Polygon-based Technique for Image Fusion and Land Cover Monitoring; Case Study World Islands/UAE

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Keywords: Polygon Features, Image Fusion, Matching, Change Detection, Similarity Measure.

Abstract: The vast increase in the volume of remotely sensed data has created the need for robust data processing techniques that can fuse data observed by different acquisition systems. Image registration is an essential process for data fusion and aligning images captured by different sensors under different geometric and radiometric properties where conjugate features in images can properly align with same object space. Accurate image registration of the collected multiple temporal images would guarantee full understanding of the phenomenon under consideration. To solve the registration problem, the paradigm consists of selecting the most proper primitives, a representative transformation function, appropriate similarity measure and matching scheme. In this study, polygon-based image registration segments have been used for co-registration as well as the main element for a reliable change detection procedure. Change detection has been implanted on Dubai World Islands /UAE from 2004 until 2016. The approach relies on pixel-pixel subtraction of edge the extracted polygons features. The study shows the various range of development for the world islands / Dubai that has been accrued during 12 years. Quantitative analysis based on growth areas and the Annual Urban Spatial Expansion Index shows that study area has been increased by 4 times during 12 years. Polygon features were successfully used for image registration and change detection.

1 INTRODUCTION

Rapid population growth creates urban economic, social and environmental challenges in our world. Land cover detection and urban growth pattern mapping for urban areas play an important role in planning and management procedures required for reducing the impact of various challenges due to urban growth and cities expansion. The changes have to be accurately and reliably illustrated for full understanding of the physical and human development processes (Al-Ruzouq & Habib 2012). Remotely sensed satellite considered as one of the most appropriate sources of information to determine urban growth and patterns of land-cover change. The appropriate dataset used to examine land-cover changes include multi-temporal spatial images with various spatial and spectral resolutions (Dare & Dowman 2001).

Image registration aims at geometrically overlaying multiple images so that corresponding pixels and landscapes elements (roads, buildings, boundaries etc.) representing the same feature in object space may be fused (Wolfson 1990; Hsieh et al. 1997; Al-Ruzouq et al. 2012). Traditional procedures for image registering require manual selection of tie points in each image (Al-Ruzouq & Abueladas 2013; Seedahmed & Martucci 2002; Fonseca & Manjunath 1996; Boardman et al. 1996). The conjugate points are then used to determine the parameters of a transformation function, which is consequently used to transfer one of the images the other one. While registration based on manual point selection maybe be suitable for infrequent image processing tasks, automatic registration techniques are crucial to handle the huge volume of spatial data. Image registration paradigm involves selecting registration features (points, lines or polygons), identifying the most appropriate transformation function, matching approach and elements of similarity features.

For reliable change detection procedure, based on multi-temporal and multi-resolution images, accurate image registration must be satisfied where features in the object space refer to conjugate features in multi-temporal images space. Inaccurate registration will result in changes due to miss-alignment rather than real changes.

Change detection can be defined as the process of identifying differences in the state of an object or

Al-Ruzouq, R.
Polygon-based Technique for Image Fusion and Land Cover Monitoring; Case Study World Islands/UAE.
DOI: 10.5220/0006354702560261
In *Proceedings of the 3rd International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2017)*, pages 256-261
ISBN: 978-989-758-252-3

phenomenon by observing it at different times (Habib and Al-Ruzouq, 2004). It involves the ability to quantify changes using multi-resolution, multi-spectral, and/or multi-source imagery captured at different times. Traditional change detection studies are based on a visual/manual comparison of temporal datasets (such as satellite scenes, aerial images, maps, etc.). However, the huge flux of imagery that is being captured by a huge number of satellites imposes the progress of automatic and reliable change detection techniques. Such techniques are essential to reduce the high cost associated with spatial data updating activities. Several change detection methods have been developed and reported in the literature (Al-Ruzouq et al. 2012; Cavallaro & Touradj 2001; Agouris et al. 2000; Bruzzone & Prieto 2015; Singh 1989; Dowman 1998). These procedures are based on image subtraction, image ratio, change vector analysis, principle component analysis, neural network, or morphological mathematics.

The previous research utilized satellite images to detect spatial and temporal changes of objects (e.g. cities or lands). Nassar et el. quantified the land cover change in neighboring Dubai City using time series of remotely sensed data for the period between 1972 to 2011 (Nassar et al. 2014). Their results indicated a dramatic increase in the expansion of Dubai's urban area. Specifically, the compound annual growth rate over the whole study period was 10.03%, where the peak growth happened at a rate of 13.03% during 2003-2005. Furthermore, they noted that the urban growth of Dubai included a substantial increase in the vegetation and water bodies, as well as the extraordinary rate of construction of offshore islands. The study provided novel insights into the pace and process of urban growth in Dubai. the study emphasized the importance of evaluating the environmental consequences of rapid urban development.

The main purpose of this study is to detect urban development in world Island at Dubai city by detecting and registering polygon features in multi-temporal Landsat images. This paper used a registration methodology that is based on polygon features and concurrently approximating the parameters of the registration transformation function while relating the conjugate polygons. Derived polygons from the registered images are used as the basis for change detection. pixel–pixel subtraction has been implemented using multi- temporal Landsat images for world island/ Dubai City.

2 STUDY AREA

The world island in Dubai city, United Arab Emirates (UAE) is located in water along the northern coast of the Arabian Gulf on the Arabian Peninsula about 4.0m of the coast of Dubai city with a central coordinate of 25°13' 40" N 55° 9' 54" E, Figure 1(a), (b) shows in sequence world island image within Landsat image of Dubai city.

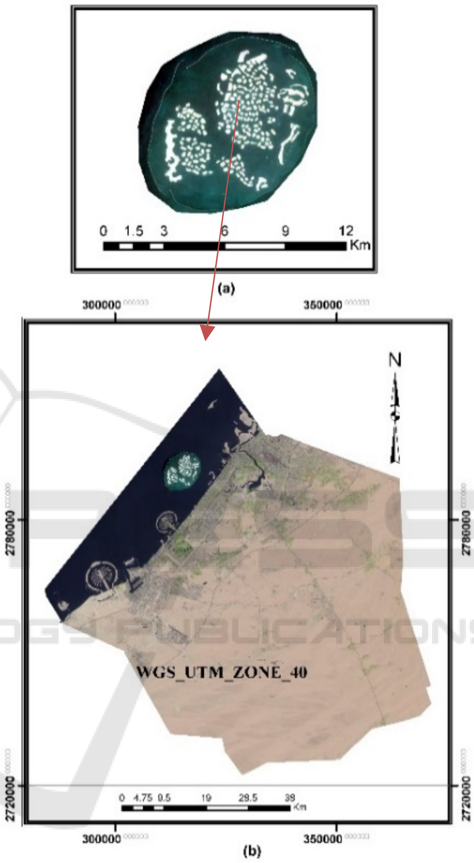

Figure 1: Study Area (a) World island, (b) Dubai / UAE.

The world islands project was designed to have 300 artificial Islands that range from 14,000 to 42,000 square meter in area, where 232 km of shoreline was Roughly created. The initial concept of this island is to bond the mankind through the world regardless of race, origin, and religion.

The world islands represent an ideal case for this study where registration features such as point and lines are unavailable and the use of polygon for registration (island) would be mandatory.

3 GEOSPATIAL DATA

The data used in this research include a diversity of satellite images with different radiometric and geometric resolution captured in different years. These data will be used for image registration and change detection. Table 1 lists the source of each image including capturing data and the spatial resolution in meters. Figure 2-a shows a sample of the Landsat images for the study area for years 2004 until 2016.

Table 1: Landsat images captured at various years.

Year	Resolution (m)
2016	15
2010	15
2008	30
2006	30
2004	30

Figure 2 shows two Multi-temporal Landsat images (the year 2016 and 1995) for Dubai city associated with unsupervised classification where visual inspection can show the amount of changes in the whole city from 1995 until 2015. Various land features that appear off shore in 2016 that was not existing at the year 1995.

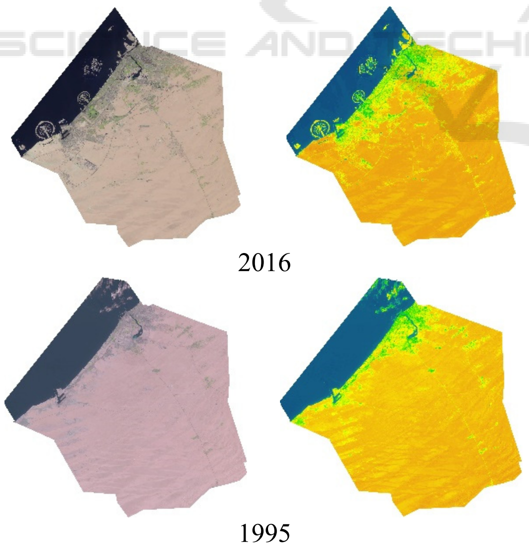

Figure 2: Multi-temporal Landsat images (the year 2016 and 1995) for Dubai city Associated with Unsupervised Classification.

4 METHODOLOGY

In this paper image registration based on polygon feature, and pixel–pixel subtraction has been implemented using Landsat images that have different spatial and temporal resolution. Multi-temporal imagery over the city Dubai (world islands) has been used and registered to the Landsat image captured at 2016.

Image registration procedure necessarily deals with four main topics; registration primitives, a transformation function, similarity measure, and matching strategy(Al-Ruzouq et al. 2012). Polygon features (registration primitives) are usually available in urban areas can be automatically extracted from the images. These features (islands in urban areas) were used as the base for change detection. After finding the transformation function between the reference and input images, one can be transformed into the other image, Figure 2 shows an example of Landsat clipped image after image registration and resampling process. The resampling is followed by applying canny edge detection and majority filter to both images. Then, the resulting images are subtracted to produce a change image, which is enhanced by application of the majority filter. Section 4.1 will discuss the theory and principle of the image registration process. Change detection criteria and stages will be discussed in section 4.2.

4.1 Image Registration

Image registration aims at geometrically overlaying multiple images so that corresponding pixels and landscapes elements (roads, buildings, boundaries etc.) representing the same feature in object space may be fused (Al-Ruzouq & Habib 2012).

To start the registration process, the appropriate elements that will be used for registration must be selected (for example, discrete points, linear landscape elements such as roads, or closed regions that compose polygons). In this research, homogeneous regions represented by world island polygons have been used as the registration primitives, Figure 3. Canny Edge detection (Canny 1986) has been used to extract polygons for the study area. Various image processing techniques and enactment have been implemented to capture the closed polygons, for example, the Gaussian filter was used to smooth the image and remove the noise where non-maximum suppression was also applied to get rid of spurious response to edge detection. To finalize the detection of whole polygons, thresholding and edge connection were conducted.

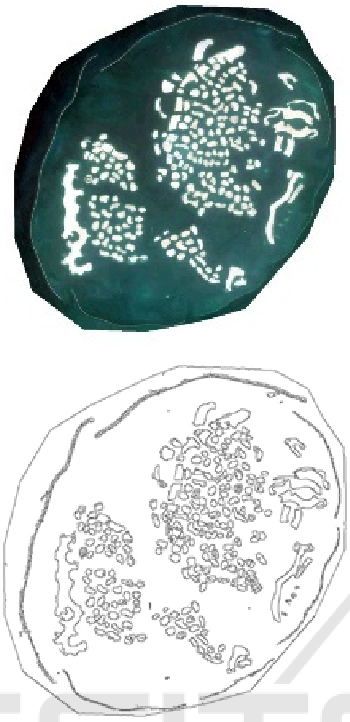

Figure 3: World islands image and extracted polygons.

The database has been established for all vector polygons features. The database will act as a signature that will be used to identify each polygon depending on centroid coordinate, area, polygon perimeter and curvature parameters.

For Mathematically describing the relation between the imagery in question, considering the narrow angular field of view over relatively approximately flat terrain, affine transformation, Equation 1, can be used to overlay the reference and input images properly.

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a_0 \\ b_0 \end{bmatrix} + \begin{bmatrix} a_1 & a_2 \\ b_1 & b_2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{1}$$

Where (x, y); reference image coordinate, (x', y'); input image coordinate.

While choosing homogeneous regions (polygons) as registration elements, mathematical constraints to validate the corresponds between related polygons is required. Let's assume that a polygon A, B and C in the reference image corresponds to the polygon A', B' and C' in the input image. Once selecting polygon, A, the centroid will be exerted and surrounded by the buffer to find the nearest two other centroids of polygons B and C. A' can be identified manually (conjugate of Polygon A) where A' and B' can be also identified based on centroid and buffer criteria. The three points from each image(centroid) will be used to extract the initial parameters of the affine transformation. The initial parameters will be used to transfer one image to another where polygons geometry can be compared based on centroid coordinate, area, polygon perimeter and curvature parameters. The results would allow for initial filtering of the matched polygons based on accepted threshold. Polygons that pass the previous step will contribute in the subsequent stage where corresponds elements and parameters of transformation function can be simultaneously calculated based on least square adjustment procedure.

The constraints must mathematically overlay polygon **A** with the corresponding polygon **A'** after applying the transformation function. Such constraint can be satisfied by forcing the perpendicular distances between the endpoints of a line segment (line connecting two centroids) in the reference image, after applying the transformation function, and the corresponding line segment in the input image to be zero. The constraint can be mathematically described using Equation 2.

$$x_1' \cdot \cos\theta + y_1' \cdot \sin\theta - \rho = 0 \tag{2}$$

Where (ρ, θ): polar reference image coordinate, (x', y'); input image coordinate after applying the transformation function. two points from two adjacent polygons can be used to composed line segments needed for the suggested constraint. This process will be repeated for each segment connected between two centroids in a sequence order. the resulted parameters of affine transformation will be used to fill an array for each parameter and find value with higher frequency (most probable value). It has to be mentioned that size of the array for parameter depends on the confidence of the input values such as the resolution of the images and centroid extraction algorithm, the whole process can be repeated with shorter array width as shown in Figure 4.

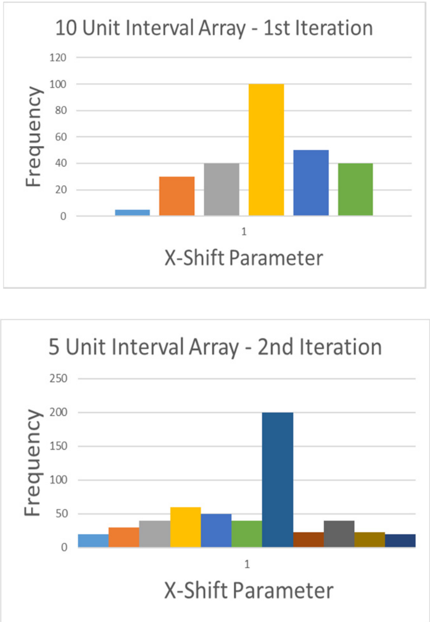

Figure 4: Frequency of parameters with different width interval.

4.2 Change Detection

After deriving the parameters of the registration transformation function, one of the images can be resampled into the reference frame associated with the other one. Within the resampled images, corresponding pixels are assumed to point to the same object space feature. Therefore, a simple pixel-by-pixel comparison/differencing between the resampled images could be used to highlight object space changes. The suggested change detection methodology starts by extracting edge cells using canny edge detector (Canny, 1986). Figure 5 shows a sample of derived edges for the study area at different years. The filtered images will highlight areas with interesting features since they would lead to a dense distribution of edge cells. Afterward, the filtered images are subtracted to highlight areas of change

To quantify the changes in the world islands, the study utilized the Annual Urban Spatial Expansion Index (AUSEI) proposed by (Aljoufie et al. 2013). The index describes the temporal changes of an urban area in terms of its annual urban growth rate and annual growth rate. The AUSEI is computed as shown in equation 3:

$$AUSEI_t = \frac{(U_t - U_{t-1})/U_t}{(N_t - N_{t-1})} \times 100 \qquad (3)$$

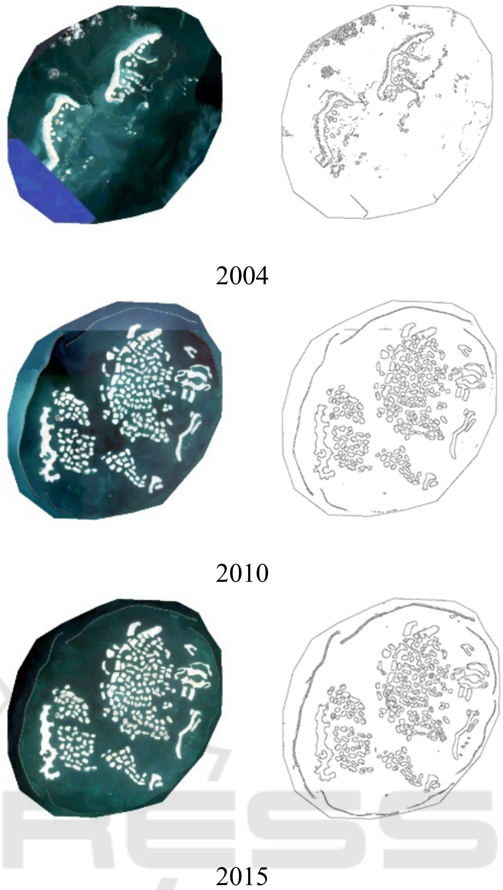

Figure 5: Multi-Temporal images with extracted polygons.

Where AUSEI is the annual urban spatial expansion index for year t; U_t and U_(t-1) are the total urban areas of the study area in hectares at current year t and former year t-1, respectively; and N is the total number of years from current year t and former year t-1, respectively2. Table 2 shows the total urban area and the computed AUSEI indices during the past 12 years.

Table 2: 12 years AUSEI indices.

Year	Changes (Km2)	AUSEI	
		Period	Index Value (%)
2016	8.7	2010-2016	3.6%
2010	10.6	2008-2010	16.5%
2008	7.1	2006-2008	16.2%
2006	4.8	2004-2006	20.8%
2004	2.8	-	

5 CONCLUSION AND FUTURE WORK

This paper presents a polygon-based image registration together with a suggested procedure for detecting changes between the involved images. The approach has been tested on real datasets, which showed its effectiveness in registering and detecting changes among multi-temporal and multi-resolution imagery.

The illustrated procedure has been used for image registration of multi-source imagery with varying geometric and radiometric properties. The presented approach used polygon features (islands) as the registration primitives since they can be reliably extracted from the images. To avoid the effect of possible radiometric differences between the registered images, due to different atmospheric conditions, noise, and/or different spectral properties, the change detection is based on derived edge images. The use of polygons vectors is attractive since it would lead to an effective detection of urbanization activities. The images are then subtracted to produce a change image, which could be enhanced by applying an image processing filters to remove noise. The change detection results are found to be consistent with these visually identified. Future research will concentrate on using high-resolution images for change detection at the same time establishing ground truth for quantitative evaluation of the suggested approach.

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