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Requirement Analysis and Optimal Design of an Operational Change Detection Software

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Abstract : This paper describes what an operational change detection tool requires and the software which was designed and developed according to the requirements. The top requirement for the application of the software to operational change detection was identified: minimization of false detections, missing detections and operational cost. In order to meet such a requirement, the software was designed with the concept that the ultimate decision and isolation of changes must be performed manually by visual interpretation and all automatic algorithms and/or visualization techniques must be defined as support functions. In addition, the modular structure of the proposed software enables the addition of a new support function with the minimum development cost and minimum change of the operational environment.

Key Words : Change Detection, Support Functions, Operational Software.

1. Introduction

One of the most important value of satellite remote sensing is its repeatability. The development of effective methodologies for the analysis of vast amount of multi-temporal data has been challenging issues for the past decades. The multi-temporal image analysis is based on the processing of data collected at different times and is important in many applications such as land-use/land-cover change detection, de-forestation, and environmental monitoring, etc.

The processing sequence for multi-temporal image data applications can be categorized in three processes: change detection, change analysis and information update. The change detection process detects objects or regions which were changed between two subsequential images. The determination of "what" or "how" of the changes is carried out in the change analysis process. Finally, the geographic information of the changed objects or regions such as map features, topologies, and so on is extracted, surveyed and updated in the information update process. The change detection which is the major concern of this paper, says that "this region seems changed, but what and how of the changes need to be analyzed further". The description of "seems changed" is appropriate because the real object change cannot be determined absolutely only using satellite images due to the inherent errors of satellite images,

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different imaging conditions, detection algorithm errors and ultimately non-perfectness of human visual interpretation. It is therefore very important to recognize not only the value but also the limitation of the change detection by using satellite images and to minimize false detection ratio for operational applications. A false detection in an operational sense causes unnecessary budget spending in the surveying and analysis of the detected objects, and hence, it degrades the reliability and the usefulness of the change detection tool.

The coverage and completeness is also one of the important criteria in the change detection. Since the main purpose of the change detection is to provide the information of all suspicious changes, the missing detection results in worse consequence than the false detection. Therefore, the change detection tool must support the detection of all possible changes within the entire images. The cost-effective detection can benefit from the wide field of view of space-borne sensors.

The ultimate decision of changes must be made by human interpretation. Although the results of the change detection may contain inherent false detections as well as missing detections, the practical application of any automatic change detection algorithms cannot help generating errors which can be reduced by the interpretation of human operators at the expense of bearable efforts. In other words, the human image interpretation cost for eliminating false detections and finding missing detections from the results of any automatic algorithms is practically much less than the cost for handling them in the following processes (detection analysis process and information update process). Therefore, skillful and experienced operators for visual interpretation of image are required and the change detection tool must provide not only state-of-art automatic change detection algorithms but also efficient user interface in order to minimize the cost and performance of the human visual interpretation.

Although many studies relating to automatic change detection algorithms and multi-temporal image analysis have been carried out and published (see Section 2), it has. hardly been published what the requirements of an operational change detection software must satisfy nor how the software must be designed and developed for the most cost-effective practical application of the software to the operational change detection process.

This paper introduces an operational change detection software which is designed and developed for satisfying all the aforementioned practical requirements for a change detection tool. Some of important backgrounds for the change detection are described in Section 2. The major requirements and the approaches for the operational change detection software design are described in Section 3. In Section 4, a change detection software is introduced and the implementation of the approaches described in Section 3 is explained. Finally, the conclusions and further consideration for more cost effective operation change detection are summarized in Section 5.

2. Backgrounds on Change Detection Process

The change detection process consists of three sequential processing steps as shown in Fig.1.

Since the basic concept of the change detection is the comparison of two images, they must be co-registered as accurately as possible. The accuracy of the co-registration impacts so much on the final performance of the change detection process. The co-registration includes both spatial and radiometric aspects.

Several papers have been published for the analysis of spatial co-registration effects on the change detection (Stow and Chen, 2002; Dai and Khorram, 1998; Townshend *et al.*, 1992). A registration error of less than one pixel has been considered adequate for reducing mis-registration artifacts in change detection products

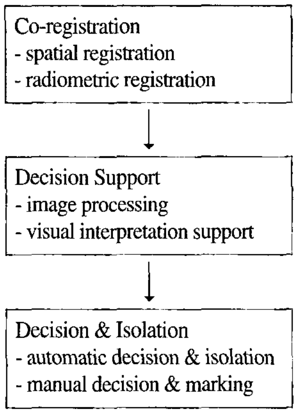

Fig. 1. Change Detection Process.

(Chavez and MacKinnon, 1994; Sachs *et al.*, 1998). A registration error of 0.5 pixel or less is also suggested as the minimum requirement for change detection analyses (Jensen, 1981). More specifically, it was studied that the registration accuracy of less than 0.2 pixel is required to achieve a change detection error of less than 10% (Dai and Khorram, 1998). In practice, the authors agree with the study by Gong *et al.* (1992) that achieving 0.5 pixel or less mis-registration is very difficult across an entire dataset especially for high-resolution images which require accurate digital elevation model for ortho-rectification. In overall, a sub-pixel level spatial co-registration is certainly required for the operational change detection process.

An accurate radiometric co-registration of two images is another important factor. The measured image radiance is generated by complex physical interactions between the source illumination, material surfaces and the intervening atmosphere. Changes in atmospheric conditions and the relative positions of the sensor, surface, and illumination source cause variations between images of the same scene collected at different times. These changing illumination and backscatter effects must be compensated in order to detect changes under the same radiometric condition.

The next step following the co-registration is a decision support step. This step includes either/both automatic image processing algorithms or/and image display techniques that help human visual interpretation in order to support the final decision on change or not.

Many studies have been carried out for finding accurate automatic image comparison algorithms such as image differencing (Singh, 1989), principal component analysis (Buruzzone and Prieto, 2000), change vector analysis (Buruzzone and Prieto, 2002), Markov random fields (Gong, 1993), neural network (Dai and Khorram, 1998), feature extraction (Zeng *et al.*, 2002) and so on.

However, not many studies have been published on the visual interpretation support techniques for the remotely-sensed change detection because they depends heavily on psychology and they are based mainly not on theoretical background but on experience. The concept of change, change-blindness and the nature of visual attention are well studied and summarized by Rensink (2002). Lim *et al.* (2003) introduced an image overlay technique and a float window technique for visual interpretation support to detect changes from a high-resolution satellite image pair. They also showed the functions and the user interface of a change detection software while no reason by which the software was designed as such nor the effectiveness of the design were thoroughly studied nor described.

The final step of the change detection process is the decision and isolation step. The change is determined either by an automatic rule or by visual recognition in this step. In addition, the changed region or object (generally not the pixel-by-pixel) is isolated and extracted in this step.

The automatic decision is based on one of the unsupervised classifiers which use many different features generated in the decision support step. The classifiers can range from a simple threshold divider to a neural network while the features can be extracted based on pixel intensity, texture, probabilistic statistics

(Kalayeh and Landgrebe, 1986; Bruzzone *et al.*, 2000) and context (Kittler and Foglein, 1984; Toussaint, 1978; Melgani and Serpico, 2003). The manual decision depends completely on the operator's recognition and interpretation. In this case, the visualization and controllability of the results from the decision support step is the most important concern.

The relationship between the decision and the isolation would be automatic-automatic, automatic-manual, and manual-manual (manual decision and automatic isolation is impossible). The manual isolation is often called marking (an area of interest). In order to reduce and minimize the false detection ratio, it is general and practical to confirm and isolate the changed region by manual marking.

One of the most important part of the change detection process which is not illustrated in Fig.1 is a reporting. The report on the changed region must be generated and provided to the subsequent change analysis process and the information update process.

3. Software Design Approach

This section describes the major approaches by which the proposed software was designed. These approaches were selected in order to maximize the performance, i.e. accuracy, and minimize the operational cost of the change detection process. It is assumed that the accurately co-registrated image pair are ingested to the change detection software, so that the co-registration step is defined out of the scope of this paper.

Support-Recognition-Marking: The developed software is based on the fact that the ultimate decision and isolation of the changed region is performed by visual interpretation and manual marking in order to minimize false detections. This does not mean at all that poor automatic processors or classifiers are allowed in the software. All automatic data processing results and visual display techniques are categorized as the decision support step. The accurate automatic processing is required to reduce the operational cost (mostly time consuming) of the ultimate decision.

Expandibility of Support Functions: The decision support functions must be able to be added to the software as simply as possible. There is no "the best" support function for all kinds of images (the question would be the same as "are SAR images better than optical images?"). Different support functions give complementary information so that some changes can be detected by one function and others by another. Therefore, new and effective decision functions must be added to the change detection software without much effort. More importantly, the addition of a new support function must not change the operational and visual environment of the software.

Coverage and Completeness: The missing detections are as critical as false detections. Considering that the change detection process provides all suspicious changes to the information update process, all possible changes must be detected efficiently over the whole coverage of the overlapped image pair.

4. Development of Change Detection Software

This section describes a change detection software which was designed and developed according to the approaches described in Section 3.

Fig.2 illustrates the main graphic interface of the developed software which contains four image views: overview, support view, before-view and after-view.

The before-view and the after-view display the before-image and the after-image respectively. The brightness and contrast of each image can be adjusted by histogram equalization or interactive histogram linear stretch. Their viewports can be enlarged, shrink and

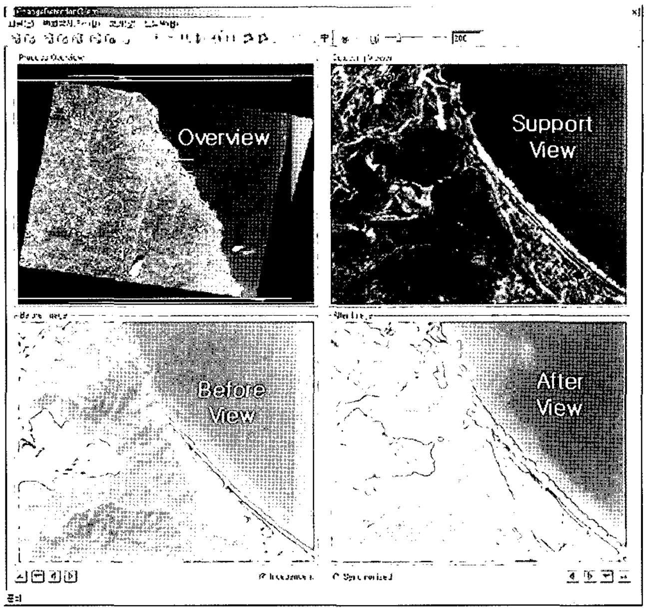

Fig. 2. Change Detection Software Main Graphic Interface.

shifted according to arbitrary zoom levels and panning operation. The operator can change the viewport(s) independently and synchronously (see the bottom of main interface). In the synchronous mode, the zooming or panning of one viewport changes the other viewport correspondingly and automatically. This can save the time for the visual comparison of original images. In order to reduce visual ambiguities due to the mis-registration of the two images, the software supports sub-pixel level adjustment of the original image viewports (see the arrow buttons at the bottom-left, bottom-right of the before-view and after-view respectively).

The support view displays the results of "all" support functions. The support functions may include automatic image processors (differencing, texture generation, classification, segmentation, feature extraction and so on) as well as visualization techniques (flickering, floating window and so on). The viewport of the support view can also be synchronized with original image views.

Two key points regarding to software interface design must be mentioned. Firstly, an operator needs to look at the original images as well as the results of a support function in order to double-confirm and decide the change-or-not. The software must, therefore, show the two original images and the support results in the same viewport simultaneously in order to minimize the false detections and the operational cost. Secondly, the user interface is fixed while any support functions can be added to the software. The software was designed and developed such that each support function module could be added as an independent component with a fixed input-output data interface. The development of an additional support function component and the addition of a simple function driving button to the main graphic interface minimizes the efforts for the support function addition in the view of the software upgrade. Moreover, the operator does not have to learn a new way of recognition technique because the additional support function results in the same view (support view).

The existence of the overview in Fig.2 was designed for satisfying the requirement of the coverage and

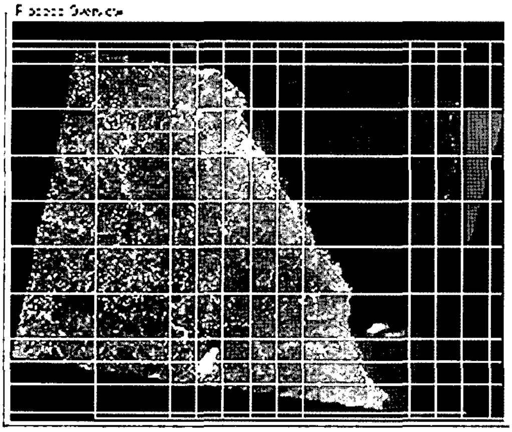

Fig. 3. Overview Grid.

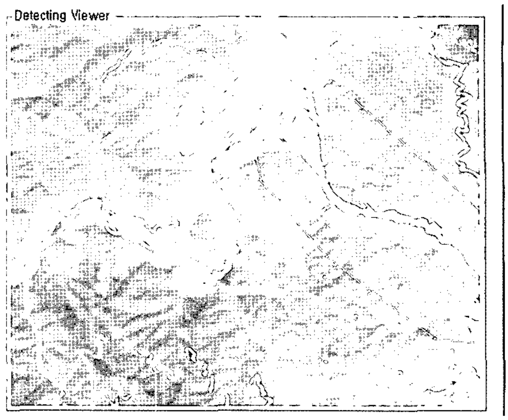

Fig. 4. Changed Region Marking.

completeness. It shows the entire view of the two images with their bounding boxes by which the operator can recognize the overlapped area. Each image in the overview can be shown and hidden by a simple right-mouse button click on the overview. The bounding boxes of the original viewports are shown in the overview. The original viewports are changed automatically by moving the bounding boxes in the overview, so that the operator can select any region in the entire image for visual analysis.

A useful function for maximizing the completeness (detection of all changes in entire images) is the overview grid which is shown in Fig.3. The operator can display regular grids with an arbitrary spacing on the overview. The viewport of the three other views are automatically set according to the grid spacing and their viewports can be moved only within a selected grid cell (no arbitrary panning of each viewport is possible in this mode). Since the operator can assess and decide the changes cell-by-cell, all overlapped area can be interpreted visually without any unnecessary efforts. The operator can mark each cell with a different color after the assessment (simply double clicking of the cell) in order to prevent himself/herself from going back to the cell which has already been assessed.

After a support function provides results in the support view, the operator can make a final decision of a change and mark the changed region by a polygon (see Fig.4). The marking can also be performed while a support function is dynamically running (e.g. image flickering). The image flickering visualization technique, for example, is one of the best support functions. The software provides flickering speed adjustment and viewport adjustment while the flickering is being performed in order to maximize the visual interpretability as well as minimize the operational time. In addition, the marking can be performed not only in the support view but also in the original views because sometimes the operator can recognize the changes by comparing the original images. The operator can move the current support viewport in order to mark the changed region which is extended beyond the current support view.

All marked changed region can be displayed in the overview, the support view and the original views. The software also provides the list of marked area in a report view which can also be printed as a hardcopy (Fig.5). The report provides the information of the detected regions such as the geographic coordinates, the areas of the polygon and the bounding rectangle which can be

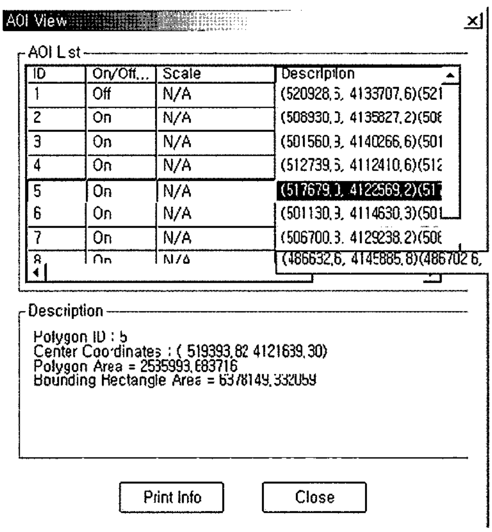

Fig. 5. Changed Region Report.

used in the following applications (the change analysis process and the information update process). For example, a map update organization benefit from the results of the change detection so that it takes an aerial photograph of the changed region in order to analyze the changes and update the current map accurately.

The software was tested by using a pair of SPOT images (taken in 1997 and 1999 respectively). The whole overlapped area of 40km by 60km was searched cell-by-cell in the overview grid and analyzed only by using the flickering support function. While the quantitative assessment of false detections and missing detections cannot be performed, the thorough interpretation, identification and confirm of all suspicious changes over the whole area by an operator took only five hours. This level of the operational time is much more than useful in practical operations because the change detection of land-cover/land-use with remotely-sensed images is in general based on the yearly or bi-yearly operation. The visual interpretation and the manual marking operation of several hours may be comparable to the time for the co-registration of the two images requires (ground control point extraction over the whole overlapped region). In practice, more accurate and advanced support functions are required not for reducing the manual works but for decreasing the ratios of false detections and missing detections.

5. Conclusions

In this paper we described what an operational change detection tool requires and the software which was designed and developed according to the requirements. The change detection process was defined and the top requirement for the operational application of the change detection software was identified: minimization of false detections, missing detections and operational costs.

In order to meet such a requirement, the software was designed with the concept that the ultimate decision and isolation of changes must be performed manually by visual interpretation and all automatic algorithms and/or visualization techniques must be defined as support functions. In addition, the modular structure of the proposed software enables the addition of a new support function with a minimum development cost and a minimum change of the operational environment. Several ideas for increasing visual interpretability and reducing the operational cost were also implemented in the developed software.

For the practical application of the change detection process, it is also important to develop a cost effective image co-registration tool which must precede the proposed change detection software because the absolute and accurate co-registration requires more operational cost than the application of the change detection itself. The most important future work is the real application of the developed software. More requirements of the support functions and the user interface of the software can be driven mainly by the experience of the software operator because they cannot be derived theoretically nor mathematically.

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