Time series aerial photographs to detect spatio-temporal changes in coastal areas of Fiji

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ABSTRACT

Time series of aerial photographs, which are reasonably widely available in the Pacific Island countries, provide a useful resource of geospatial data and can be used for the detection and quantitative assessment of spatio-temporal changes in the most dynamic coastal areas, which are often economically and culturally valuable, but also vulnerable to the effects of natural and anthropogenic stresses. Quantitative analysis, based on GIS and advanced image processing, is the most precise but time-consuming method. In many cases, visual detection and preliminary assessment of changes is a rational way to decide quickly whether more sophisticated techniques should be employed to map spatial changes in more detail. This paper elaborates on different techniques available for rapid change detection and analysis using time series of aerial photographs. The rationale and applicability of such methods are illustrated in a feasibility study that was implemented to detect changes since the mid-1960s in mangrove cover in the Korotogo area of the Coral Coast, on the southern coast of the main island of Fiji.

1 INTRODUCTION

The main goal of this paper is to illuminate the efficiency of historical aerial photographs for quick detection and quantitative assessment of spatio-temporal changes in coastal areas, specifically in island countries of the South Pacific. Prior to the existence of satellite images, aerial photographs were widely used for many decades to acquire information on features of the Earth's surface. In the early 1970s the first satellite images were captured, but at a low resolution that was not yet comparable with the pictorial quality and resolution of aerial photographs (Lillesand et al., 2007). Nowadays, many satellite-borne sensors do provide very clear and detailed pictures of the Earth. OrbView, QuickBird and Ikonos sensors, for example, acquire multi-spectral imagery at sub-metre resolution and can periodically capture almost any part of the Earth's surface within short time intervals.

Yet, in spite of all the advantages of satellite remote sensing technologies, aerial photography is still popular around the world for mapping the current condition of the Earth, and is one of the only sources for historical images prior to the modern satellite era. In the South Pacific region, aerial photography has been used for documenting and mapping purposes since the 1940s (Dutt and Volavola, 1977). Aerial photographs of different scales and areal coverage are regularly taken through most countries, and source films and photographic prints are kept in government archives. These data are a valuable resource for the assessment of any changes occurring in coastal areas that are vulnerable to human impacts, degradation, erosion or shoreline retreat. For example, in Fiji, time series aerial photographs were the main data source used for analysis of changes along the Coral Coast, a major tourist destination on Viti Levu island (Pitman et al., 2001). On Tongatapu island in Tonga, aerial photographs from 1968 and 1990, together with high-resolution Ikonos satellite imagery acquired in 2000, were used to assess shorelines and vegetation cover over this period. Analysis revealed that by 2000, many mangrove forests had been removed, and that coastal erosion was associated with this vegetation reduction (Forstreuter, 2001). These studies indicate how aerial photography is a valuable tool for assessment of coastal environmental changes.

2 USING AERIAL PHOTOGRAPHS TO DETECT CHANGES IN THE ENVIRONMENT

Time series of aerial photographs are a valuable data source for many tasks related to the use of Remote Sensing techniques for environmental studies, especially in detecting and visualizing environmental changes through time. There are two main approaches to detect changes on the Earth's surface using such time series photographs:

1. Inherent use of the primary image data (mostly for visual detection of changes), such as
   - pseudo-colour composites;
   - dynamic toggling;
   - basic computer-assisted methods such as image subtraction and differencing.
2. Use of derived products for advanced quantitative change analysis
   - GIS-based vector analysis of digitized time series imagery;
   - comparison of results of automated image classification either in raster or vector form.

Visual analysis of source images has been effectively used for quick detection and preliminary observation of occurring changes (Masry *et al.*, 1977). Such analysis does not provide quantitative information, but is often used as a first step in more sophisticated GIS-based and image post-classification methods to analyze spatial changes in numerical form.

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2.1 USE OF PRIMARY IMAGE DATA

2.1.1 PSEUDO-COLOUR COMPOSITES

The colour composite technique is widely used in spatio-temporal image analysis (Wickware and Horwarth, 1981; Lillesand *et al.*, 2007). Pseudo-colour image composites are made by combining three panchromatic photographs taken at different times, and applying three primary colour filters (red, green and blue) to each image correspondingly. Theoretically, if the geometries of all component images are identical, and no spatial changes occurred, then the resulting RGB-composite should be half-toned in black-and-white. In reality, however, all three aerial photographs were acquired in different conditions, including sensor-object-sun orientation and viewing geometry, which has an effect on the composite image colour. For example, Fig 1. illustrates the impact of illumination on colour composites for an unchanging artificial object (synthetic Digital Elevation Model). Three pictures have been generated under different directions of the light source – 0°, 120° and 240°. As there are no changes in the object's shape, one would assume that the colour composite should remain black-and-white. Yet, the reality shows that the resulting synthesized image is coloured due to shadow decomposition caused by the 'non-flatness' of the object. The same effect occurs with real aerial photographs and satellite images.

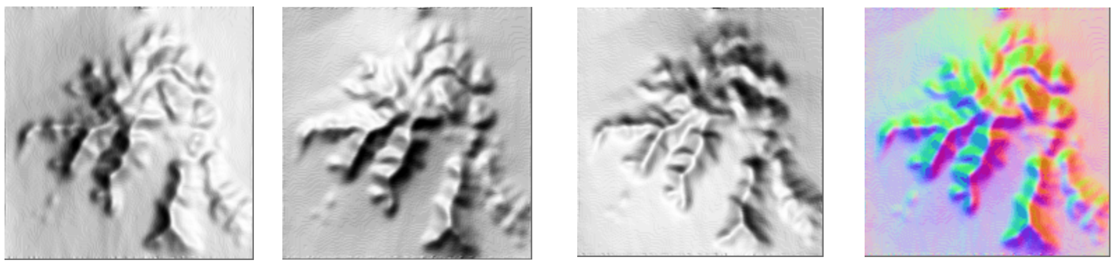
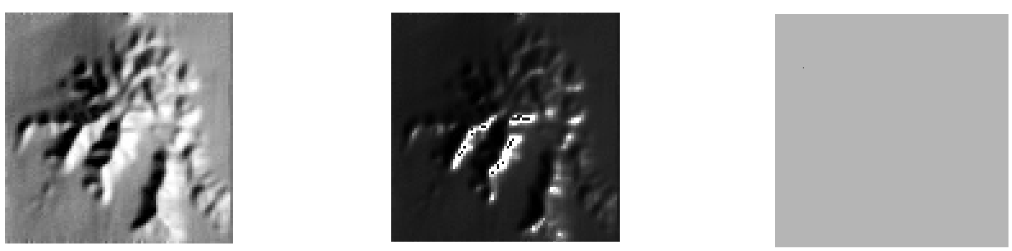


Figure 1 Three pictures of the same artificial object (synthetic Digital Elevation Model) generated at different light directions source – 0°, 120° and 240°. The resulting composite image is coloured due to shadow effects.

2.1.2 IMAGE DIFFERENCING

Colour composite images can also be used to visualize local variations in geometric inaccuracy in aerial photo rectification, which occur due to the limitations of image transformation, and insufficient or inappropriate location of ground-control points. This visualization of geometric inaccuracies is known as 'image differencing'. The method is quite similar to the pseudo-colour composite method, except that it requires two images only. In theory, the subtraction of one image from another should form a monotonous black image where no changes occurred from one image to the next, but produce tonal variations from black to white in areas of change. In practice, however, implementation always introduces some limitations of the resulting images (see Figure 2).



a b c

Figure 2 Image subtraction (a) and division (b) for synthetic digital elevation model. As there were no changes in our test object, both image subtraction and image division methods should provide monotonous grey images, similar to image (c), but again, as in the case with colour-composite methods, variations in illumination give false information on non-existing changes.

While the examples above illustrate that there are certain limitations in basic image manipulation for change detection purposes, the proper implementation of these methods and careful use of data, nonetheless do allow users to achieve quite reasonable results in uncovering and mapping real environmental changes. The remainder of this paper assesses the feasibility of applying pseudo-colour composites of time series aerial photographs for the detection of spatial dynamics of surface features in the Fiji Islands. The case study used to test the methodology is an analysis of recent urban growth and associated changes in the extent of mangrove areas in adjacent coastal zones.

2.2 IMAGE-DERIVED PRODUCTS FOR QUANTITATIVE CHANGE DETECTION

Geo-referenced and rectified aerial photographs provide precise and detailed information for accurate mapping and quantitative assessment of environmental changes (Townshend *et al.*, 1992). GIS-based vector analysis of digitized time series of imagery is the common and well documented method for precise quantitative assessment and mapping environmental changes (Chang and Kasturi, 2006). The potential of GIS techniques is further strengthened when other non-imagery geospatial data (such as vectorized maps and digital elevation models) are available and used in combination with aerial photographs for comparative study of changes of the Earth surface (Gutman *et al*., 2004).

Another change detection technique is image post-classification (Wickware and Horwarth, 1981). Post-classification is based on analysis of results of automated image classification, mostly applied to multi- or hyper-spectral spectral imagery. Landsat was the first satellite system that provided global multispectral coverage for the entire Earth surface. Unfortunately Landsat images have only 30 m resolution, which is significantly lower than any aerial photographs (up to 10 cm, depending on image scale and scanning resolution); moreover, the Landsat system was launched in 1972, so no images are available for earlier times. Modern high-resolution hyper-spectral systems generally provide better spatial resolution, comparable with aerial photography, but again, the hyper-spectral imaging systems have only become operational since the 1990s (Lillesand *et al*., 2007, Borengasser *et al*., 2008), and even nowadays are not widely available due to production cost, especially for many remote Pacific Islands.

3 MATERIALS AND METHODS

3.1 THE STUDY AREA

The area of study forms part of the Coral Coast in the Fiji Islands (Figure 3). The Coral Coast is located on the south-western side of Viti Levu island, one of two major islands in the Fiji group. This area was chosen because it was found to be experiencing a number of coastal management issues that are of major concern in Fiji today. These include harvesting of live rock, overexploitation of other marine and coastal resources, poor coastal water quality, poor solid waste management, unsustainable development and lack of assessment and information on these coastal problems (IAS, 2002). Two specific sites for investigation are the Korotogo mangrove area and Sigatoka Sand Dunes, located in the western end of the Coral Coast near the town of Sigatoka.

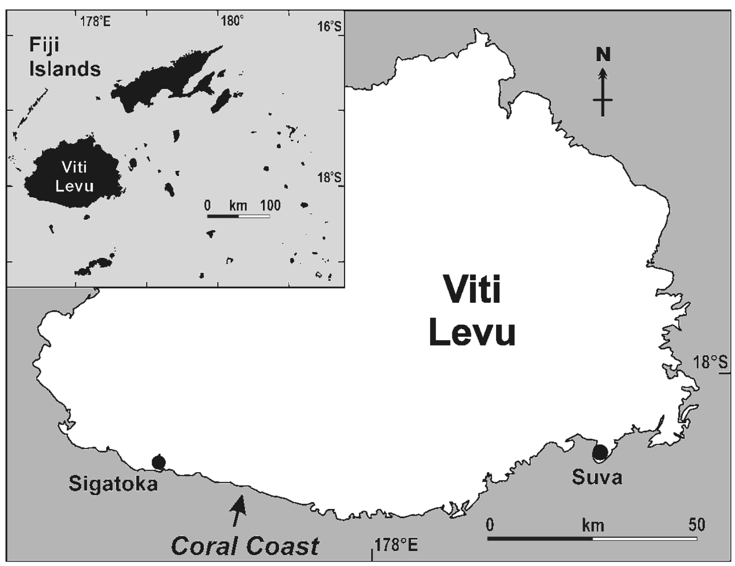


Figure 3 Location of Sigatoka Town and the nearby Coral Coast in Fiji. The Coral Coast is characterised as an area of relatively high local population density (living in traditional Fijian villages), and tourism development (international hotels and resorts). The village of Korotogo lies 5 km to the east of Sigatoka and Sigatoka Sand Dunes lies 10 km to the West of Sigatoka.

3.2 SOURCE DATA: ACCURACY AND RESOLUTION

Modern remote sensing sensors acquire images of the Earth surface directly in digital form, and the term Ground Sample Distance (GSD) is widely used to refer to spatial resolution of images on the surface. For example, ground sample distance of mid-resolution sensor Landsat ETM+ is 30 m (bands 1-5, and 7), while GSD of very high-resolution GeoEye-1 sensor is 0.41 m (GeoEye, 2008). In the case of scanned aerial photographs the ground sample distance is calculated based on pixel size in the image (defined by the scanning resolution of a scanner) and the scale of particular photograph (originally in paper form). Professional flatbed scanners provide a wide range of optical scanning resolutions, from 100 dpi (dots per inch) to 4800 dpi. Scanning paper aerial photographs at such a high resolution (4800 dpi) will produce digital images with pixel size 5.3 μm in the image. While higher scanning resolutions are theoretically possible, a reasonable upper level of scanning resolution can be defined based on recommendations of photogrammetry which set precision limits for coordinate measurements of aerial photographs in range of 2-5 μm (ASPRS, 2004). For such very precise photogrammetric measurements, physical properties of the photographic paper as well as calibration parametres of the scanner should be taken into account (Linder, 2006). In practice, scanning resolution should be chosen based on image scale, photographic quality of the image, and the requirements of a particular study, such as the minimum size of objects to be mapped, the accuracy of control points for geo-referencing, etc.

The aerial photographs used in this research were taken at different times and at various scales, falling into two distinct categories – 1:25000 and 1:50000 (see Table 1). To equalize ground sample distance in all the digitized images, the source photographs need to be scanned at different scanning resolutions. While the ratio of image scale denominators (50000:25000) defines the corresponding ratio of scanning resolutions (2:1), particular dpi values are chosen based on the ground sample distance of the high-resolution Ikonos image used in our study.

Pan-sharpened colour Ikonos imagery has a spatial resolution of 1 m; therefore to be spatially comparable, all scanned aerial photographs should have a similar ground sampling distance. Scanning 1:25000 aerial photographs at 600 dpi will produce pixels with size of 42.3 µm in the image. Pixels in the source photograph at 1:50000 scale, scanned at 1200 dpi, will be as small as 21.2 µm. Projected onto the ground surface, pixels in the corresponding aerial photographs would cover an area approximately 1×1 m, equivalent for all the aerial photos. Thus, scanning the original aerial photographs at different resolutions in correspondence with the given image scales allows us to equalize spatial resolution for all photographic and digital imagery data for further processing (Table 1).

Table 1 Aerial and satellite imagery used in this study

Year	Type of image	Number	Scale	Scanning resolution, (dpi)	Ground sample distance, (m)
1967	Aerial photographs	12	1:24 000	600	1.0
1978	Aerial photographs	12	1:26 000	600	1.1
1986	Aerial photographs	6	1:54 000	1200	1.1
1994	Aerial photographs	5	1:50 000	1200	1.0
2006	Satellite image	2	N/A	N/A	1.0

In order to use time-series aerial photographs for change detection purposes, it is imperative that the images are geometrically rectified (Townshend *et al*., 1992; Macleod and Congalton, 1998). Rectification is usually done by geo-referencing scanned photographs into a common map projection, using existing topographic maps or another available source used as a precise reference. In many cases scanned aerial photographs can be geo-referenced using another image (image-to-image referencing), or ground control points, defined by land surveying or GPS measurements. Choice of one or another method is defined by several factors, including accuracy of the source data (i.e. the aerial photographs) and accuracy of the reference data.

The horizontal accuracy of topographic maps usually expressed as 0.5-0.7 mm on the given map scale and integrates accuracy of data compilation, accuracy of graphic measurements, and errors caused by physical paper deformation due to humidity, physical wear and tear, and paper aging (Malin, 1989). For example, the accuracy of object locations on topographic maps at 1:50,000 scale can be estimated as 25-35m on the ground.

The accuracy of defining object coordinates in digital images depends on several factors, including the size of an object, scanning resolution, image scale and geometric properties of an image (image distortions and displacements). In general, to be identified with a reasonable level of confidence, an object (or its features) should occupy not less than 3-5 pixels in a digital image. This margin can be used as a starting point to estimate inaccuracy of object coordinating in a digital image. Due to many other factors such as image illumination conditions, photometric quality of the image and photographic paper deformation, the measurement accuracy of scanned aerial photographs can be 1.5-2.0 times coarser (ASPRS, 2004). For scanned aerial photographs with 1 m GSD such inaccuracy in image measurements will result into 6-10 m locational errors on the ground. This error estimation is still too optimistic as it does not take into account the impact of image geometry, tilt and surface topography, but it can be used as a general guide for our study as all areas of interest are located along the shoreline and aerial photographs are nearly vertical with tilt angles not exceeding 3°.

Precise photogrammetric processing requires accuracy of the reference data (ground control points) to be at least two times higher then accuracy of the source data to be referenced (aerial photographs) (ASPRS, 2004). This general practice advises that available topographic maps at 1:50,000 scale can not guarantee accuracy of ground control points, required for geometric rectification of aerial photographs used in our study. In response, ground control points were defined by field surveying using mapping grade handheld GPS receivers with estimated horizontal accuracy of 5-7 m.

3.3 IMAGE CO-REGISTRATION

While GPS-defined ground control points were used for geo-referencing all aerial photographs in our study, for areas where high resolution satellite images were available we implemented image-to-image registration. Figure 4 shows aerial photographs (1967 and 1986) and the Ikonos satellite image (2006) for one of the test areas – the Sigatoka Sand Dunes.

The quality of image co-registration can be expressed in terms of spatial, geometric and photometric matching. To be compatible for precise change detection it is preferable to have images with equal ground sampling resolution. Geometric quality of co-registration shows how well geometry of the source image matches geometry of the reference image. Residuals in tie-point coordinates are normally used as a measure of geometric accuracy of image co-registeration. Summarized residual error is expressed as RMSE (Root Mean Square Error). Normally

RMSE should not exceed the value of sqrt(2)×pixel size for precise co-registering of images with the same geometry taken in similar conditions, for example successive aerial photographs from one flight run (ASPRS, 2004). Co-registering images taken with significant time intervals and under variable conditions usually results in larger RMSE values. Table 2 illustrates the accuracy of image co-registration of aerial photographs for Sigatoka Sand Dunes area taken in 1967 and 1986 (source images) into satellite image acquired in 2006 (reference image) (see Figure 4). Variation of RMSE in coordinates of tie-points for different geometric transformations (orthogonal, affine, quadric and projective) can be used as another criterion of geometric quality of image co-registration.

Figure 4 Sigatoka Sand Dunes: aerial photographs, acquired in 1967 and 1986, and Ikonos satellite image, acquired in 2006

Table 2 Accuracy of image co-registration

Source image	Reference image	Number of tie-points	Transformation	RMS (m)
Aerial photo 1967	Ikonos 2006	8	Affine	1.80
Aerial photo 1986	Ikonos 2006	13	Affine	2.44

Photometric similarity of images significantly impacts on the quality of co-registration. Quite often photometric equalization of photographs is needed to ensure accurate location and measurements of tie-points in all time-series images. Leveling photometric quality is usually done by finding an image with the best histogram (photometric reference image) and matching all other photographs to the photometric reference image by histogram equalization. This image transformation uses the histogram of a reference image as the target histogram distribution, i.e., each colour component of the source image is remapped so that its histogram matches the corresponding component histogram of the reference image.

Most of the photographs in our case study were acquired along the shoreline and contain large water surface areas. To eliminate the effects of histogram distortion all source images were masked to exclude water surfaces and overexposed areas such as clouds and spumous sea waves along shores, although bright sandy beach areas were left uncorrected. Figure 5 illustrates the histograms for aerial photographs of the Sigatoka Sand Dunes (see source images in Figure 4). The 1967 photograph was used as the photometric reference image and other images (1986 and 2006) have been equalized to match the reference image. The quality of photometric matching can be evaluated from grey levels remapping curve for each image (Figure 5).

Precise co-registration of composite images normally requires aerial photographs to be ortho-rectified to avoid misalignment caused by relief displacement. However, as we restricted our study area on the images to the relatively flat area within the coastal zone, no ortho-rectification of aerial photographs was implemented.

3.4 VISUAL DETECTION OF CHANGES: THE USE OF COLOUR-COMPOSITE IMAGES

3.4.1 PSEUDO-COLOUR COMPOSITES: RGB

Three aerial photographs, acquired in 1978, 1986, and 1994 for the Korotogo area near Sigatoka, have been displayed as three spectral channels, coloured in the three primary colours (RGB). The resulting overlay produces a synthetic RGB pseudo-colour image composite, shown in Figure 6. In general, it is seen that the composite image displays both negative and positive changes (i.e. referring to the appearance or disappearance of objects). Changes identified include: cutting of mangrove forest, re-growth of natural vegetation, changing agricultural land-use patterns, and finally urbanization – either the appearance of new settlements or changes in both the extent of occupied areas and the density of buildings or houses within urban areas. Our experiments with RGB pseudo-colour composites where one primary colour is used for each date of time-series images (R+G+B formulae) re-confirmed certain limitations of the method, discussed in section 2. Quite often the resulting pseudo-colour composite is overloaded with derivative colours confusing the visual perception, especially if illumination and geometry of multi-temporal images are different.

To reduce the effects of excessive derivative colours, we composed a pseudo-colour image for two dates only. The first date image is tinctured in the first primary colour, and the other date image is formed as a composite of the two remaining primary colours. If the R+GB formulae is used (Red colour for one date and Green+Blue colour for another), the composite image comprises two colours, red and cyan, and becomes similar to anaglyphs that are comfortable for visual perception.

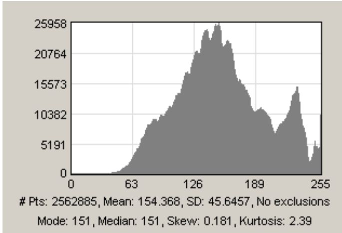


Image histogram, 1967

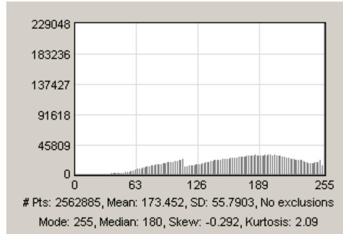


Image histogram, 1986

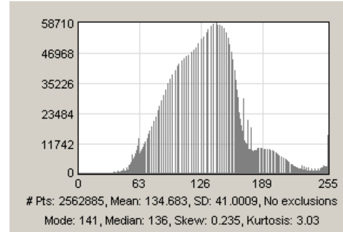
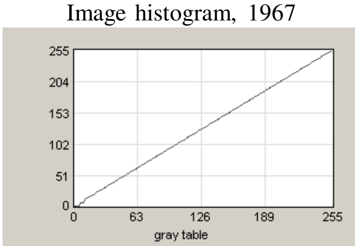
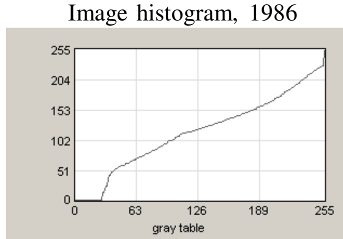


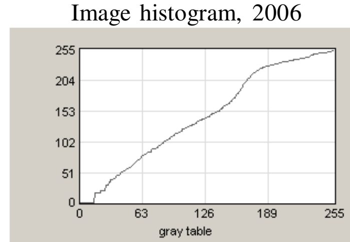
Image histogram, 2006



Ideal grey level remapping curve



Grey level remapping curve 1986→1967



Grey level remapping curve 2006→1967

Figure 5 Histograms of images acquired in 1967, 1986 and 2006 (see Figure 6 below), and grey level remapping curves for 1986→1967 and 2006→1967 histogram equalizations. The quality of grey level transformation can be evaluated against an ideal re-mapping curve which is a straight line

1978

1986

1994

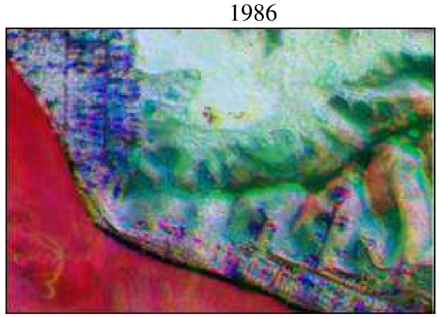


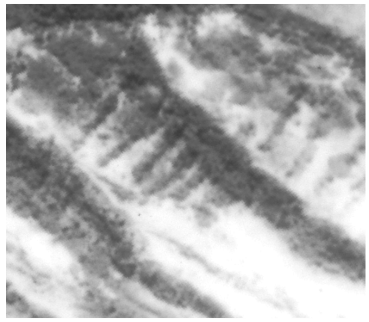
Figure 6 Original aerial photographs, acquired in 1978, 1986 and 1994 (top row), and corresponding three year RGB pseudo-colour composite (negative) (bottom row). Bright and dark areas in the composite image indicate no changes, green and orange-brownish show changes in two different types of vegetation, while blue and magenta outline the extent of urban areas, occurring mostly between 1978 and 1986.

3.4.2 PSEUDO-COLOUR COMPOSITES: HSI

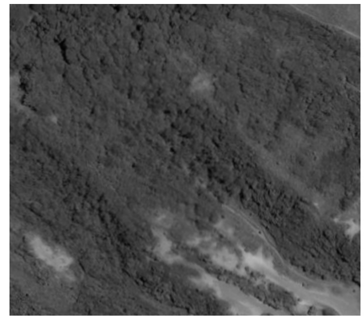
The Hue, Saturation, Intensity (HSI) colour model has been tested to compute pseudo-colour composites for time-series photographs. At the first step a HSI composite is computed for each date where the same panchromatic image has been used as the input for Hue, Saturation and Intensity components. The resulting HSI colour composite comprises three colour components. It has been noticed that in many cases ratio of two HSI composite images suppresses the saturation component (seen as blue colour) of two HSI images (occurring in similar areas in both images), while two other components (hue and intensity) produce two colours (vermilion and acid-green), highlighting differences in the source panchromatic images.

Figure 7 compares the results of three colour composite techniques for a fragment vegetated area in our time-series images (Sigatoka Sand Dunes, 1967, 1986, and 2006).

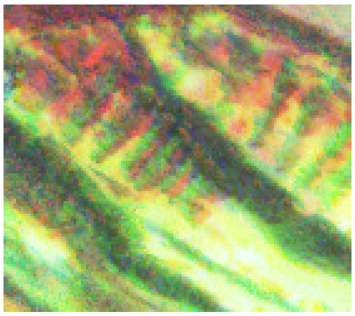
1967



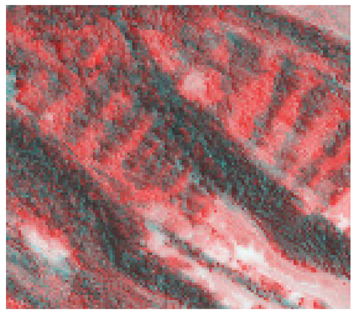
1986



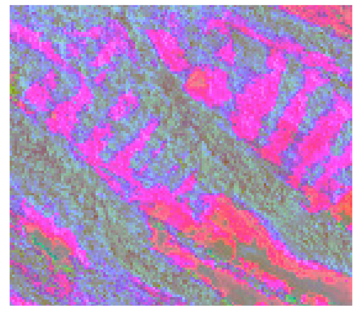
2006



1967+1986+2006
three years - three colour (R+G+B) composite



1967+2006
two years - three colour (R+GB) pseudo-anaglyph composite



1967-2006
two years - three colour HSI ratio composite

Figure 7. Fragment of vegetation area in time-series photographs (1967,1986 and 2006) and colour composites, illustrating a) three colour RGB, b) two colour R+GB and c) HSI ratio composite techniques for change detection.

While changes are clearly seen by visual inspection of the source time-series photographs (see Figure 7, top row), it is hard to locate particular zones and quantitatively evaluate the amount of change that has occurred. The three years–three colour composite provides excessive colour mixtures and the reader is always tempted to have a look at the source images to interpret one or another colour in such images, so some training and experience is needed to extract meaningful information from such images. Two years colour composites carry less information (for two dates only) and are therefore easier to interpret, especially if composed as pseudo-colour anaglyphs according to the R+GB formula. While producing RGB colour composites by the first two methods is straightforward, to produce two year HSI colour composites one intermediate procedure (image rationing) is required, but the results are worthwhile as changes are clearly seen and easily identifiable without the need for referencing the source panchromatic photographs. Figure 8 provides another comparative illustration of pseudo-colour composite techniques, now for a fragment area where a road has been re-designed and some new houses have been built.

1967

1986

2006

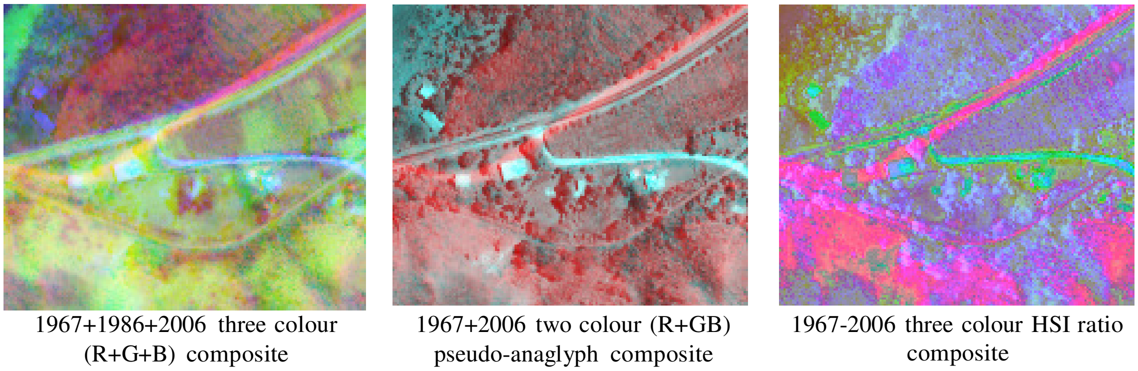


Figure 8 Fragment of time-series photographs (1967,1986 and 2006) and colour composites, illustrating three colour RGB, two colour R+GB and HSI ratio composite techniques for change detection. The road has been redesigned and some new houses have been built.

3.5 VISUAL DETECTION OF CHANGES: TOGGLING BETWEEN IMAGE LAYERS

While the colour composite method described above is limited to three images used simultaneously, image toggling can be effective in the analysis of multiple aerial photographs covering a large time span. Arranged as a sequence of image frames, toggling can create the effect of animation, where spatial changes can be detected and the evolution of changes can be studied by the image dynamics. The efficiency of toggling can not be illustrated on paper, but numerous experiments show that the method has clear advantages, and effectively supplements the colour composites for the visual detection of spatial changes.

In the study area, toggling was used to detect changes at six specific sites along the Coral Coast: Tagaqe Village, Tubakula Resort, Sigatoka Town, Sigatoka Sand Dunes, Korotogo Village and the Fijian Resort. Aerial photographs acquired in 1967, 1978, 1986, and 1994, and the Ikonos satellite image acquired in 2006, were used for our experiments in visual toggling. The source data allowed us to build a time series of five multi-date image frames with nearly 10-year intervals to investigate the dynamics of spatial changes in the study area. Detailed description of the method and results of such image analysis is beyond the scope of this paper, but preliminary experiments show that toggling proved to be particularly effective for a) detecting changes in the geometric properties (size, shape, orientation) of vegetated areas, b) detecting changes in the position of linear objects such as shorelines and roads, and c) as a general indicator of growth in scattered settlements.

3.6 QUANTITATIVE ANALYSIS OF CHANGE: ON-SCREEN DIGITIZING IN A GIS ENVIRONMENT

On-screen digitizing is a common GIS tool for data collection using geospatial imagery as source data (Chang and Kasturi, 2006). Three sets of aerial photographs (1978, 1986, and 1994) were used in our experiments. All aerial photographs have been geo-referenced to provide precise and detailed information for accurate mapping and quantitative assessment of environmental changes. Figure 9 shows digitized mangrove areas of Korotogo from these aerial surveys. The area is located next to a large international resort complex (the Outrigger Reef Resort), which was redeveloped and expanded in the early 90s as a response to the increasing number of foreign tourists visiting Fiji.

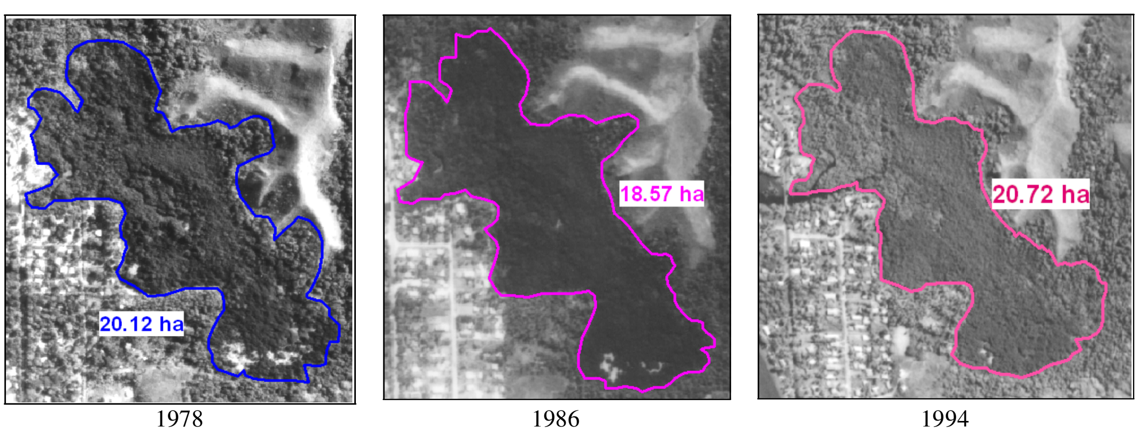


Figure 9. Digitized boundary of Korotogo mangroves; numbers represent areas forested in the years of aerial survey.

Quantitative analysis of the extent of mangrove forests at Korotogo showed a decrease in 1986 but an increase again by 1994. The estimated total loss of forest between 1978 and 1986 is 1.6 ha (7.7%), giving an average loss of 0.19 ha/yr for this period. The decline in mangrove cover observed in the 1986 photograph has been associated with the development of the original Outrigger Reef Resort complex that started in the early 1980s. Mangroves were cut down to create space for building hotel rooms. From 1986 to 1994 the estimated increase in mangrove area was 2.2 ha (11.6%), with an average re-growth rate of 0.27 ha/yr. This regeneration is attributed to a greater awareness among the Korotogo villagers about the importance of preserving mangroves for shoreline protection and as habitat for many finfish and crustaceans collected for food, and increasing concern about the extent of mangrove cutting associated with the production of *tapa* cloth. Tapa is a traditional Fijian ornamental cloth, made by pounding together strips of bark peeled from young mangrove poles. As a result, in the late 1980s Korotogo chiefs eventually banned mangrove cutting under traditional Fijian *tabu* (taboo) systems, which led to natural mangrove regeneration by the time of the 1994 aerial photograph. In addition, the work of Non-Governmental Organizations (NGOs), especially the Japanese group OISCA (The Organization for Industrial, Spiritual and Cultural Advancement, Japan), assisted the Korotogo community to establish a mangrove nursery and instigate a programme of seedling replanting along exposed shorelines, which began in 1993 and continues today.

4 CONCLUSIONS

In the island nations of the South Pacific, the aerial photograph collections archived by government departments remain an important but often under-utilized source of precise and detailed photographic documentary data about the Earth's surface. Supplemented by latest high-resolution satellite images, this data can be used to observe environmental change over recent decades. Several methods exist for preliminary investigation of any changes occurring between successive air photo surveys, which can be helpful in establishing the most dynamic areas and thereby allowing the prioritization of more time-consuming quantitative work. Among these quick-detection methods are the use of pseudo-colour composites, image differencing and dynamic visual toggling. The validity of results of change detection analysis very much depends on the accuracy of image co-registration – spatial, geometric and photometric. Compared to three-year RGB composite images, two-year R+GB colour composites illustrate changes in two dates only, but produce less visual information and thus seem to be more useful in change detection. Both RGB and R+GB composites provide equally sound results for detecting small to medium changes in images with reasonably similar geometric, photometric and illumination conditions. Two-year HSI ratio composites prove to be quite informative and provide more robust and "noise-proof" results, but are still burdened by many 'false' areas being highlighted where no actual changes took place, owing to the limitations common to all colour composite methods. Finally, it has been found that HSI ratio colour composites can be very helpful in searching for changes when framed visual toggling methods are used.

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