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Sensitivity Analysis of Threshold of Overlapping Pixels to the Pixel-Object Fusion Change Detection for Countering Nuclear Proliferation

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1. Introduction

For countering nuclear proliferation, satellite imagery has been utilized for image interpretation experts to monitor the suspected nuclear activities in the restricted access areas. For example, non-governmental organizations such as 38 North and CSIS have observed and analyzed the major (even minor) changes to imply suspicious nuclear activities in North Korea.

In recent years, with the increasing number of satellite imagery, it is necessary to adopt computer-based image analysis using software solutions for supporting human interpretation [1]. Accordingly, Korea Institute of Nuclear Nonproliferation and Control (KINAC) has developed the pixel-object fusion change detection algorithm to efficiently analyze the massive satellite imagery for nuclear nonproliferation. Although the algorithm can save time and cost for image interpretation, the change detection results can include uncertainties related to governing variables, such as the threshold of overlapping pixels (TOP), determined by human interpretation expertise.

Thus, in this study, the sensitivities (uncertainties) of TOP postulated in the pixel-object fusion change detection were evaluated by comparing the traditional accuracy assessment indices, i.e., *precision* and *recall*, within various TOP values. Prior to the sensitivity analysis, the area of interest (AOI) and the process and result of the pixel-object fusion change detection were also explained in detail.

2. Methods and Results

2.1 AOI: The Yongbyon nuclear complex

The Yongbyon nuclear complex is the indispensable facility of North Korea's nuclear weapon program, which consists of the uranium enrichment plant (UEP), the radiochemical laboratory (RCL) (known as the reprocessing facility), and the 5 MW_e reactor. With analyzing satellite imagery, 38 North (2021) estimated that UEP and RCL had been still in operation by observing smoke emission at thermal plant for RCL and smoke or vapor rising from UO_2 production building [2]. Therefore, from the perspective of nuclear nonproliferation, the Yongbyon nuclear complex was selected as the monitored area of interest (AOI).

Fig. 1 and Table I show the SkySat satellite images of the Yongbyon nuclear complex, specifically UEP, and the characteristics of images, respectively.

Fig. 1. Satellite images of the Yongbyon nuclear complex, specifically UEP: the before (left) and the after image (right).

Table I: Characteristics of satellite images in Fig. 1.

Satellite sensor type	SkySat
Acquisition date	2019.04.15. / 2020.04.12.
Spectral bands	Panchromatic Red, Green, Blue, NIR*
Spatial resolution	0.50 m
Off-nadir angle	8.5 ° / 0.2 °
Subset image size (pixel)	890 × 890

* NIR: Near Infrared

2.2 Pixel-object fusion change detection algorithm

In this study, the pixel-object fusion change detection algorithm was performed with the following three steps as described in Fig. 2.

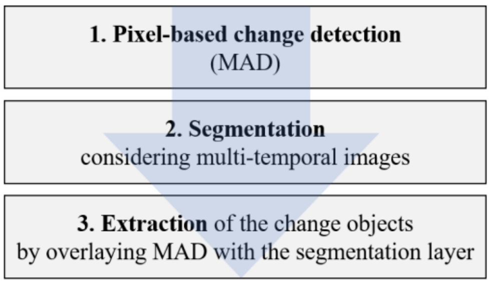
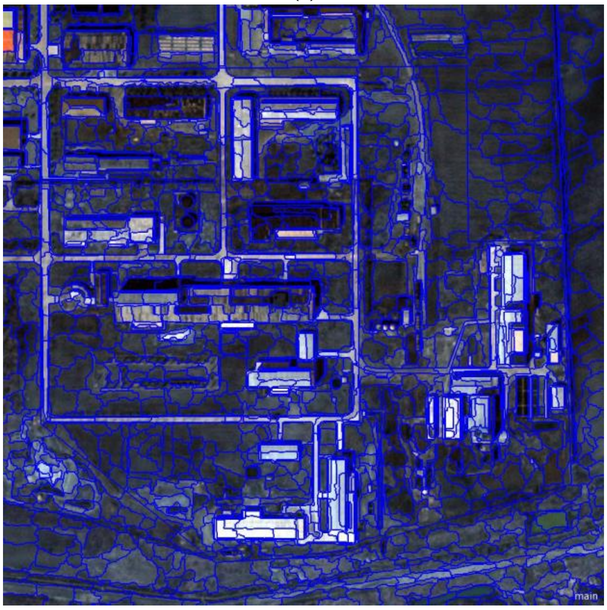


Fig. 2. Process of the pixel-object fusion change detection.

First, the changed pixels between the before and the after images were discriminated by utilizing the multivariate alteration detection (MAD) with a statistic reliability of 70 %. The left of Fig. 3 shows the MAD result, where the white pixels are regarded as the changed pixels.

Second, the multi-temporal images (the before and the after images) are segmented into image objects with similar spectral homogeneity by considering all layers (8 bands of both images). The right of Fig. 3 describes the segmentation result, where the blue are the boundaries surrounding image objects.

(a)

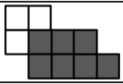
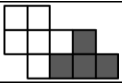
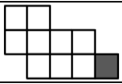


(b)

Fig. 3. (a) Pixel-based change detection result by MAD and (b) segmentation result considering all layers of both the before and the after image.

Third, the change image objects were extracted by overlaying the changed pixels of the MAD result with the segmentation layer. In this step, TOP plays a key role in distinguishing the change objects from the no-change objects. For instance, if TOP changes from 0.5 to 0.8, the change objects may also be considered as not both the segment *b* and *c* but the segment *c* in Table II.

Table II. Conceptual diagram of TOP in a segment for the pixel-object fusion change detection [3].

Segment	***a***	***b***	***c***
Ratio of overlapping pixels	0.3	0.6	0.9
Conceptual diagram*			

* Change pixels (white) and No-change pixels (black).

2.3 Sensitivity of TOP to the change detection accuracy

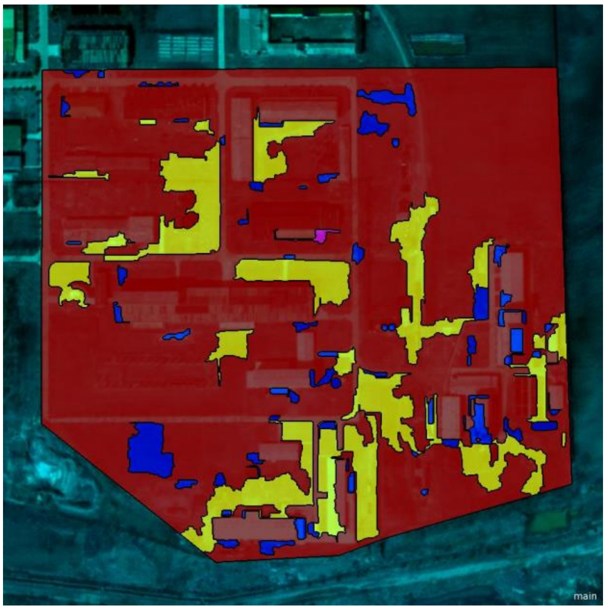
The accuracy of change detection was evaluated with *precision* and *recall*, which can be calculated by the following equations (1) to (2). In detail, *precision* indicates an error regarding false positives, also known as a type I error; *recall* reveals an error related to false negatives (a type II error). The accuracy indices above need to be appropriately utilized depending on the purpose to support remote sensing for nuclear nonproliferation.

$$Precision = \frac{TP}{TP+FP} \quad (1), \quad Recall = \frac{TP}{TP+FN} \quad (2)$$

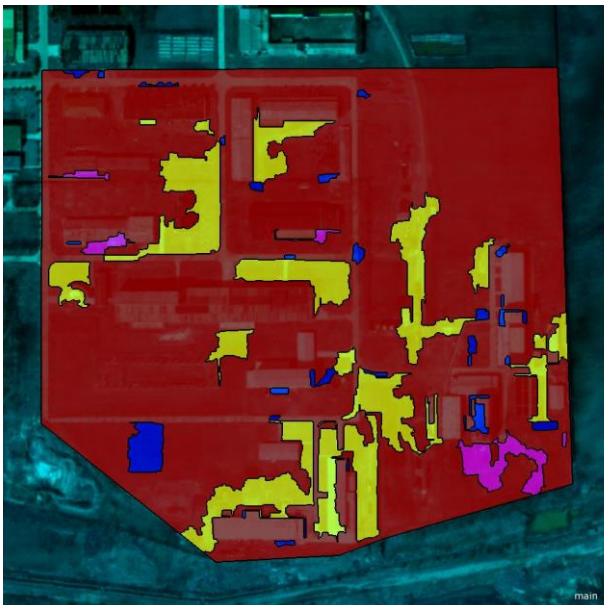
where *TP*, *FP*, *FN*, and *TN* are true positives, false positives, false negatives, and true negatives in the confusion matrix, respectively.

In this study, to analyze the sensitivity of TOP, *precision* and *recall* were estimated in accordance with various TOP values. i.e., 0.1 to 0.8, where a step size is 0.1.

Fig. 4 shows examples of the change detection results with 0.5 and 0.8 of TOP, where positives (*TP* + *FP*) were the change objects extracted by the algorithm. In addition, the larger TOP, the less *FP* and the more *FN*.



(a)



(b)

Fig. 4. Change detection results regarding TOPs, i.e., (a) 0.5 and (b) 0.8: *TP* (yellow), *FP* (blue), *FN* (magenta), and *TN* (red).

Fig. 5 quantitatively describes the sensitivity of TOP to *precision* and *recall* in the change detection results. *Precision* increased from 39 % to 89 %; *recall* decreased from 100 % to 85 % with increasing TOPs from 0.1 to 0.8. Fig. 5 also imply that the change aspects of *precision* and *recall*, which represent *FP* and *FN* respectively, are contradictory.

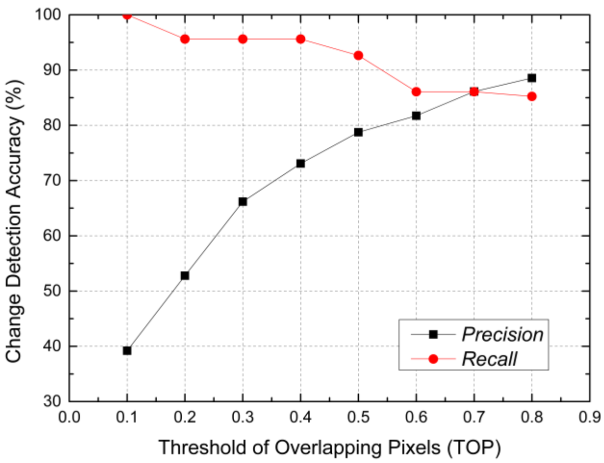


Fig. 5. Accuracy assessment results with increasing TOPs.

3. Conclusions

In this study, the sensitivity of TOP to the pixel-object fusion change detection result was evaluated by calculating the accuracy indices, i.e., *precision* and *recall*. Before the sensitivity analysis, the pixel-object fusion change detection was performed with the systematic three steps: (1) MAD, (2) segmentation, and (3) extraction of the change objects. Those conclusions of this study can be summarized as follows.

First, *precision* and *recall* related to the false detection (*FP*) and the undetected (*FN*), respectively, were estimated as contradictory with increasing TOPs. Second, the sensitivity of TOP to the change detection accuracy was investigated as 50 % increase and 15 % decrease in *precision* and *recall* with the TOP variation from 0.1 to 0.8.

As a future work, TOP in the pixel-object fusion change detection need to be optimized by minimizing both *FP* and *FN* reasonably. For example, the F_1 score, which is the harmonic mean of *precision* and *recall*, can be applied and analyzed to the optimization work.

ACKNOWLEDGMENTS

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