

AN EFFICIENT APPROACH FOR DETECTING CHANGES OF TERRAIN AND UPDATING OLD DEM

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ABSTRACT:

With the advent of high resolution satellite imagery and airborne digital image, detection and surveillance of land cover changes has been a topic of interest. Standard change detection and accuracy assessment techniques are mainly constrained to 2D plane in the geographical space. Change detection methods on terrain elevation are seldom reported, and existing operational procedure of producing DEM with digital photogrammetry workstation requires substantial manual interactive work. This paper presents an efficient and fully automatic approach to detect terrain changes and update old DEM simultaneously with outdated DEM and up-to-date aerial stereoscopic pair. The new approach makes full use of existing digital mapping results and saves productive expenditure. The related tests are done with geo-spatial data from two regions in China, and experimental results of both change detection and updating are satisfying. Compared with existing procedure in production, the approach excels at efficiency markedly, requires less for source data, produces more products, and it is more robust. It provides feasible and practical foundation for 3D change detection in geographical space.

1. INTRODUCTION

With rapid development of our society, economy and technology, land cover has been changing as a main result of continual exploitation and utilization of natural resource by human being. Detecting regions of change from multiple images of the same scene taken at different times is of widespread interest due to a large number of applications. Change detection has always been a hot issue of scholars and researchers from diverse disciplines, including remote sensing, surveillance, medical diagnosis and treatment, civil infrastructure etc.

1.1 Overview

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Timely and accurate change detection of features on the Earth's surface provides the foundation for better understanding relationships and interactions between human and natural phenomena to better manage and use resources. A detailed description of state of the art of problems and applications for change detection can be found in Jensen (1997). And the approaches can generally be classified into three categories: (1) Approaches dedicated to detecting a specific class of objects using a comparison algorithm. (2) Changes of all types based on stored models for an entire scene are processed simultaneously. (3) Compare multi-temporal images using a given similarity measure without any information on objects belonging to the scene before and after this comparison. The main drawback of approaches belonging to this third category is the lack of a measure of relevance concerning the changes which are found by this technique. Hence, the strategy is dependent on the application and the classification tools we are able to handle.

Richard J.Radke (2005) presents a systematic survey of the common processing steps and core decision rules in image change detection algorithms, including significance and hypothesis testing, predictive models, the shading model, and

background modeling. They also discuss important preprocessing methods, approaches to enforcing the consistency of the change mask, and principles for evaluating and comparing the performance of change detection algorithms. D.Lu (2004) summarizes and reviews all the major change detection approaches implemented as found in the literature. They discovered that different algorithms have their own merits and no single approach is optimal and applicable to all cases. In practice, different algorithms are often tested and compared to find the best change detection results for a specific application. Concerning change detection in the fields of remote sensing and photogrammetry, many more aspects such as threshold, registration error have been investigated. Peter (2002) offers a statistical framework for the selection of thresholds. And special attention is given to global spatial autocorrelation, which can affect the selection of appropriate threshold values. The effects of misregistration on the accuracy of remotely sensed change detection were systematically investigated and quantitatively evaluated by Dai (1998). And it is shown that a registration accuracy of less than one-fifth of a pixel is required to achieve a change detection error of less than 10%.

1.2 Motivation and Aims

Previous approaches of change detection for remotely sensed imagery are mainly constrained to 2D plane in the geographical space, and variations of elevation on the terrain are omitted. Those approaches with remotely sensed data presume that elevation of the terrain has no changes. But this presupposition can not always be true for change detection of large scale spatial database. Investigations on elevation change detection are seldom reported. Gong (2000) illustrates the usefulness of DSM and orthophotos generated with digital photogrammetry workstation in the monitoring of changes of gully erosion, water channel incision and coastal salty sand zone displacements. Automation degree of this approach is low, and it is primarily researching on the products of orthophotos and DSM artificially. Most commercial software for remotely sensed imagery, such as ERDAS, PCI and ENVI, provide elementary function for 2D

change detection and those analysis tools are imperfect for various applications, not to speak of detecting elevation changes. So investigations on 3D change detection system for surface of the Earth become urgent and promising.

Deren Li (2002) believes that existing 4D products need to be fully exploited in change detection in order to augment predictive knowledge to improve efficiency and automation; image registration and change detection need to be performed synchronously in order to reduce impact of registration error on results; changes of terrain elevation need to be considered for change detection of large scale spatial database. This paper presents an efficient approach for automatically detecting elevation changes of terrain and updating the old topographic data with two temporal spatial data of the same scene.

2. METHOD AND DISCUSSION

As spatial technology and computer science are developing dramatically nowadays, digital photogrammetry is becoming popular to produce DEM (Digital Elevation Model), DOM (Digital Orthoimage) and DLG (Digital Line Graph). As data of high resolution from airborne and spaceborne remote sensing appear, spatial databases of various scales are constructed based on 4D products, currency of digital products is becoming more and more important.

2.1 Principle

In many data management companies, there exists a large amount of DEM, DOM and DLG in spatial database. If up-to-date aerial photographs are attainable, these data can be employed to detect terrain changes directly and update old DEM to get up-to-date topographic data at the same time. Principle of our approach is depicted as: With existing database for control points or DEM/DOM, by image matching and spatial resection, orientation elements of new stereoscopic pair enhanced can be calculated. VLL matching is employed to interpolate elevation of grid points of entire stereo model, and they are compared with old DEM. If accuracy of some point is eligible, it is an unchanged point. If difference of elevation exceeds acceptable ranges, it is a dubious point. After editing and quality checking, changed points can be discriminated from dubious points, and unchanged points can take part in next iteration. Ultimate products include results of change detection, updated DEM and orientation elements of new stereo pair. If new imagery is acquired by digital camera with POSE system, orientation elements provided by POSE may be regarded as initial value, and it is advantageous for faster computation. The approach investigated in this paper can greatly improve productive efficiency and automation, save productive expenditure and reduce manual work. The approach presented is illustrated as figure 1.

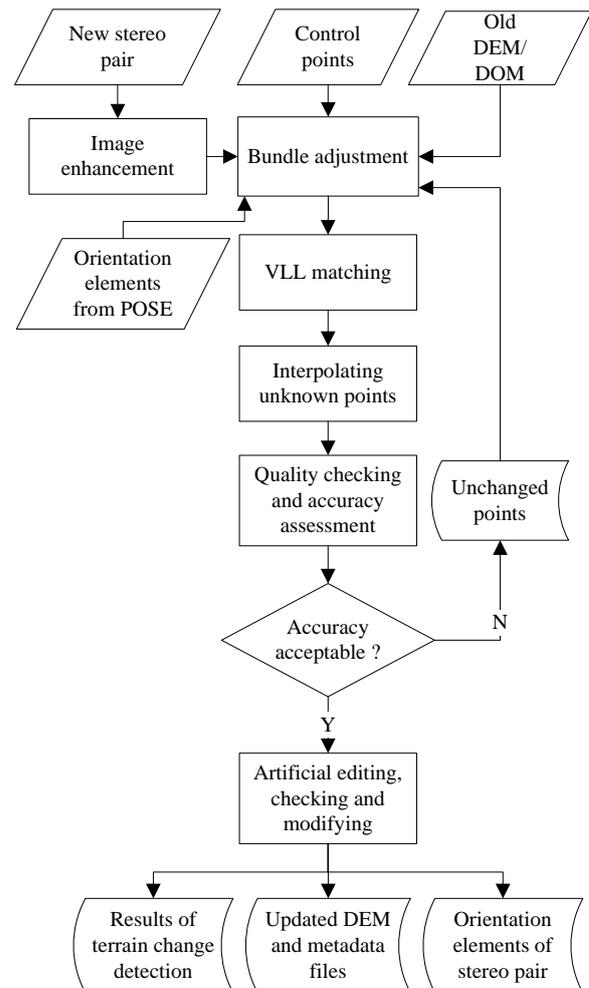


Figure 1. Procedure of change detection and DEM updating

VLL (Vertical Line Locus) is an approach used in image correlator of compound digital photogrammetry workstation composed of analytical plotter DSR-11 and CCD in Kern Company. Suppose there is a plumb line trail in object space, then its projection on photo is also a line. As this approach is based on object space, it is suitable for change detection of terrain when old DEM is given. Each spatial point on DEM can be projected back to stereo pair through collinearity equation. If image points projected are not correlated, elevation of the spatial point has changed or there exists gross error. Theory of searching conjugate points with VLL is illustrated as figure 2.

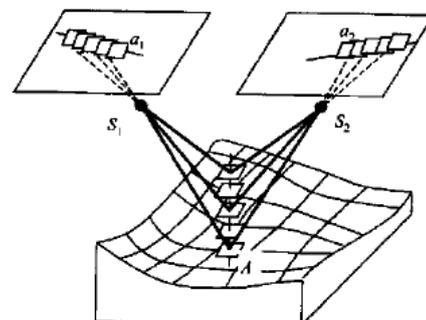


Figure 2. Principle of VLL Matching

Detailed description of VLL matching can refer to related references (Zhang Zuxun et al, 1996).

2.2 Advantages of Proposed Approach

Comparing our approach with previous procedure operating in production, some conclusions can be drawn as follows:

1) Requirements for source material are reduced. In previous procedure, elements of orientation, which are obtained from block adjustment, are essential. Ground controls of high precision, which are acquired from GPS or geodetic survey, are necessary. Accuracy of source data has great impact on quality of final products. In our approach, a few ground controls as original data are got from old DEM/DOM or database of control points, elements of orientation are optional, and they become more and more precise after each iteration process. So quality of ultimate products is less dependent on source data, and the approach is more robust.

2) Procedure is more automatic and less manual work is needed. For old procedure, after image matching, plenty of manual edit, such as smoothing and interpolating, is compulsory to modify mistaken elevation points due to mismatching. Usually we need to adjust contour generated on the terrain surface to make it represent topographic form more accurately. So lots of feature points and feature lines such as peaks, ravines, ridge lines and fractures need supplementing, especially for undulating terrain. This work will expend much time even for experienced operators. After DEM with finer grid interval is obtained by interpolation, scrupulous editing work is also requisite for capricious or complex regions. In our approach, plane coordinates and elevation of unchanged points derive from old DEM, and their elevations are verified by strict correlation condition on new image. Algorithms for blunder detection can be conveniently integrated into the iterative process to eliminate gross error. So tedious labor work is only needed after interpolating points with unknown elevation. As changed regions take up a relatively small portion for a given area, this editing work will not be too much.

3) In previous procedure, only up-to-date DEM is obtained. But in our approach, not only new DEM, but also more accurate elements of orientation and regions that have elevation changes can be obtained simultaneously. As all unchanged points can be used as control points to perform iteration process, the ultimate elements of orientation are accurate, and the detection results are reliable.

3. EXPERIMENTS

According to above description, application software is realized with C++ language on PC, which is equipped with 2.6GHz CPU, 512M RAM, Windows 2000 professional. The application software primarily comprises several modules as follows:

- Bundle adjustment, used to iteratively compute elements of orientation and detect blunder.
- Image matching based on object space (VLL matching), used to differentiate unchanged points, changed points and unknown points.
- Image processing, basic tools for processing aerial imagery, such as texture enhancement.
- Interpolation, used to interpolate elevation of unknown points.
- Visualization, used to display aerial image, DEM, results of change detection visually.
- Evaluation of precision, evaluating result precision.
- Output, outputting results of change detection, updated DEM and metadata files.

3.1 Experiment on Data from Hanzhong Area

Data from two geographic regions in China are used to perform experiments. One is from Dingjun Mountain, located in Hanzhong, Shanxi. Data for this region list as follows:

- DEM, produced with digital photogrammetry workstation and aerial photographs taken in 1988, origin coordinates: (36374300.000, 3662175.000), square grid, grid interval: 25m, grid columns number: 129, grid rows number: 230
- Several control points (at least 3 points), acquired from old DEM/DOM or existing database of control points
- Stereoscopic pair, photographed with camera Wild RC-30 in 1999, camera parameters: $f=153.589\text{mm}$ $x_0=-0.003\text{mm}$ $y_0=-0.009\text{mm}$, photographic scale: 1:35000, picture format: $23\text{cm} \times 23\text{cm}$, stereo pair are scanned to digital image with pixel size 50u and format TIFF

The stereoscopic pair and corresponding elements of orientation are provided to an experienced operator to produce up-to-date DEM with digital photogrammetry workstation, which can be used as reference data for our experimental results.

For the sake of explicit expression, supposing that DEM_0 denotes outdated DEM, DEM_1 denotes new DEM produced by operator, DEM_2 denotes new DEM generated by our prototype software. If the result of terrain change detection is perfect, the following equation should be satisfied:

$$\Delta DEM_2 = DEM_2 - DEM_0 = DEM_1 - DEM_0 = \Delta DEM_1 \quad (1)$$

or

$$\Delta DEM_2 - \Delta DEM_1 = 0 \quad (2)$$

If the result of updated DEM is perfect, the following equation should be satisfied:

$$DEM_2 = DEM_1 \quad (3)$$

or

$$\Delta DEM = DEM_2 - DEM_1 = 0 \quad (4)$$

Due to various systematic error and random error derived from original data, operating procedure, manual work etc, above equations can not be strictly satisfied. And some precision standard may be employed to evaluate quality of our experimental results. DEM precision specification with scale 1:10000 enacted by Chinese National Surveying and Mapping Administration (CNSMA) is employed.

For our experiments, standard for level 1 upland is chosen to check the results, and limit of root mean square error of elevation “ σ ” is set to 2.5m, limit of double root mean square error “ 2σ ” is 5m. Gross errors are eliminated, and formula (5) is used to compute root mean square error. Experimental results can be obtained as table 1.

$$m = \pm \sqrt{\frac{\sum (\Delta Z)^2}{n}} \quad (5)$$

where m = root mean square error

ΔZ = difference of elevation

n = number of points

Assessment data	$< \sigma$	$< 2 \sigma$	RMSE(m)
$\Delta DEM_2 - \Delta DEM_1$ (ΔDEM)	84.2%	96.1%	1.64

Table 1. Experiment results for data from Hanzhong

It can be deduced that, $\Delta DEM_2 - \Delta DEM_1$ shows the quality for result of terrain change detection, ΔDEM shows the quality for result of updated DEM. In this experiment, both results are satisfying, even though manual editing before output has been passed over in our experiments. Changed regions are marked on an aerial imagery as figure 3.

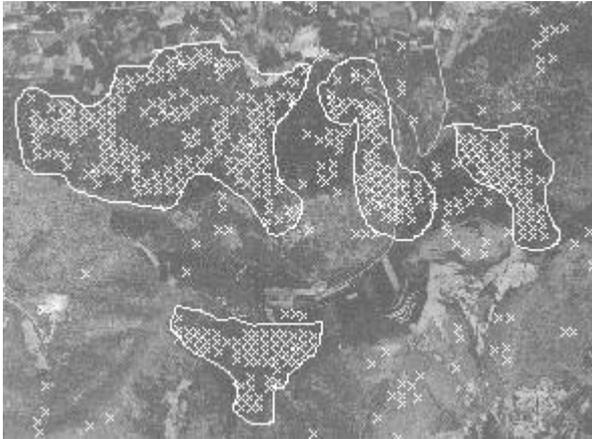


Figure 3. Terrain changed area on imagery of Hanzhong

3.2 Experiment on Data from Tongchuan Area

The other data is from Tongchuan, Shanxi. This is also a mountainous region. Data for this region list as follows:

- DEM, produced with digital photogrammetry workstation and aerial photographs taken in 1988, origin coordinates: (599275.000, 3883575.000), square grid, grid interval: 25m, grid columns number: 117, grid rows number: 247
- Several control points (at least 3 points), acquired from old DEM/DOM or existing database of control points
- Stereoscopic pair, photographed with camera Wild RC-10 in 1999, camera parameters: $f=153.177\text{mm}$ $x_0=-0.0068\text{mm}$ $y_0=0.0103\text{mm}$, photographic scale: 1:35000, picture format: $23\text{cm} \times 23\text{cm}$, stereo pair are scanned to digital image with pixel size 50u and format TIFF

Likewise, precision for terrain change detection and updated DEM is illustrated as table 2. And changed regions are marked on an aerial imagery as figure 4.

Assessment data	$< \sigma$	$< 2 \sigma$	RMSE(m)
$\Delta DEM_2 - \Delta DEM_1$ (ΔDEM)	64.0%	88.3%	2.19

Table 2. Experiment results for data from Tongchuan

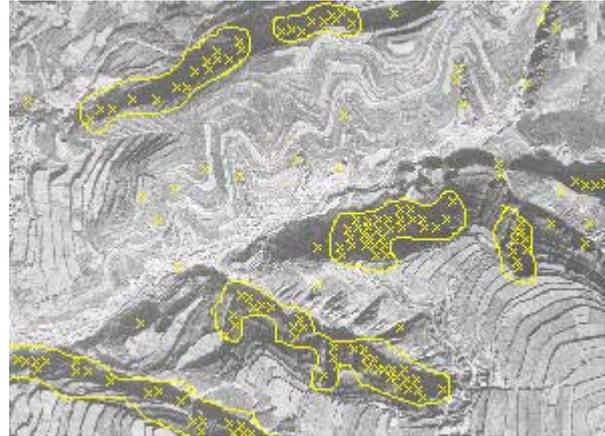


Figure 4. Terrain changed area on imagery of Tongchuan

Experiments on above two geographical data verify applicability of our approach, which is to go into practice after more improvements.

4. CONCLUSIONS

A suitable change detection technique has considerable significance to produce good change detection results for a specific research purpose or a study area. Main objective indicator for our study was to provide an algorithm with a false negative rate as low as possible. Current error rates for our experiments are quite encouraging, but substantial improvements are possible within this framework.

Many false alarms are due to artificial error and original data. As for existing DEM, its precision is highly related to imaging quality of aerial film negatives, image resolution, accuracy of geodetic control points and elements of orientation, and manual editing. As we know, high image resolution is prerequisite to DEM of high precision. Our procedure provides an efficient and fully automatic approach for detecting terrain changes and updating DEM with existing outdated DEM and up-to-date aerial stereoscopic pair. Compared with operating procedure in existence, our procedure requires less for source material, deviates the need for general orientation processes, decreases manual work significantly, and producing more abundant products. Furthermore, the approach presented is more rigorous and robust.

Follow-on research involves reducing false alarms due to tall foliage and special and complicated relief conditions (such as mountain shadow, fractures, cliffs etc), providing specific determinant rules according to multiple terrain factors, using multi-grid DEM to explore more reasonable ways to detect terrain changes, and how to decrease interactive work further.

Change detection analysis remains an active research topic and new techniques continue to be developed. The most significant conclusion of this study is that much research remains to be done to improve upon the results of land use and land cover change detection.

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