ISPRS Journal of Photogrammetry and Remote Sensing 116 (2016) 15–23

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Feature-based registration of historical aerial images by Area Minimization

Sudhagar Nagarajan [a,*], Toni Schenk [b]

[a] Department of Civil, Environmental and Geomatics Engineering, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431, United States
[b] Department of Geological Sciences, University of Buffalo, 411 Cooke Hall, Buffalo, NY 14260, United States

ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form 2 February 2016
Accepted 24 February 2016
Available online 12 March 2016

Keywords:
Photogrammetry
Exterior orientation
Historical aerials
Registration
Free-form lines
Area Minimization

ABSTRACT

The registration of historical images plays a significant role in assessing changes in land topography over time. By comparing historical aerial images with recent data, geometric changes that have taken place over the years can be quantified. However, the lack of ground control information and precise camera parameters has limited scientists' ability to reliably incorporate historical images into change detection studies. Other limitations include the methods of determining identical points between recent and historical images, which has proven to be a cumbersome task due to continuous land cover changes. Our research demonstrates a method of registering historical images using Time Invariant Line (TIL) features. TIL features are different representations of the same line features in multi-temporal data without explicit point-to-point or straight line-to-straight line correspondence. We successfully determined the exterior orientation of historical images by minimizing the area formed between corresponding TIL features in recent and historical images. We then tested the feasibility of the approach with synthetic and real data and analyzed the results. Based on our analysis, this method shows promise for long-term 3D change detection studies.

1. Introduction

Recent human development and climatic changes have caused the surface of the earth to change continuously, both in two dimensions (2D) and three dimensions (3D). Some of these changes include sea-level rise, coastal erosion, loss of forest biomass, land subsidence, land cover change, and urban sprawl. The direct impact of these changes on climate has not been well studied due to the unavailability of methods to generate accurate maps from historical data. Therefore, it is important to develop methods to map them, so the impact of changes in the environment can be explained better. Analyzing long-term time series data is also essential to better predict changes over time.

Change detection studies of long-term time series data require both recent and historical data. Recent 2D/3D data of the United States is usually available with high resolution and accuracy through various Federal and State agencies. The historical data is usually available in the form of topographic maps and aerial photographs. The historical topographic maps were mostly derived from photogrammetric and ground-based surveying methods and hence, each cartographic feature in the map may have different levels of accuracy. Also, it usually takes several years and, in some cases, decades to generate a topographic map. Therefore, the map features cannot be associated with one single year. This limits the use of historical topographic maps for reliable change detection studies. Also, the level of detail in a topographic map is less precise due to the large map scale. Similarly, the quality of historical aerial photographs is typically low and lacks relevant ground control data for change detection analysis. Ground control points for the historical photographs can be acquired from historical topographic maps, but identifying points that are visible in both data sets is a difficult and sometimes nearly impossible task (Redecker, 2008).

Since 1920, millions of historical aerial photographs have been collected by various national organizations of the United States such as the United States Geological Survey (USGS), the Department of Energy (DoE), the Bureau of Land Management (BLM), the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), the National Park Service (NPS), the Federal Emergency Management Agency (FEMA), and the Department of Agriculture (DoA). Among them, USGS alone hosts over 6 million photographs through their web-portal. A vast

* Corresponding author.
E-mail addresses: snagarajan@fau.edu (S. Nagarajan), afschenk@buffalo.edu (T. Schenk).

http://dx.doi.org/10.1016/j.isprsjprs.2016.02.012
0924-2716/

quantity of these photographs were collected before the era of digital photogrammetry (before early 1990s), but most of them have been converted to digital images (referred as historical images in this paper) and are available for download through various portals (USGS, 2015). Most of these images, however, lack sufficient metadata to extract metric information from them. The required metadata includes Interior Orientation (IO) parameters of the camera and ground control information. The interior orientation parameters of the camera include the calibrated focal length, principal point location, radial and tangential distortion coefficients and fiducial coordinates. Though USGS assumed responsibility for calibrating aerial metric cameras from the early 1950s (Merchant, 2012), solid calibration standards were not available until efforts by Eisenhart (1963) of the National Bureau of Standards in the 1960s (Luman et al., 1997; Redecker, 2008; Slama et al., 1980). Therefore, the photographs that were collected before 1960 may not have sufficient calibration information readily available. The calibration reports can be acquired for the photographs collected after 1970 through USGS (Merchant, 2014). The second important component of the metadata is ground control information. Most of the historical aerial photographs were mainly used for interpretative purposes such as crop health monitoring, farm history, reconnaissance, urban development and site selection. These historical photographs were rarely utilized for metric photogrammetry, so the required Ground Control Points (GCPs) are often not available. Redecker (2008) and Nocerino et al. (2012) discuss other issues with historical photographs such as missing flight maps, poor radiometric quality, distortions due to sudden movements and inaccurate processing of films.

In the absence of ground control information or camera calibration, the use of historical images for mapping and change detection becomes a challenge. One possibility is to identify the stable areas that have not changed over time and survey it by a GNSS (Global Navigation Satellite System) receiver (Redecker, 2008). First, identifying the region that is unchanged over time requires comparison of historical images with recent ones. When such regions are identified, the next step is to identify common points that are visible in the recent and historical aerial images. Due to different reasons, such as quality and resolution of images, data acquisition mode, and change in land cover, it is often difficult to identify specific points in multi-temporal data sets (Ma, 2013). This paper presents an alternative method of using line features appearing in the stable areas for the registration of aerial images. Registration of images in this paper refers to extracting Exterior Orientation (EO) parameters.

2. Literature review

Historical aerial images are considered of high importance for long-term change detection in ecology, forestry, urban planning, land use management, coastal management and geomorphology related studies (Cardenal et al., 2006; Cohen et al., 1996; Drexler et al., 2013; James et al., 2012; Kääb et al., 1997; Morgan et al., 2010; Necsoiu et al., 2013; Redecker, 2008; Redweik et al., 2009; Walstra et al., 2004).

Depending on the application, there have been several approaches presented to register historical aerial images for change detection applications. The method presented by Luman et al. (1997) assume that a polynomial transformation is sufficient for low relief terrains and register historical images by measuring control points from Digital Orthophoto Quadrants (DOQ). Furthermore, this method is not appropriate for 3D change detection methods and for scenarios where accurate planimetric position is important such as coastal erosion, widening of roads, encroachments, and land rights. Though Luman et al. (1997) realize the appropriateness of rigorous mathematical models for accurate determination, polynomial methods are adopted to reduce the cost associated with the control point collection and 3D capture. Ma (2013) uses a method similar to Luman et al. (1997) but computes Digital Elevation Models (DEMs) and orthophotos of historical images using the Rational Function Model (RFM), which is a ratio of polynomials. The method uses control points from recent (2009) DEM and Digital Orthophoto Quarter Quadrants (DOQQ) to register aerial images acquired in 1938. However, as admitted by the author, identifying control points in 1938 images is a challenging task. Due to the sensitivity of RFM to asymptote surfaces in the model, Ma (2013) suggests that only linear RFM is practical. Patias et al. (2011) use a 1956 topographic map, 1963 aerial images and 2006 Quickbird images to detect changes in urban area. This approach uses polynomial transformation for maps and projective transformation for aerial images with control points from Quickbird satellite images.

The existing literature clearly states two critical issues in using historical images, namely the lack of camera calibration and GCPs. The polynomial (Luman et al., 1997), projective (Patias et al., 2011) and RFM based methods (Ma, 2013) that do not require any camera calibration are expected to perform well if the surface has relatively low relief and accuracy expectations are also low (Nocerino et al., 2012). Morgan et al. (2010) discuss the importance of positional accuracy and how small errors in position can make a significant difference in studies for ecological monitoring. Therefore, for stable and accurate results, EO or self-calibration by rigorous photogrammetric methods are recommended (Aguilar et al., 2009). Also, the accuracy of derived parameters will be meaningful only when rigorous mathematical models are used. Regardless of the method used, having a reliable network of ground control information is essential. Redweik et al. (2009) use old field notes with drawing and coordinates to recover GCPs for registration. However, having access to such historical field notes is not always possible. The other approaches discussed in the literature (Cardenal et al., 2006; Luman et al., 1997; Ma, 2013; Nocerino et al., 2012; Redecker, 2008; Redweik et al., 2009) use recent maps, orthophotos, DEMs and field survey to carefully choose GCPs in stable areas. It is also widely agreed in the literature that such a process is extremely time-consuming, cumbersome, inaccurate and unreliable (Nocerino et al., 2012). Gruen and Baer (2001) present a similar point-based method, but register recent images using historical images with known EO. However, due to several years of land cover change, point features may no longer be visible in the images (Ma, 2013). By taking all these factors into consideration, this research uses line features to register images since the identification of higher level (line and surface) features is easier than that of low level point features (Schenk, 2004).

Michel and Avouac (2006) use historical aerial images to determine co-seismic surface deformations after an earthquake event. The registration of images was achieved by choosing ground control points from SPOT orthoimage or a shaded relief image created from the DEM. This method of selecting GCPs from lower resolution SPOT images to register higher resolution aerial images may produce EO parameters with higher uncertainty. This will eventually affect the accuracy of surface deformations. Leprince et al. (2007) develop a similar method called Co-registration of Optically Sensed Images and Correlation (COSI–Corr) that has the ability to co-register and orthorectify aerial and satellite images. Ayoub et al. (2009) use this COSI–Corr approach to determine horizontal ground deformation using aerial images. The work makes an assumption that the surface topography remains the same after and before an earthquake. However this assumption is questionable since earthquakes indeed cause topographical changes. Necsoiu et al. (2013) adopt the same COSI–Corr approach and perform change detection of water bodies in Alaska using aerial and