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The Scheme and the Preliminary Test of Object-Oriented Simultaneous 3D Geometric and Physical Change Detection using GIS-guided Knowledge

Chang LI*[1, 2], Wenzhong SHI[3], Fangfang LI[4]
[1]Key Laboratory of Disaster Reduction and Emergency Response Engineering of the Ministry of Civil Affairs, 6 Guangbai East Road, Chaoyang District, Beijing, 100124, China
[2]College of Urban and Environmental Science, Central China Normal University, 152 Luoyu Road, Wuhan 430079, China
[3]Joint Spatial Information Research Laboratory, The Hong Kong Polytechnic University and Wuhan University, Hong Kong and Wuhan, China
[4]College of Information Systems and Management, China National University of Defense Technology, Changsha 410073, China
*Corresponding author, e-mail: lcshaka@126.com; lichang@mail.ccnu.edu.cn

Abstract

Current methods of remotely sensed image change detection almost assume that the DEM of the surface objects do not change. However, for the geological disasters areas (such as: landslides, mudslides and avalanches, etc.), this assumption does not hold. And the traditional approach is being challenged. Thus, a new theory for change detection needs to be extended from two-dimensional (2D) to three-dimensional (3D) urgently. This paper aims to present an innovative scheme for change detection method, object-oriented simultaneous three-dimensional geometric and physical change detection (OOS3DGPCD) using GIS-guided knowledge. This aim will be reached by realizing the following specific objectives: a) to develop a set of automatic multi-feature matching and registration methods; b) to propose an approach for simultaneous detecting 3D geometric and physical attributes changes based on the object-oriented strategy; c) to develop a quality control method for OOS3DGPCD; d) to implement the newly proposed OOS3DGPCD method by designing algorithms and developing a prototype system. For aerial remotely sensed images of YingXiu, Wenchuan, preliminary experimental results of 3D change detection are shown so as to verify our approach.

Keywords: *remotely sensed change detection, GIS-guided knowledge, OOS3DGPCD*

1. Introduction

The importance and enormous potential of observations and dynamic detection of changes in the earth's surface by using satellite remote sensing have been recognized increasingly by many national and international organizations, such as USGS, NASA and CEOS [1][4]. In earth observations, change detection provides us with information about the dynamics of the real world and plays a very important role in many fields of economic construction and national defence [5], such as urban planning and disaster mitigation.

During the past two decades, a number of change detection theories and methods based on remote sensing images have been put forward by researchers. These methods are classified into the following categories [6]: (i) algebra, (ii) transformation, (iii) classification, (iv) object-oriented method, (v) visual analysis, (vi) model method, (vii) time series analysis and (viii) hybrid methods. It has been generally agreed that change detection is a complex and integrated process. Over the past years, researchers have put forward large numbers of change detection techniques of remote sensing image and summarized or classified them from different viewpoints [7][8]. Although many successful application cases have been reported on the monitoring and detection of environmental change, there are enormous challenges in applying multi-temporal imagery to derive timely information on the earth's environment and human activities. It has been generally agreed that change detection is a complicated and integrated process. There is no existing method that is optimal and able to solve to all possible change detection cases universally. Furthermore, at present the degree of automation is low to

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prevent real-time applications. The previous reviews have assorted the detection approaches and drawn many useful conclusions [9].

With the construction and application of all kinds of spatial databases, it is an important development trend in change detection [5]. In some applications such as urban GIS updating, and monitoring of military objects, the changing altitude of the objects needs to be detected. In addition, object-oriented method is also called object-based comparison method. The critical challenge of the object-oriented method is the object detection and segmentation. Because feature and object extraction from images is often difficult and prone to error, in practice this method is mostly applied to image-to-map and rarely used for image-to-image change detection [6]. To overcome the difficulty of object extraction, the method of image segmentation techniques is often employed. Another approach is based on a knowledge-based system so that more efficient and accurate object extraction can be achieved.

Furthermore, current methods of remotely sensed change detection almost assume that the DEM of the surface objects do not change. However, for the geological disasters areas (such as: landslides, mudslides and avalanches, etc.), this assumption does not hold. And the traditional approach is being challenged. Thus, a new theory for change detection needs to be extended from two-dimensional (2D) to three-dimensional (3D) urgently.

As mentioned above, in order to detect the change of 3D geometry and physical information accurately and automatically, an innovative scheme of object-oriented simultaneous 3D geometric and physical change detection (OOS3DGPCD) using GIS-guided knowledge is presented. And the preliminary experiment of 3D geometric change detection is given out to test our approach in this article. The overall logic follow of the proposedOOS3DGPCD method is illustrated in Figure 1. The key scientific problems to be resolved in developing the method are illustrated as below.

2. Establishment of Priori Knowledge

A priori knowledge and information from GIS database will be used to support OOS3DGPCD. One essential item of knowledge to be used in this study is context knowledge, i.e. knowledge about the context and objects when the image is acquired. A priori knowledge will be used in a number of process steps of OOS3DGPCD. The knowledge from existing Digital Line Graphic (DLG) will be utilized to aid image registration based on extracted line segments from DLG and furthermore they will be used for controlling image segmentation -- by avoiding unsuitable segmentation. In an earlier study, a priori knowledge from DLG for the Wen Chuan earthquake have been accumulated together with other information and knowledge from DEM, DOM and DRG for the area by using Digital Photogrammetry Grid (DPGrid) system which was researched and developed by Wuhan University, P. R. China. Combining the progress of digital photogrammetry hardware and theory, the ideal, that DPW to DPGrid, is educed. The structure and function of a DPGrid are explained, including cluster processing system based on blade computer, fully seam-less mapping system based on network and their features [10]. These information and knowledge will be transferred and used to support OOS3DGPCD, in the experimental study for this research. The object-orientated three-dimensional model proposed by Shi [11] will be further extended by introducing knowledge on object spectrum characteristics, texture characteristics, evolution rules of spatial or temporal distribution and objective geographical environment to better represent OOS3DGPCD.

3. Image Pre-processing

1) Initial radiometric correction

Radiometric correction will be applied to reduce the inconsistency between the measured reflectivity by the spectral radiation grayscale and sensors to be detected. An image for the area for change detection is regarded as a reference image, and the radiation spectrums of the other image will be adjusted to make it match with the reference image. The key issue here is to determine time-invariant features for the normalization. Initial radiometric correction model for OOS3DGPCD is invariant to affine and linear scaling for radiometric normalization. Furthermore, an improved method, validated with unbiased statistical tests based on invariant features for radiometric normalization, will be developed in this study to obtain the initial value of radiometric correction parameters.

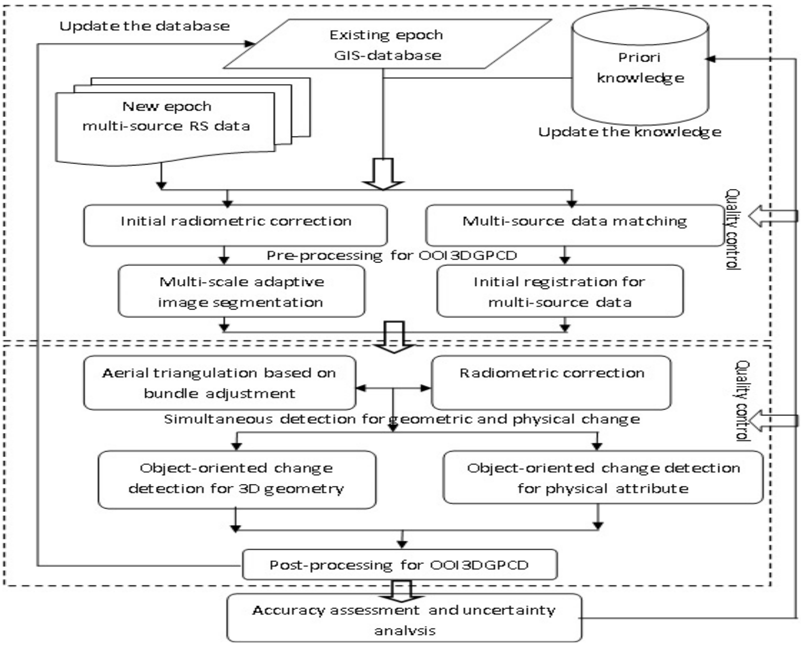


Figure 1. Logic Flow of the Proposed OOS3DGPCD

2) Multi-source data matching

Multi-source data matching is to: a) solve exterior orientation elements and b) generate digital surface model (DSM). Space coordinate transformation, corresponding points and lines features, which are also called as ground control points (GCPs) and ground control lines (GCLs), should be acquired by image matching to improve the level of automation in change detection.

a) To take advantages of their features, Feature-Based Matching (FBM) and Area-Based Matching (ABM) will be integrated for a robust and high accuracy matching. Specifically, Speeded Up Robust Features (SURF) [12], which is a FBM method, is used to acquire the robust GCPs for solving exterior orientation elements; furthermore least squares image matching (LSIM) [13], which is a ABM method, is used to improve the accuracy.
b) The objective law, which states that the global distribution of spatial objects is discontinuous but local distribution is continuous, has been proved very effectively for image matching, such as Zhang [10], Li [14] also presented a straight line stereo matching algorithm based on this objective law. Therefore, the objective law will be adopted in this research for dense image matching. A priori knowledge from GIS, such as the fact from digital line graph (DLG), digital orthophoto map (DOM) and digital elevation model (DEM), will be used as object reference. The dense image matching based on improved geometrically constrained cross-correlation (GC^3) and Vertical Line Locus (VLL) algorithm will be implemented to generate 3D point cloud, 3D lines and DSM for 3D change detection.

3) Adaptive image segmentation

Image segmentation is a very necessary prerequisite for generating spatial objects from remotely sensed images, and object-oriented change detection can be performed based on the extracted objects. Image segmentations are performed at multiple scales and sometimes can be performed from coarse to fine scales [15]. It is a key issue to determine an appropriate scale for image segmentation. With the aid of GIS prior knowledge about the size of the polygons in the area of interest, the scale and segmentation parameters for image segmentation and change detection can be better estimated. Furthermore, in order to overcome the problem of unsuitable segments on an image such as those that spanned across roads or which contained mixed classes, ancillary information, such as digital vector lines from GIS, can be employed.

In this research, a GIS-aided image segmentation method will be developed. Firstly, a global image segmentation is performed on the image, where the outline of the area coved by the image and stored in GIS is used as the prior knowledge to aid the image segmentation. Secondly, a local image segmentation is performed within each of the first step segmented regions. In this local segmentation, multi-features (including image channels, scale parameter, color, shape, smoothness and compactness) are used. Here the segmentation regions are determined adaptively, varying from coarse to fine scales. An improved active contour algorithm with local fuzzy variance polynomial will also be used to extract homogeneous regions within segmented polygons.

This proposed image segmentation method is based on the prior knowledge in GIS, thus there is potential instability, caused by the manual intervention in resetting parameters for image segmentation for different images, which can be overcome by the adaptive determining the segmentation parameters. As a result, the proposed GIS-based image segmentation can form a reliable basis for the later object-oriented change detection.

4) Initial registration (geometric correction) for multi-source data

Initial image registration is used to transform different sets of data into one coordinate system. Point and line photogrammetry have been developed, and furthermore the vanishing point (infinite point) theory are synthesized to the generalized point photogrammetry (GPP) [16][17], which can be used for raster and vector registration. Moreover, Shi [18] also proposed the Line-Based Transformation Model (LBTM) for image rectification and registration.

In this research, the generalized-line-based iterative transformation model (GLBITM), which integrates the advantages of both GPP and LBTM, will be proposed for multi-source data registration based on line features. Firstly, initial values of the scale and rotation coefficients for transformation relationships are acquired by 2D-LBTM or 3D-LBTM. Secondly, on the basis of GCLs, the adjustment model of linear features from image (extracted lines) or GIS-aided DLG based on GPP is utilized for iteratively solving the affine transformation or rational function coefficients, to eliminate the translation amount and recalculate scale and rotation coefficients. Gross errors are taken into account so as to improve the generalization and robustness of GLBITM. Quality control based on posterior variance estimation (iteration method with variable weights) for gross error detection is utilized.

In this proposed model, information from GIS (e.g. DEM or DLG) and relatively rigorous geometric imaging model -- rational function model (RFM) is utilized so as to overcome the problem of undulating topography in mountainous regions and urban areas. Orientation parameters solved by the model are used as initial value in subsequent change detection procedures.

4. A Simultaneous 3D Geometric and Physical Change Detection Method

Within the proposed OOS3DGPCD, one of the main methods to be developed is a simultaneous geometric and physical change detection method, wheretwo types of changing information are detected simultaneously. One is geometric change, and the other is physical attribute change. As mentioned above, geometric and physical information in remote sensing are complementary to each other. E.g. the physical spectrum $g(x, y)$ is a function of geometric coordinates (x, y). Thus, without taking geometric information into account, the independent processing of radiometric information for change detection is not sufficient. In this method, geometric change and physical change modeling whose initial values (radiometric correction parameters and geometric orientation parameters) have been solved simultaneously by the above pre-processing must be unified into an integrated model.

For 3D geometric change detection, geometric parameters (orientation elements or rational function coefficients) recalculation and 3D change detection are carried outsimultaneously with the aid of information from GIS. 3D points with gross error are regarded as potential change 3D points through the detection process. Firstly, a 3DCD model is expressed by a collinearity equation model (CEM) or a rational function model (RFM), based on GIS the control information (GCPs, GCLs) derived from DOM, DEM and DLG. Then, both geometric parameters and 3D geometric changes derived from a new phase stereo pair can be calculated and detected by spatial resection. Secondly, aerial triangulation based on bundle adjustment will be implemented. Specifically, bundle adjustment is to jointly refine a set of 3D structure and initial camera parameter camera (camera calibration and pose) estimates to find that interior and exterior orientation parameters that optimally predict the locations of the observed points, GIS points from DOM and 3D DEM points generated by dense image matching, in the set of available images. The reason for bundle adjustment is that if orientation elements are inaccurate, comparing the elevations acquired directly by spatial resection with the old phase DEM for 3DCD, can lead to incorrect results. Thirdly, in this proposed model, the corresponding points generated by the above multi-feature image dense matching from a new phase stereo pair are substituted into the bundle adjustment model as image coordinates. Corresponding 3D points obtained from DOM (X, Y) and DEM (Z) from the existing GIS data are also substituted into the bundle adjustment model as object coordinates. Fourthly, an iteration method with variable weights is utilized to detect gross errors. Obviously, the changed 3D points no longer satisfy the CEM or RFM equation, therefore the point with gross error is regarded as point 3D change. If the error of a point is smaller than a specified threshold, the point is regarded as an invariant point. The difference of DEM point, which exceeds an acceptable range, is considered as a variant point.

For physical attribute change detection, relative radiometric correction and attributes change detection are realized simultaneously with the aid of information from GIS. With an existing DOM in GIS as a spectral reference that is rectified by images dodging and color balance, a radiometric normalization model called as re-weighted Multivariate Alteration Detection (IR-MAD) transformation by Canty [19], is improved and utilized to acquire the initial value of radiometric correction parameters. A combined mathematical model is proposed by considering simultaneous bundle adjustment equation with re-weighted Multivariate Alteration Detection equation. In this novel model, all invariant information (geometric coordinate and physical spectrum) is utilized as a control to simultaneously recalculate radiometric correction parameters and geometric orientation parameters so that the accuracy of radiometric and geometric parameters is enhanced. At the same time, spectral and geometric changes are detected in the iteration solution. Consequently, this proposed simultaneous method of geometric and physical change detection can improve the 3DCD efficiency and reliability.

Traditional pixel-based detection methods are mainly based on physical attributes, and spectral information is mainly used for the detection and classification [20]. However, spectral information possesses uncertainty and furthermore there is an uncertainty interval in detecting attribute changes based only on spectral information, as mentioned above. Therefore, in this study, the object-oriented change detection approach is proposed as a more reliable approach by reducing the effect of spectral uncertainty found with remote sensing images.

In order to enhance the precision of physical attribute change detection due to spectral uncertainty, the object-oriented change detection method by fusing the spectral, textural and geometrical feature of high-resolution remotely sensed images is proposed in this project. Firstly, segmented object is obtained with the aid of information from GIS. Secondly, textural and geometrical feature information is extracted based on information from the spectral remotely sensed images information. Moreover, the gray level co-occurrence matrix is used to obtain textural features and morphological gradients are used to obtain geometric features. Thirdly, the correlation coefficient and hypothesis testing method is used to analyze differences, to obtain differences image based on spatial object region. Finally, multi-features decision fusion method based on fuzzy sets theory is introduced in this study. In this proposed fusion method, spectral, textural and geometrical features are combined leading to more reliable OOS3DGPCD results.

5. Post-processing of OOS3DGPCD

In order to remove virtual changes and to keep only the real changes, post-processing for OOS3DGPCD will be developed. An adaptative post-processing step is suggested in order to distinguish real from virtual changes. Opening and closing morphological operations will be used to make the real changes more compact and the virtual ones thinner. Contextual knowledge describing the geometry of the changed objects will be utilized depending upon the geospatial environments for which change detections will be conducted. 1) When dealing with man-made structures such as a building, its geometry is one of the most important features to be introduced for better characterization. The two shape features: size and compactness will be defined as object-based filters for post-processing. 2) For the mountainous areas with no man-made structures, the Markov random field (MRF) method, which exploits the inter pixel class dependency context, will be adopted to enhance the precision of final OOS3DGPCD results.

6. Data Quality Control

1) Uncertainty propagation estimation for change detection

Change detection often involves comparing images taken at different epochs of the area interest, where the registration of different images is essential. This is a multi-layer object-based (pixel) or field-based (polygon) overlay problem, a combination of two or more polygon layers into a new layer, addressed in GIS. Consequently, Shi has further developed a probability vector and corresponding parameters. Thus, uncertainty of position and attribute for field-based change detection will be estimated by probability vector [21]. For object-based change detection, the polygons are all homogeneous areas. Then, polygon attribute changes will be transferred to a classification problem based on probability vector. Therefore, an improved probability vector method will be developed to analyze the uncertainty of object-based change detection.

2) Quality control for OOS3DGPCD

OOS3DGPCD quality control will be realized by controlling and reducing the uncertainties in each step of the OOS3DGPCD procedure presented in Figure 1. A level-wise quality control and data adjustment method will be proposed in this study, which is to control the quality of change detection in each of the componential level/ step of the overall change detection procedure.

In this proposed research, a mathematical model and a physical attribute estimation method for controlling the quality of OOS3DGPCD will be set up. The nature of the error which leads to uncertainties in change detection includes systematic errors, random errors and gross errors. Consequently, these three types of errors leading to OOS3DGPCD uncertainties will be processed simultaneous. Here, the gross error in the change detection is removed based on redundant measurements using an integrated method which includes the random sample consensus (RANSAC) and M-estimator algorithms. The systematic error is corrected based on a parameterized function applied to the measurements. The least square adjustment method has been identified as the appropriate core method for random error correction in this study.

The change detection quality control is proposed throughout the entire OOS3DGPCD processing procedure, as specified below:

(1) Quality control for priori knowledge and spatial information building from GIS–by ensuring a) the quality and reliability of the source data from GIS and b) the models for building the knowledge and spatial information from the source data using experts' knowledge, redundant sampling, and quality evaluating techniques.

(2) Quality control for object-oriented spatial objects of the geometrical reliability of vector data uses the Gauss-Markov adjustment model. Basic element in an object-oriented model are polygon or area object. A systematic strategy for controlling the quality of object-oriented change detection is proposed in future study.

(3) Quality control for field-oriented spatial objects is to analyze aerial or satellite data based on analytic geometry method. The basic element of a field-based data model is a pixel in remote sensing images. Geometric distortion (positional error) and spectral distortion (attribute error) are two types of error in a remotely sensed image.

(4) Quality control for DEM is to improve its precision based on novelly suggested interpolation methods in OOS3DGPCD. Applying an interpolation model to a set of elevation points can obtain a DEM. Thus, both the quality of the original elevation points and the interpolation model will be improved to control the quality of a DEM. The hybrid interpolation model and the bi-directional interpolation model proposed by Shi [22] will be further extended by introducing objects into DEM interpolations named as object-orientated DEM interpolation.

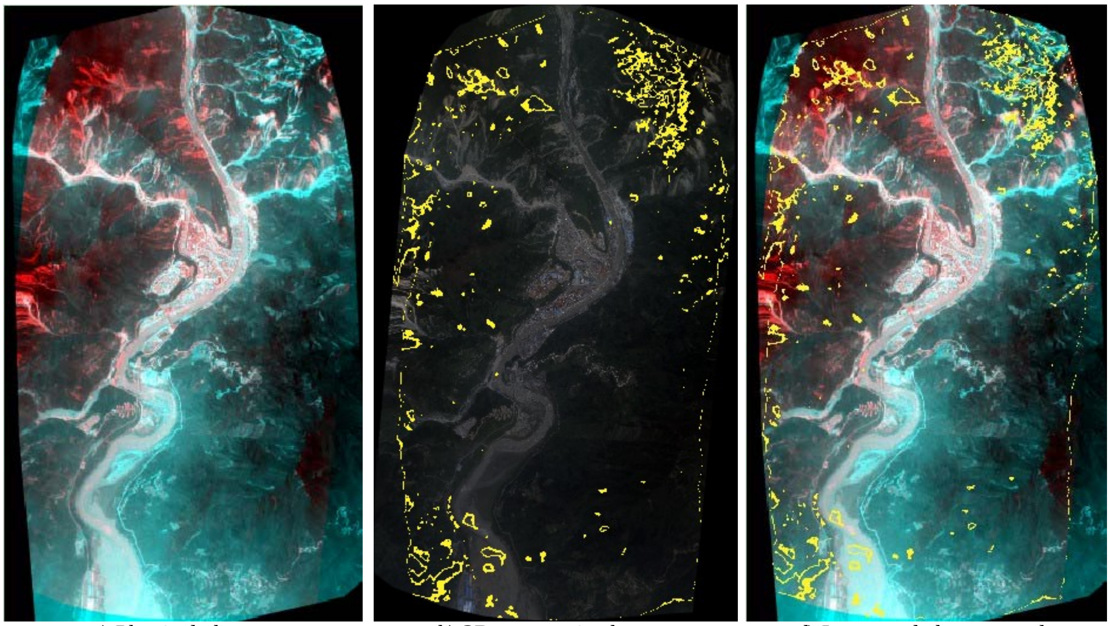
(5) In fact, the quality control runs through the entire OOS3DGPCD process. The related methods are also introduced in the above sections in describing the steps *i*) ~ *iv*). As a

result, the quality of the OOS3DGPCD is controlled, and the reliability of change detection results is ensured.

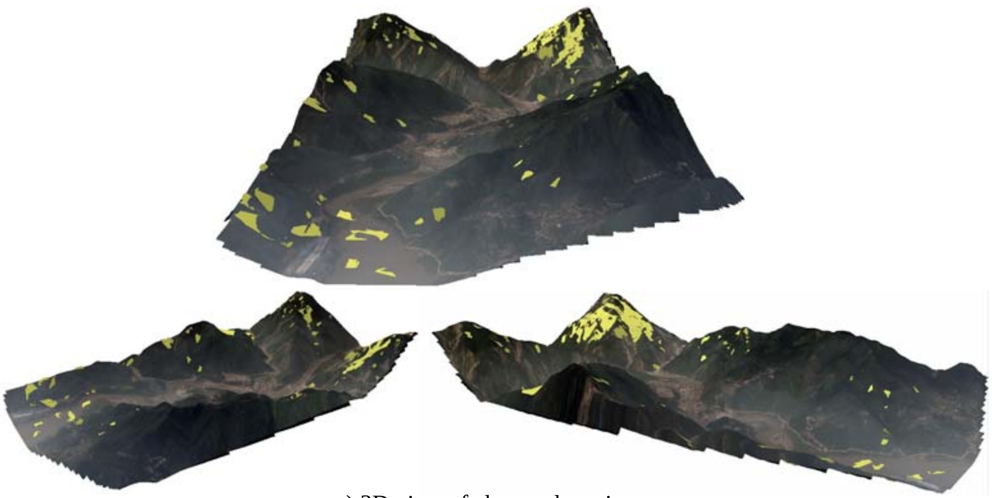
7. Preliminary Experimental Results and Conclusions

The preliminary experiments are address to test the feasibility of the OOS3DGPCD. The data set of two epochs (2010.04 and 2011.06, in Yingxiuwenchuan) was obtained by the procedure described in the following. Stereo images of two epochs were acquired by Vexcel Imaging GmbH UltraCamX prime (11310*17310 pixels). And the DOM (9313*15873 pixels) and DEM (925*1588) generated by DPGrid from 2010.04 stereo pair were used as the reference image and priori knowledge. According to the previously described procedure, we obtained the results of change detection. In Figure 2, physical and 3D geometric changes were shown.

This paper aims to present an innovative scheme for change detection method — OOS3DGPCD. Moreover, the preliminary experiments were implemented. Much work proposed by us should be further investigated in the future.



a) Physical change *b*) 3D geometric change *d*) Integrated change results



c) 3D view of change detection

Figure 2. Change Detection Result of Two Temporal Remote Sensing Images

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