Historical Analysis of the Land Movement in Landslide Area Using Elastic Image Registration and Conditional Statement Approach

Siti Khairunniza-Bejo*, Abdul Rashid Mohamed Shariff
Department of Biological and Agricultural Engineering,
Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, MALAYSIA
**E-mail: skbejo@eng.upm.edu.my*

Abstract

Temporal amount of land movement is one of the important input parameter in a study of landslide detection and prediction. Automatic approach in monitoring this movement is needed to replace conventional ground surveying technique which is time consuming. An elastic image registration and change-unchanged conditional statements procedure appropriate for historical analysis of the land movement in landslide area is presented herein. Four deformation operators were used during the registration process. The similarity between two images was measured by a similarity function which takes into consideration the value of mutual information, geometric deformation and maximum overlapping area between the two images. Landslide areas were detected using the amount of pixel movement during a registration process. Two stages of four change-unchanged conditional statements had been developed to monitor landslides of future years. These conditional statements made used of the sequence of detected change images as the input parameter. It was shown that the size of pixel movement can be used to detect changes in landslide areas. The more sequences of changed images were used, the more information about the history of the area can be gathered.

Keywords: *Landslide monitoring; Image registration; Change detection; Conditional logic*

1. Introduction

Landslide is a type of mass movement that causes damage in many areas. Erosions, heavy rains, earthquakes and volcanic eruptions are geological and geographical factors can cause landslides to occur at the same area as in the past. Under the assumption that future landslides will occur under conditions similar to those in the past [1], the area where a landslide occurs is categorised as belonging to the prone-to-landslide environment. Areas in such environments have high potential of new landslide occurrence. Therefore, an effective way to prevent future damage is to identify and analyse the history of the landslide areas. When such an area is identified, its activity may be monitored and specific analysis can be done, so that precautions can be taken. Remote sensing technology has been successfully applied to the detection and mapping of landslides [1, 2]. The use of Geographic Information Systems (GIS) [1] and neural network [3] in the field of landslide study is becoming of great significance. It is done by analyzing information such as temporal amount of the land movement at the landslide location before the event. Automatic approach on inspecting feature changes is needed to replace the conventional ground surveying technique which is time consuming [4].

Image registration is the process of spatially matching two images taken at different times or from different viewpoints or different sensors so that matched pixels in the two images correspond to the same physical region of the scene being imaged [5]. Image registration consists of four basic components: feature extraction, image transformation, image resampling and the use of a measure of similarity. There are two types of approach for registering landslide images: those with and those without sub-pixel accuracy. In registering landslide images without sub-pixel accuracy, two images are overlapped and a set of Ground Control Points (GCPs) in both images is extracted. This set of GCPs features have sharp contrast with their surrounding area and must be well distributed throughout the images. Sheng et al. [6] used the stable lake centroids between the two images as the tie points for image registration. It is because the centroids of lakes are generally stable even if their shorelines are not. In order to correlate two homogenous GCPs, Honda and Nagai [7] and Casson et al. [8] used the correlation coefficient to calculate image similarity. However, it requires images taken from the same sensor. Mutual information has been found to be especially robust for multisensor image registration [9, 10]. In such studies, the set of points matched is used to generate a transformation function between the two images, such as affine transformation and polynomial transformation. Transformation estimation algorithms for non-rigid transformation vary in their handling of local deformations. Zagorchev and Goshtasby [11] conducted a comparative study of four of the commonly used transformation functions for non-rigid transformation, namely, thin plate spline (TPS), multiquadric (MQ), piecewise linear (PL), and weighted mean (WM) transformations. Their study showed that PL function performs better than those of TPS and MQ when tie points are sparsely distributed but however, WM performs best in case large number of tie points and the tie points has positional errors. As the geometric position of pixels changes, the grey values at the vacated grid positions need to be calculated. In addition, Temesgen et al. [12], Hervás et al. [13] and Chen et al. [14] used the nearest neighbour interpolation while Vassilopoulou et al. [15] used bilinear interpolation for the resampling process.

The image registration technique has been applied to detect changes in the land used areas. Since the change detection study requires precise image registration, therefore, the input images are first precisely registered before performing the image registration technique for change detection. Yamaguchi et al. [16] developed two different algorithms to detect a landslide movement as geometric misregistration between two image data of different acquisition dates: the "imageodetic" method and the parabolic function method. In the former method, bilinear interpolation is used to generate a sub-pixel image by interpolating the values of the original pixels while maximising the correlation coefficient until the sub-pixel accuracy becomes 1/128 of the image resolution. In the latter method, a parabolic function was employed to model the correlation coefficient around its peak and from it to locate the position of the peak with sub-pixel accuracy. Kosugi et al. [17] mapped a high resolution image to another one observed at a different time of the same area to detect feature changes in the images. The set of shifting vectors is found by referring to the set of moving pixels during a registration process.

In this paper, an image registration method which is inhomogeneous to account for the local deformations of the terrain, and allows the registration of images with sub-pixels accuracy will be used. A conditional approach is then used to analyze the historical condition of the land movement. Section 2 presents methodology of the algorithm. Section 3 presents results and discussion, and finally, the conclusions will be presented in section 4.

2. Methodology

2.1. Elastic Image Registration

The image registration method which is elastic and inhomogeneous to account for the local deformations of the terrain is based on the image registration technique to detect landslide deformation put forth by Khairunniza-Bejo and Petrou [18]. Therefore, in order to apply an elastic image registration method, two sequence of images i.e. $image_{before}$ and $image_{after}$ captured by the same sensor both geocoded and coregistered are assumed to be available. Starting from $image_{before}$, a sequence of deformed images denoted by $image_{before1}$, $image_{before2}$, $image_{before3}$, ..., $image_{beforeN}$ is created. Each image in the sequence is more similar to $image_{after}$ than the previous one. Each image is created from the previous by applying to it one of the four deformation operators as shown in Figure 1 chosen at random and applied at a random position. As the image is deformed, the grey values at integer locations are calculated using the nearest neighbour interpolation rule. If the imposed deformation improves the cost function value, the change it creates is accepted. If it does not, it is rejected and another operator is invoked. The process stops when the deformed image is sufficiently similar with $image_{after}$. Figure 2 shows flowchart of the image registration method. Detail description of the algorithm can be found in [18].

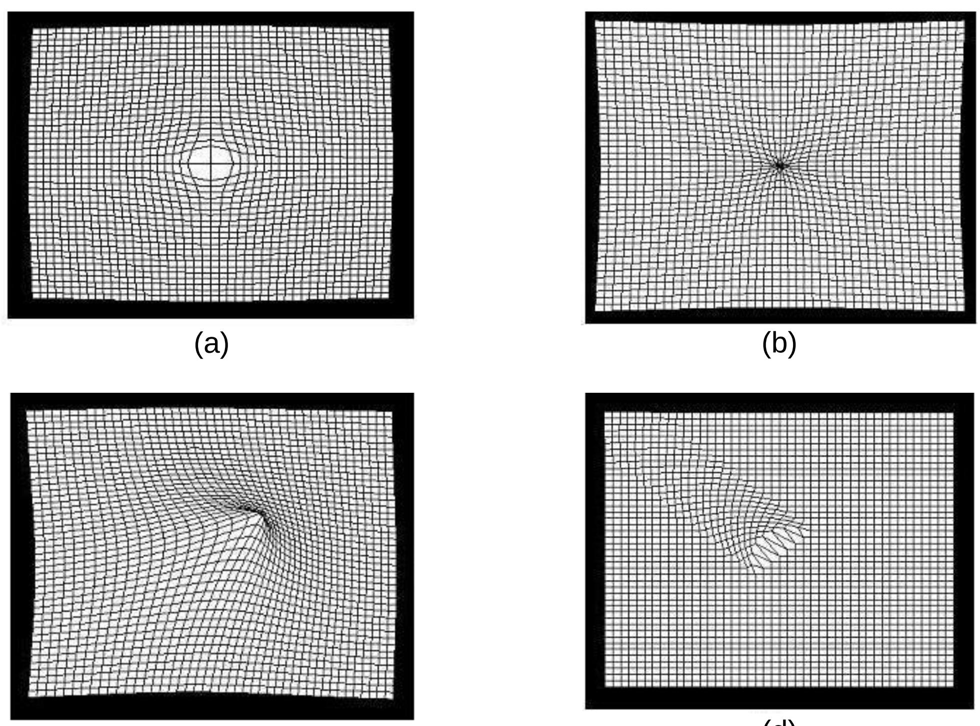


Figure 1: Effects of the four deformation operators used in a regular 45 x 45 grid: (a) exponential growth, (b) exponential shrinkage, (c) exponential translation and (d) exponential parabolic flow front operator.

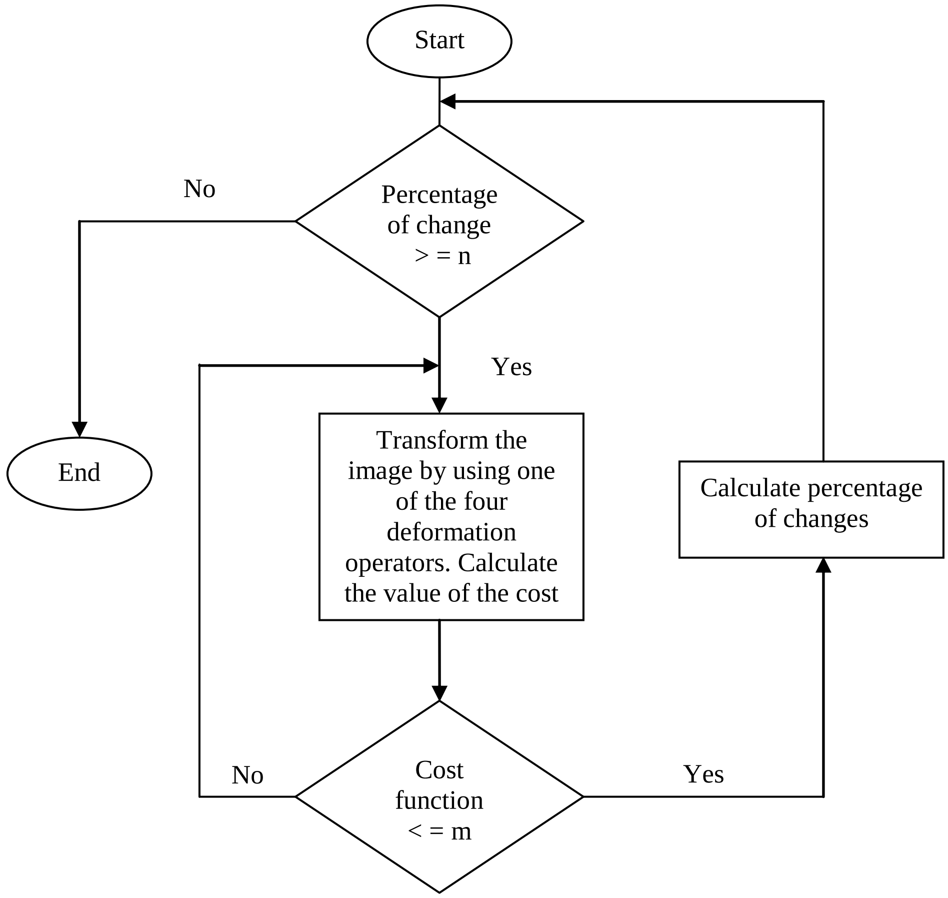


Figure 2: Flowchart of the Elastic Image Registration Method.

2.2. Locating Landslides Using the Size of Pixel Movements

Image to image registration tries to fit one image to the other. The similarity between pixels located at the same location in the two images is low if both of them carry different value of information. These locations are also defined as locations where changes had happened. Therefore, these locations will suffer a lot of distortion during a registration process. Distortions will cause a high value of pixel movement in the image. In this study, the size of pixel movements will be used as guide in locating landslides. The movements in every pixel location are scaled to have a range of [0, 255] by using the minimum and maximum value of the pixels among them. The grey values used for displaying have the same meaning in all images:

$$grey = \left(\frac{move_n - move_{\min}}{move_{\max} - move_{\min}} \right) \times 255 \quad (8)$$

where $move_n$ is the movement in every pixel of the images, $move_{\min}$ is the minimum movement in the images and $move_{\max}$ is the maximum movement in the images. A binary change image, $detect_n$ is then produced by applying an image thresholding method to the scaled movement image.

2.3. Change Conditional Statements

Figure 3 shows four different conditions of the land cover changes. The exist term is used to represent the existing land cover, whilst the lost term to represent the lost of land cover.

a) Condition 1

Condition 1 is when there exist land cover at location (x,y) in $image_n$, but the land cover at the same location shows a loss in $image_{n+1}$ and exist again in $image_{n+2}$. Here, although the land cover changes happen between $image_n$ and $image_{n+1}$, and also between $image_{n+1}$ and $image_{n+2}$, however it seems like there were no changes happening between $image_n$ and $image_{n+2}$ since the land cover at the same location is exist in both images.

b) Condition 2

Condition 2 is when there exist land cover at location (x,y) in $image_n$ but, the land cover at the same location is a loss in $image_{n+1}$ and a loss again in $image_{n+2}$. Here, the land cover changes happen between $image_n$ and $image_{n+1}$, and no land cover changes between $image_{n+1}$ and $image_{n+2}$. The no land cover changes between $image_{n+1}$ and $image_{n+2}$ means that the changes in $image_{n+1}$ is carried through in $image_{n+2}$. It is also shown that there are changes from $image_n$ to $image_{n+2}$ showing exist to loss.

c) Condition 3

Condition 3 is when there exist land cover at location (x,y) in all subsequence images i.e. $image_n$, $image_{n+1}$ and $image_{n+2}$. Here, there are no land cover changes between $image_n$ and $image_{n+1}$ and also between $image_{n+1}$ and $image_{n+2}$. This sequence of land cover changes shows that there are no changes land form between $image_n$ and $image_{n+2}$.

d) Condition 4

Condition 4 is when there exist land cover at location (x,y) in $image_n$ and $image_{n+1}$, but registering a loss in $image_{n+2}$. Here, no changes happen between $image_n$ and $image_{n+1}$. However, the changes happen between $image_{n+1}$ and $image_{n+2}$. This sequence of land cover changes shows that there are changes from $image_n$ to $image_{n+2}$ where from exist to loss condition.

All of these land cover conditions were used as guidelines in developing the change-unchanged conditional statements. The IF-THEN conditional logic approach has been used. Sequence of change images produced by using size of pixel movements during a registration process are used as the input parameter. The change area is represented by the white pixels (1), which are defined as the loss of land cover. The unchanged area is represented by the black pixels (0) which are defined as the existing land cover. Therefore, for a sequence of change images, $detect_n$, $detect_{n+1}$, $detect_{n+2}$,…, $detect_N$, two stages of the IF-THEN conditional statement were developed to monitor the landslide areas taken from $image_n$ to $image_N$. The first stage monitor the changes between two neighbouring sequence of changed images and defined as $change_{n,n+1}$. The second stage monitor the changes between the first changed image in the sequence and the last image in the sequence, and defined as $change_{n,N}$. The combination of $change_{n,n+1}$, $change_{n+1,n+2}$, …, $change_{N-1,N}$ will produce $change_{n,N}$. The IF-THEN conditional statement in all conditions is shown in Figure 4.

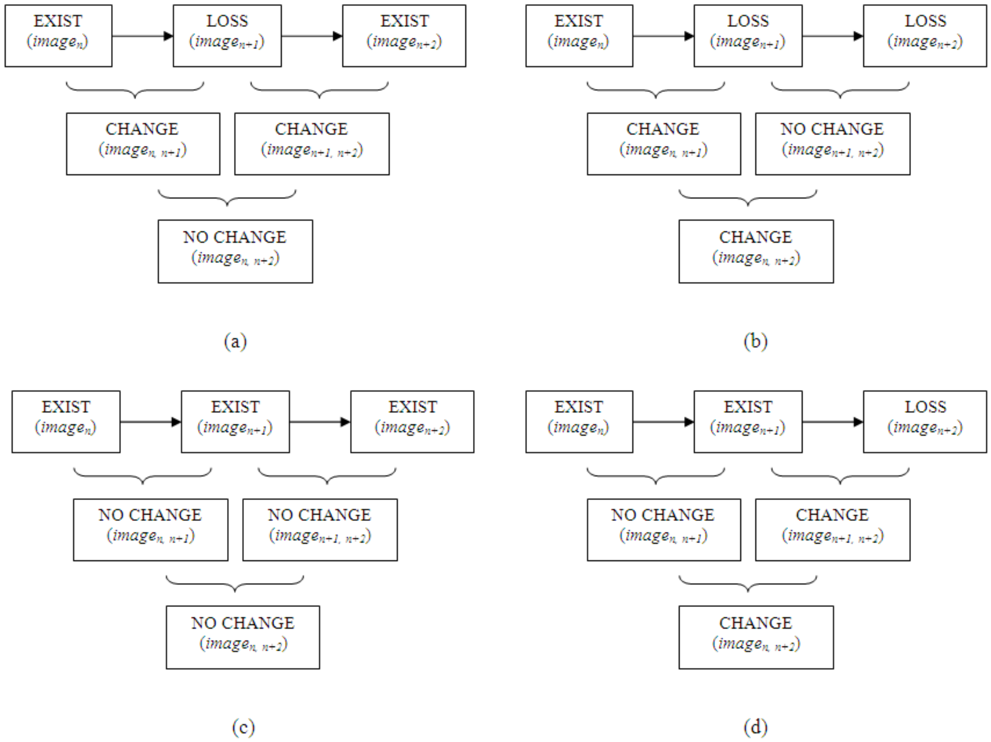


Figure 3: 3-year sequence of land cover changes. (a) Condition 1: Exist → Loss → Exist. (b) Condition 2: Exist → Loss → Loss. (c) Condition 3: Exist → Exist → Exist. (d) Condition 4: Exist → Exist → Loss.

STAGE 1

IF $detect_n == 0$ && $detect_{n+1} == 1$
THEN $change_{n,n+1} = 1$
IF $detect_n == 1$ && $detect_{n+1} == 0$
THEN $change_{n,n+1} = 1$
IF $detect_n == 0$ && $detect_{n+1} == 0$
THEN $change_{n,n+1} = 0$
IF $detect_n == 1$ && $detect_{n+1} == 1$
THEN $change_{n,n+1} = 0$

STAGE 2

Condition 1:
IF $change_{n,n+1} == 1$ && $change_{n+1,n+2} == 1$
THEN $change_{n,N} = 0$
Condition 2:
IF $change_{n,n+1} == 1$ && $change_{n+1,n+2} == 0$
THEN $change_{n,N} = 1$
Condition 3:
IF $change_{n,n+1} == 0$ && $change_{n+1,n+2} == 0$
THEN $change_{n,N} = 0$
Condition 4:
IF $change_{n,n+1} == 0$ && $change_{n+1,n+2} == 1$
THEN $change_{n,N} = 1$

Figure 4: The IF-THEN Conditional Statements.

3. Results and Discussion

Multitemporal satellite images of Tapah-Ringlet, Cameron Highlands, Malaysia taken from Landsat 5 TM shown in Figure 5 were used in the experiments. These images are already geocoded and co-registered by the Malaysian Remote Sensing Agency. The elastic image registration were applied to detect changes of the image between years 1996 and 1998; 1998 and 2002; 2002 and 2005; 1996 and 2002; 1998 and 2005; and 1996 and 2005. The change conditional statement to monitor changes in three different cases i.e. from year 1996 to 2002, from year 1998 to 2005 and from year 1996 to 2005 was used. The 3 different combinations of changed areas are as follows:

Case 1:

$$change_{96,02} = change_{96,98} + change_{98,02}$$

Case 2:

$$change_{98,05} = change_{98,02} + change_{02,05}$$

Case 3:

$$change_{96,05} = change_{96,98} + change_{98,02} + change_{02,05}$$

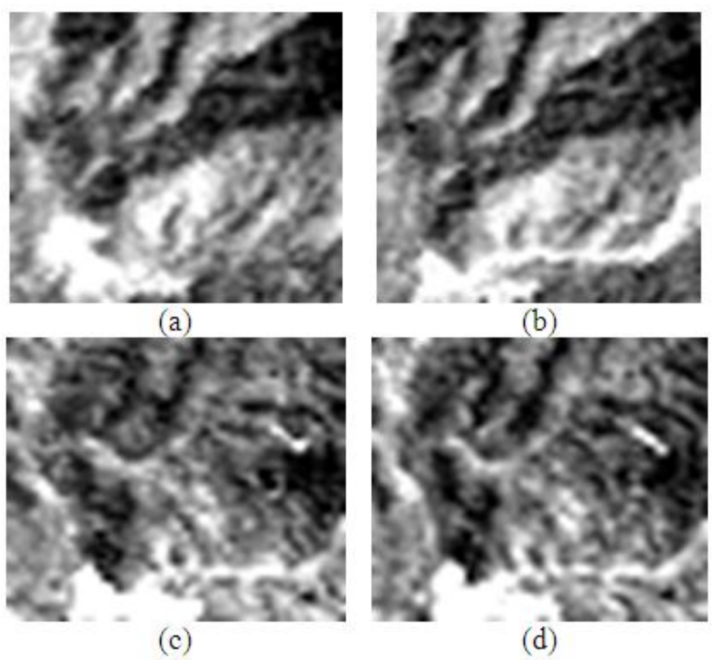


Figure 5: Images of Tapah-Ringlet, Cameron Highlands. (a) Year 1996. (b) Year 1998. (c) Year 2002. (d) Year 2005.

In order to identify the change area, a threshold value of 100 has been chosen for the scaled images. Pixels with the grey values greater than 100 were identified as the changed areas and represented with the white pixels. Figure 6 shows binary images of the change areas in the all cases. The results show that most of the changes are detected at the bottom left of the images.

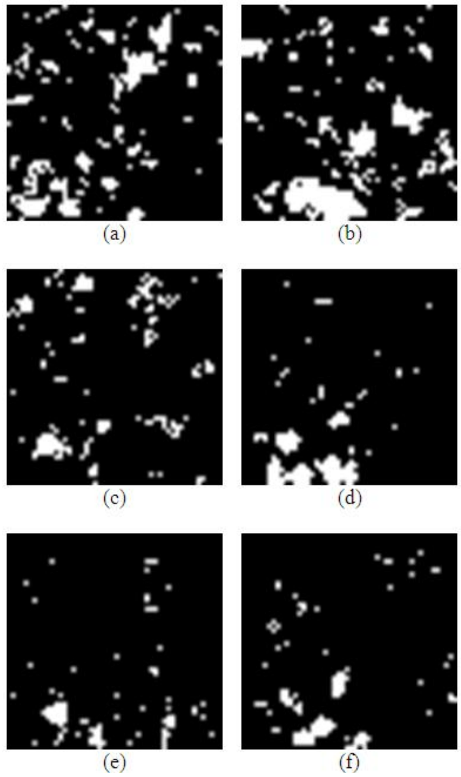
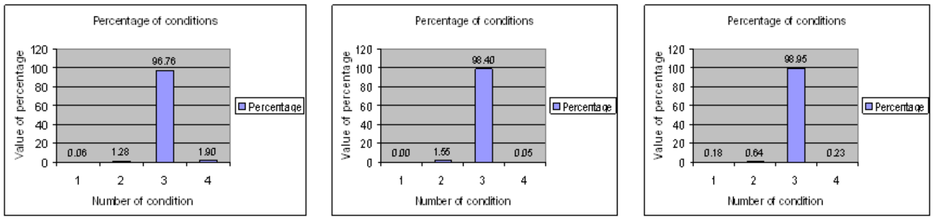


Figure 6: Binary change images created using the size of movement during a registration process. (a) detect96,98. (b) detect98,02. (c) detect02,05. (d) detect96,02. (e) detect98,05. (f) detect96,05.

These binary images were then used as the input for the IF-THEN conditional statement in landslides monitoring. For example, in order to monitor the changes from year 1996 to 2002, the IF-THEN conditional statement is applied to the binary image of $detect_{96,98}$ and $detect_{98,02}$. If the pixel at location *(x,y)* in $detect_{96,98}$ and $detect_{98,02}$ is detected as 1 (change), then the conditional statement will defined pixel at location *(x,y)* in $change_{9602}$ as 0 (unchanged) (refer to Figure 4). Although the conditional statement identified that there are no changes in this location between year 1996 and 2002, however it can give details on what actually had happened based on the result of $detect_{96,98}$ and $detect_{98,02.}$ In Figure 3, we can see that this condition happened because the existing land cover at location *(x,y)* in 1996 is lost in 1998. This change condition is detected as 1 in a binary image of $detect_{96,98.}$ In 2002, the land cover exists at this location. However, there were changes happening in this location between 1998 and 2002. It is detected as 1 in a binary image of $detect_{98,02.}$ Although the change happened in this location between 1996 and 1998, and between 1998 and 2002, however, the conditional statement will identified this location as no changes between 1996 and 2002. This is because the land cover at this location is exists in both years i.e. 1996 and 2002.

In order to monitor changes from year 1996 to 2005, the same process were applied to the binary images of $detect_{96,98\ ,}$ $detect_{98,02}$ and $detect_{02,05.}$ Changes from year 1998 to 2005 were monitored by applying the same process to the binary image of $detect_{98,02}$ and $detect_{02,05.}$ Figure 7 shows the percentage of condition monitored in all cases. The unchanged condition is represented by condition 1 and condition 3. Condition 1 refers to the condition of exist $\rightarrow$ loss $\rightarrow$ exist. Condition 3 refers to the condition of exist $\rightarrow$ exist $\rightarrow$ exist. The identified unchanged condition is defined by condition 2 and condition 4. Condition 2 refers to the condition of exist → loss → loss. Condition 4 refers to the condition of exist → exist → loss. From this graph, it was shown that the study areas did not encounter significant changes whence the changes detected in all cases is 3.18%, 1.6% and 0.88% for Case 1, Case 2 and Case 3, respectively.



(a) (b) (c)

Figure 7: Percentage of conditions identified using conditional statements approach. (a) Monitored from 1996 to 2002. (b) Monitored from 1998 to 2005. (a) Monitored from 1996 to 2005.

The consistency of the result is determined by comparing the changes in every case detected by the conditional statement (between $image_n$ and $image_N$) with the changes detected through elastic image registration. Table 1 shows the percentage of change and unchanged pixels generated by both methods. Results from the table shows that both methods give a high percentage of unchanged pixels more than 93%. The mismatch condition is summarized in Table 2. Error 1 is defined as the condition where pixel at location *(x,y)* is detected as changes in the image registration method but not by the conditional statement method. Error 2 is defined as the condition where the pixel at location *(x,y)* is detected as unchanged in the image registration method but not with the conditional statement method. The results show that both methods give almost similar location of change and unchanged condition with the percentage of mismatch locations being less than 4% for all conditions.

Table 1. Percentage of change and unchanged identified in the image registration and conditional statement method.

Case no	Condition	Image registration (%)	Conditional statement (%)
1	$change_{96,02}$	Unchanged = 93.76 Change = 6.24	Unchanged = 96.82 Change = 3.18
2	$change_{98,05}$	Unchanged = 96.24 Change = 3.76	Unchanged = 98.40 Change = 1.6
3	$change_{96,05}$	Unchanged = 95.24 Change = 4.76	Unchanged = 99.12 Change = 0.88

Table 2. Percentage of error detected between the image registration and conditional method due to mismatch conditions.

Case no	Condition	Error 1 (%)	Error 2 (%)
1	$change_{96,02}$	0	2.36
2	$change_{98,05}$	0	1.96
3	$change_{96,05}$	0	3.8

4. Conclusions

Elastic image registration can be used to detect landslide location and provide information on the amount of land movement at the landslide area. The size of pixel movements during a registration process can be used to detect the areas changed. Areas changed are defined as the locations where a lot of pixel movements happened during a registration process due substantial changes suffered in that location when compared to the other locations. The conditional statements which were developed by considering four change conditions and use subsequent of sequences of binary change images can be used to monitor changes in the landslide areas. Detail information on the changes at locations can be gathered if the more sequence of binary change image are used as the input parameters. Therefore, it can provide information on the historical change condition in the study area. Errors between changes detected by using conditional statement approach and elastic image registration approach appeared only in conditions where the pixel at location (x,y) was detected as unchanged in the image registration method but not at the conditional statement method. The right selection of the threshold value in producing a binary change image could solve this problem.

Acknowledgement

The authors would like to express their appreciation to the Ministry of Science, Technology and Innovation Malaysia (MOSTI), for providing the funds for this project number 01-01-04-SF0590 under the E-ScienceFund initiative.

References

[1] H. X. Lan, C. H. Zhou, L. J. Wang, H. Y. Zhang, and R. H. Li, "Landslide hazard spatial analysis and prediction using GIS in the Xiaojiang watershed, Yunan, China," *Engineering Geology*, vol. 76, pp. 109-128, 2004.
[2] Z. Zhang, H. Gong, W. Zhoa, and Y. Zhang, "Application of remote sensing to study of landslide," in *Geoscience and Remote Sensing Symposium, IGARSS '05*, vol. 3, pp.1546-1549, 2005.
[3] L. Hung-Ming, C. Shun-Kung, W. Jian-Hong, J. C. Hsein, "Neural network-based model for assessing failure potential of highway slopes in the Alishan, Taiwan Area: Pre- and post-earthquake investigation," *Engineering Geology*, vol. 104, pp. 280–289, 2009.
[4] R. Potro, H. Pinkerton, and M. Hürlimann, "An analysis of the morphological, geological and structural features of Teide stratovolcano, Tenerife," *Journal of Volcanology and Geothermal Research*, vol. 181, no. 1-2, pp. 89–105, March 2009.
[5] Y. Bentoutou, N. Taleb, K. Kpalma, and J. Ronsin, "An automatic image registration for applications in remote sensing," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 43, no. 9, pp. 2127-2137, Sept. 2005.
[6] Y. Sheng, C. A. Shah, and L. C. Smith, "Automated Image Registration for Hydrologic Change Detection in the Lake-Rich Arctic," *IEEE Geoscience and Remote Sensing Letters*, vol. 5, no. 3, pp. 414-418, July 2008.
[7] K. Honda, and M. Nagai, "Real-time volcano activity mapping using ground-based digital imagery," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 57, no. 1-2, pp. 159-168, Nov. 2002.
[8] B. Casson, C. Delacourt, D. Baratoux, and P. Allemand, "Seventeen years of the La Clapiere landslide evolution analysed from ortho-rectified aerial photographs," *Engineering Geology*, vol. 68, no. 1-2, pp. 123-139, Feb. 2003.
[9] J. Le Moigne, W. J. Campbell, and R. F. Cromp, "An automated parallel image registration technique based on the correlation of wavelet features," *IEEE Transaction on Geoscience and Remote Sensing*, vol. 40, no. 8, pp. 1849–1864, Aug. 2002.
[10] A. A. Cole-Rhodes, K. L. Johnson, J. Le Moigne, and I. Zavorin, "Multiresolution registration of remote sensing imagery by optimization of mutual information using a stochastic gradient," *IEEE Transactions on Image Processing*, vol. 12, pp. 1495–1511, Dec. 2003.

[11] L. Zagorchev, and A. Goshtasby, "A comparative study of transformation functions for nonrigid image registration," *IEEE Transactions on Image Processing*, vol. 15, no. 3, pp. 529-538, March 2006.
[12] B. Temesgen, M.U. Mohammed, and T. Korme, "Natural hazard assessment using GIS and remote sensing methods, with particular reference to the landslides in Wondogenet Area, Ethiopia," *Phys. Chem. Earth (C)*, vol. 26, no. 9, pp. 665-675, Sept. 2001.
[13] J. Hervás, J. I. Barredo, P. L. Rosin, A. Pasuto, F. Mantovani, and S. Silvano, "Monitoring landslides from optical remotely sensed imagery: the case history of Tessina landslide, Italy," *Geomorphology*, vol. 54, pp. 63-75, 2003.
[14] C. M. Chen, G. F. Hepner, and R. R. Forster, "Fusion of hyperspectral and radar data using the IHS transformation to enhance urban surface features," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 58, no. 1-2, pp. 19-30, June 2003.
[15] S. Vassilopoulou, L. Hurni, V. Dietrich, E. Baltsavis, M. Pateraki, E. Lagios, and I. Parcharidis, "Orthophoto generation using IKONOS imagery and high-resolution DEM: a case study on volcanic hazard monitoring of Nisyros Island (Greece)," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 57, no. 1, pp. 24-38, Nov. 2002.
[16] Y. Yamaguchi, S. Tanaka, T. Odajima, T. Kamai, and S. Tsuchida, "Detection of a landslide movement as geometric misregistration in image matching of SPOT HRV data of two different dates," *International Journal of Remote Sensing*, vol. 24, no. 8, pp. 3523-3534, 2003.
[17] Y. Kosugi, M. Sakamoto, M. Fukunishi, W. Lu, T. Doihara, and S. Kakumoto, "Urban change detection related to earthquakes using an adaptive nonlinear mapping of high-resolution images," *IEEE Geoscience and Remote Sensing Letters*, vol.. 1, no. 3, pp. 152-156, July 2004.
[18] S. Khairunniza-Bejo, and M. Petrou. "Elastic image registration for landslides monitoring," *International Journal of Signal Processing, Image Processing and Pattern Recognition*, vol. 3, no. 3, pp. 71-86, 2010.