT).

Additionally, analysing satellite imagery, IAEA acquires additional information to make a strategy on inspections, complimentary access, and other technical visits. The nonprofit organisations, including 38 North, CSIS, and ISIS, has also been reporting analysis results in the national/global security perspectives. In the case of an area of interest (AOI) where inaccessible such as the Yongbyon nuclear facility in North Korea, satellite imagery has been used for monitoring undeclared or clandestine nuclear activities. By improving the resolution of satellite imagery, recognising small-scale objects is being facilitated to detect their existence or changes.

On the other hand, there are various sites requiring attention for global security that necessarily involves a significant number of skilled analysts to interpret satellite images. This has led to the development of an automated process for change detection. Essentially, images have to be correctly registered prior to change detection, meaning identical locations of each pixel represent the same objects (if there is no change on the images).

In a few decades, many studies have discussed automated registration. Lowe (1999) provided the scale-invariant feature transform (SIFT), and Bay et al. (2008) have overcome aliasing during downsampling of images using the box filters for Gaussian smoothing with integral images, so-called the speeded-up robust features (SURF) model (2013).

For the use of the algorithm-based registration method in monitoring nuclear activities, this paper assesses the accuracy of the SURF method and discusses its applicability. Further, the effect of the location of ground control points (GCP, also known as matching points) for registration is analyzed.

2. DATA SET

The area of interest in this study is the Yongbyon nuclear complex in North Korea located in the southeastern part of North Korea at 39º 47′ 50″ north latitude and 125º 45′ 17″ east longitude. The subset images of Yongbyon have been optimised to 1,500 pixels × 1,500 pixels for effectively deriving matching points and the area of interest is approximately 0.44 km^2.

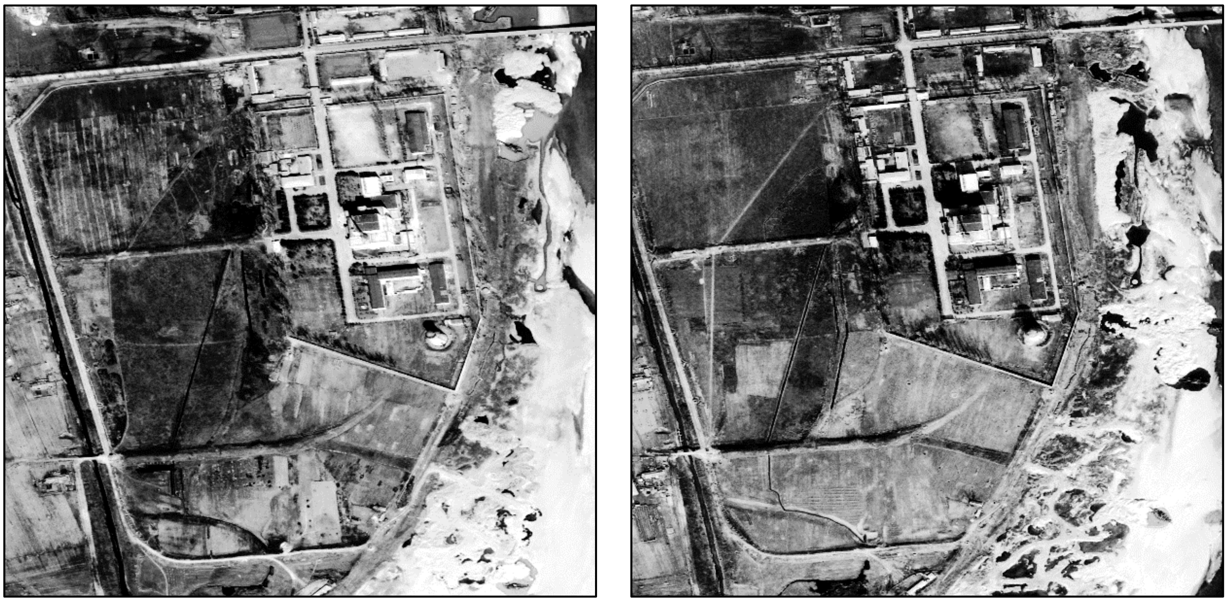
The two temporal satellite imagery from QuickBird-2 with multi-spectral bands (red, green, blue) of which spatial resolution is 2.4 m was chosen. The images of Yongbyon was taken on 28 Mach 2005 (hereafter referred to as 'reference image') and on 18 February 2007 (referred to as 'sensed image'). The dimensions of all images are set to 1,500 pixels × 1,500 pixels, and it is normalised by histogram equalisation to facilitate extraction of feature/matching points. The specification of the data set is summarised in Table 1.

The area of interest, presented in Fig. 1, has been regarded as one of the crucial sections in Yongbyon for analysing suspicious nuclear activities such as plumes, construction/repair of buildings, reclamation, movement/presence of vehicles, personnel, etc. As the objective herein is to evaluate accuracy and applicability of image-to-image registration methods prior to change detection, target objects of image registration were selectively simplified to (i) several buildings including the 5 MW_e reactor and (ii) road network within the subset images.

Table 1: A data set of the QuickBird-2 satellite imagery

		QuickBird-2	
Acquisition date		28 March 2005 (reference)	18 February 2007 (sensed)
Resolution†	Spectral	Red, Green, Blue	
	Spatial	2.4 m	
	Radiometric	16 bit	
Image size (pixels)		13,369 × 10,295	
Subset image size (pixels)		1,500 × 1,500	
Location		39º 47′ 50″ north latitude / 125º 45′ 17″ east longitude	

† The data set is a part of information technically available from the QuickBird-2.



(a) (b)

Figure 1: Subset satellite imagery of the Yongbyon Nuclear Complex from QuickBird-2 converted to grayscale: (a) Acquired on 28 March 2005 (reference image) and (b) on 18 February 2007 (sensed image).

3. METHODS

3.1 Image Registration using the SURF Model

The SURF algorithm was modelled using MATLAB and figure 2 shows a flow chart of SURF model application. The first process is to convert reference and sensed images to grayscale with 8-bit of the radiometric resolution, which is required in the SURF algorithm. Since the spectral and radiometric resolution of original data set obtained from QuickBird-2 is RGB and 16-bit, respectively, they need to be converted to 8-bit and to be transformed into grayscale, *P*, using Eq. (1):

$$P = 0.289 \times R + 0.5870 \times G + 0.1440 \times B \qquad (1)$$

where *R*, *G* and *B* denote DN values in red, green and blue, respectively. The second process is to extract features from reference and sensed images. The grayscale images with 8-bit converted in the first process were normalised by histogram equalisation to facilitate extraction of feature points.

The SURF model has improved the scale-invariant feature transform (SIFT) model to reduce the computation time using the box filters for Gaussian smoothing with integral images. Feature points are extracted by Hessian matrix (Bhatia, 2007):

$$H(p,\sigma) = \begin{pmatrix} L_{xx}(p,\sigma) & L_{xy}(p,\sigma) \\ L_{xx}(p,\sigma) & L_{yy}(p,\sigma) \end{pmatrix} \qquad (2)$$

where $L_{xx}(p,\sigma)$ is the convolution of the second-order derivative of Gaussian filter in *x*-direction at point, p, with scale, σ. A number of matching pairs are excluded by the random sample consensus (RANSAC) algorithm (Torr et al., 2000). Twenty matching pairs have been derived for registration, and the procedures aforementioned are implemented by the MATLAB via the embedded functions of detectSURFFeatures, extractFeatures and estimateGeometricTransform.

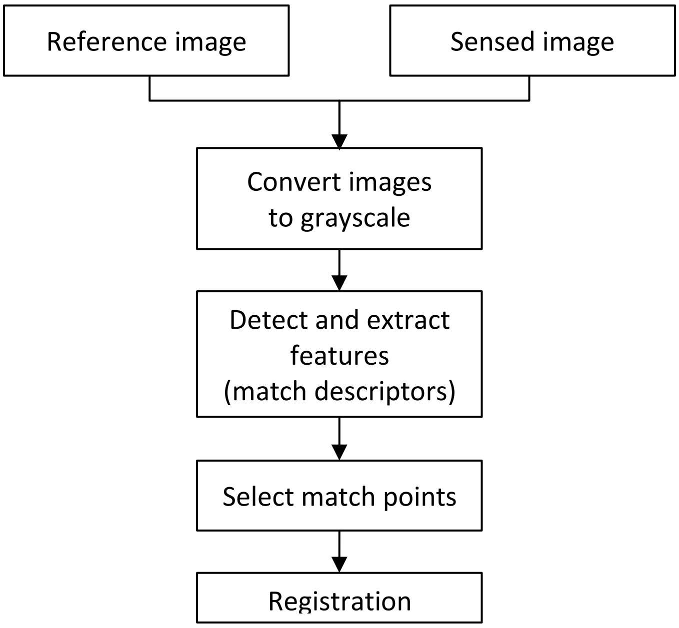


Figure 2: A simplified flow chart of the SURF model application.

3.2 Image Registration using GCPs Manually Assigned

This study aims at assessing not only the accuracy of the SURF model but also its applicability. One of the concerns with the SURF model is locally-produced matching points which could locally distort the images. It is not easy for the SURF model to position the matching points globally or at the intended locations. Therefore, in addition to the SURF model, registration using GCPs manually assigned by two different target objects, (i) several buildings including the 5 MW_e reactor and (ii) road network, has been carried out to see the effect of positioning the matching points. The images are converted into grayscale for the consistency with SURF model and the registration is implemented by the ENVI via the second-order polynomial method.

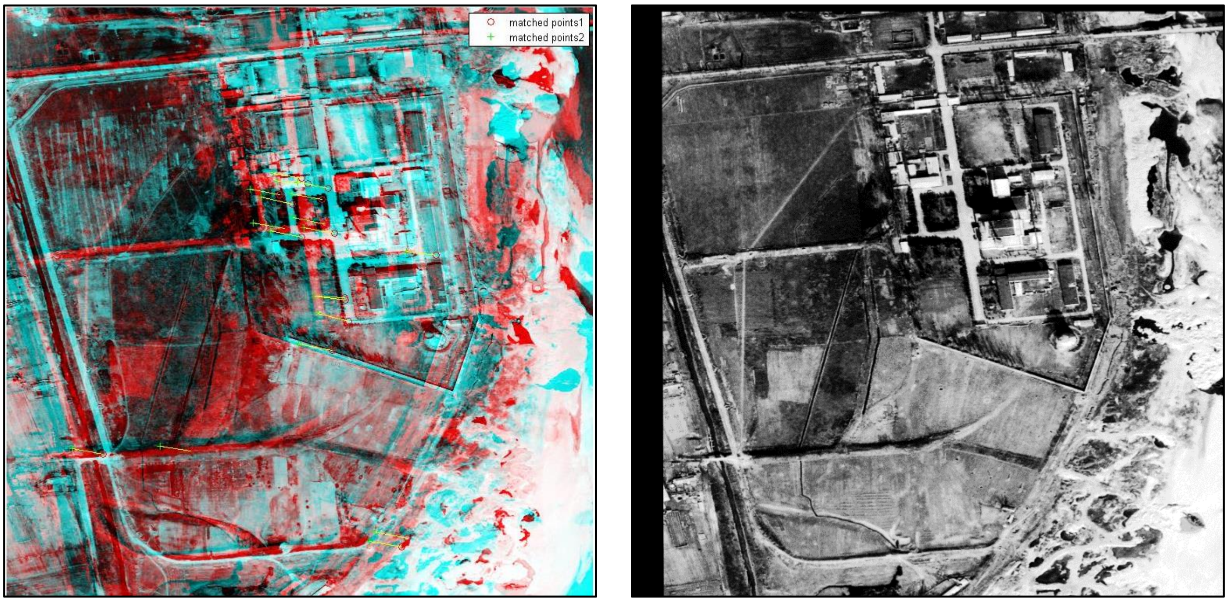
3.3 RMSE Estimation

The accuracy of image registration methods was assessed using root mean square error (RMSE) which is generally introduced in measuring a distance on images. Similar to criteria on assigning matching points, eight checkpoints (CPs) are selected by two different criteria which are building-oriented and road network-oriented.

4. RESULTS AND DISCUSSION

4.1 The SURF Model

Figure 3 presents the results of the SURF model application. The referece and sensed images are overlapped in Fig. 3(a) with twenty matching points on the artificial structures, showing that most points tend to be set on the artificial structures. Although the SURF model can control the number of matching points and global configuration by threshold values, it is unable to determine the locations of matching points as intended. It can be clearly seen that the sensed image was shifted to the bottom and right side, as shown in Fig. 3(b).



(a) (b)

Figure 3: Image-to-image registration using the SURF model: (a) matching results on the reference and sensed images and (b) registration results of the sensed image.

4.2 The GCPs Manually Assigned

The registration using the manually assingned matching points (GCPs) was carried out to see the effect of locations of matching points according to the target of interest. Figures 4(a) and 4(a) shows GCPs with two criteria on assigning matching points which are building-oriented and road network-oriented, respectively. The registration results presented in Figs. 4(b), and 5(b), showing similar trends in general. In the case of building-oriented shown in Fig 4(b), the bottom right corner is compressed since the GCPs have been concentrated in the centre of the image in order to precisely correct the buildings.

(a) (b)

Figure 4: Image-to-image registration using the building oriented GCPs: (a) matching points (GCPs manually assigned) on the sensed image and (b) registration results of the sensed image.

(a) (b)

Figure 5: Image-to-image registration using the road network-oriented GCPs: (a) matching points (GCPs manually assigned) on the sensed image and (b) registration results of the sensed image.

4.3 Discussion on the Accuracy and Applicability

The accuracy of registration methods is assessed by the RMSE evaluation. Figure 6 shows eight checkpoints (CPs) with the criteria of assigning the CPs which is the same as the GCPs' (building-oriented and road network-oriented). Table 2 summarises the RMSE and the conformity by using Eq (3).

$$Diff.(\%) = \frac{RMSE(A) - RMSE(B)}{RMSE(A)} \times 100 \quad (3)$$

where *RMSE(A)* is calculated between original images (without registration) and *RMSE(B)* is from the reference and registered (sensed) images.

Between original images, *RMSEs* are 3.42 and 1.22 for building-oriented and road network-oriented CPs, respectively. This difference results from the angle of satellite sensors producing perspective (tilt) images due to the elevation of buildings. Although the terrain also has similar effect, it is approximately three times lower than the artificial structures (e.g., buildings), in general.

For the SURF, both *RMSEs* are decreased by 5.5% and 21.4% for building-oriented and road network-oriented CPs, respectively. Considering the target objects for change detection, registration using manually assigned GCPs provides better accuracy than the SURF. It has increased from 5.5 to 12.5 and from 21.4 to 37.1 for the buiding-oriented and road network-oriented criteria, respectively.

From the practical viewpoint, *RMSEs* from the road network-oriented CPs provide lower than 1.0 pixel. On the other hand, for the building-oriented GCPs' results with the road network-oriented CPs, the conformity is worse than without registration.

(a) (b)

Figure 6: Reference images to evaluate RMSE showing the CPs with different criteria: (a) building oriented and (b) road network-oriented.

Table 2: Evaluation of RMSE with two different groups of checkpoints.

		RMSE (pixels)	***Diff. (%)***	***RMSE (pixels)***	***Diff. (%)***
Criteria on assigning CPs		Building-oriented CPs		Road network-oriented CPs	
Original (A) (w/o registration)		3.42		1.22	
Registration methods (B)	SURF	3.24	5.5	0.96	21.4
	Building-oriented GCPs (manually assigned)	3.00	12.5	1.25	-2.2
	Road network-oriented GCPs (manually assigned)	3.30	3.7	0.77	37.1

5. CONCLUSIONS

This work assessed the accuracy of applicability of image registration methods for use in change detection within the nuclear facilities in North Korea. Due to the limited data acquisition in North Korea, the perspective (tilt) satellite images from QuickBird-2 were anlaysis using the SURF model. To see the effect of positioning the matching points, registration using the GCPs manually assigned with the two criteria (building-oriented and road network-oriented) was also investigated. For the SURF model, RMSEs were decreased by 5.5% and 21.4% for building-oriented and road network-oriented CPs, respectively. For the registration using the GCPs manually assigned, the road network (overall configuration of images) can be improved by 37.1%. Overall, the RMSE with the building-oriented CPs is approximately three times higher than that with the road network-oriented CPs. Considering the spatial resolution of 2.4 m, it is not feasible to change detection for small-scale nuclear activities.

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