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Short Communication

Use of digital photogrammetry for the study of unstable slopes in urban areas: Case study of the El Biar landslide, Algiers

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ABSTRACT

Recent developments in remote sensing techniques provide powerful tools for geomorphological studies. The geometric and kinematic characterization of landslides is a key factor in understanding the mechanisms of movement. The purpose of this publication is to show the potential of digital photogrammetry in the spatiotemporal study of landslides in urban areas. The case study focuses on the landslide of El Biar in Algiers. Comparison of digital elevation models generated following an established methodology shows the morphological evolution of the site. Orthophotos are used to measure surface displacements. The analysis of horizontal displacements between 1995 and 2007 shows that the landslide of El Biar can be divided into two zones: a peripheral zone moving at an average speed of about 5 cm per year and a central zone moving at an average speed of about 10 cm per year. Comparing the results with those obtained by traditional survey methods shows a remarkable consistency, thus validating the techniques used. This study demonstrates that digital photogrammetry, when combined with geological and geotechnical data, can improve the characterization and understanding of landslide mechanisms, and thus help defining mitigation solutions.

1. Introduction

Landslides are one of the most common natural hazards in the world, and their consequences, especially in urban areas, can include significant threats to life and economic assets. The accelerating growth of cities has contributed to environmental transformations and concentration of people in hazard-prone areas, thereby increasing the vulnerability of societies to landslide hazards (Boullé et al., 1997; Cascini et al., 2005; Crozier and Glade, 2005; Mansour et al., 2011). Although the impact of climate change may result in higher frequencies of such events in the future (Dehn et al., 2000; Dixon and Brook, 2007), it will probably be outweighed by the effects from increasing demographic pressure (Crozier, 2010).

Past research has identified different landslide mechanisms and many controls on slope failure initiation and development (Varnes, 1978; Crozier, 1986). These controls are complex and relate to climatic variables and slope characteristics, such as material, geological and hydrological conditions, and vegetation cover. A full understanding of their interrelationships requires detailed and extensive monitoring of environmental factors and associated landform changes. Data on surface displacements provides valuable information on the kinematics and failure mechanism of the event. The ease of acquiring relevant data varies: depending on the area of study, long climate data records may be readily available, whereas obtaining accurate historical spatial data quantifying landform change is usually a rather more challenging task (Walstra et al., 2007).

A variety of techniques is available for the monitoring of landslide displacements. Geodetic techniques involve the repeated survey of discrete points on the land surface, by traditional devices such as theodolites, total stations (Franklin, 1984) and global positioning systems (GPS) (Gili et al., 2000; Mora et al., 2003). Such techniques can provide accurate measurements at high temporal resolution (if logistics allow), but their spatial distribution is limited. Remote sensing techniques on the other hand have the ability to obtain spatially distributed data, without the need for physical access to the site, as they can be operated from spaceborne, airborne or ground-based platforms. Remote sensing techniques that have been successfully applied to the monitoring of landslides include optical satellite imagery (Hervás et al., 2003; Delacourt et al., 2004), photogrammetry — either aerial (Weber and Herrmann, 2000; Casson et al., 2005; Cardenal et al., 2006; Walstra et al., 2007) or ground-based (Cardenal et al., 2008; Travelletti et al., 2012), radar interferometry (InSAR) — either spaceborne (Berardino et al., 2003; Squarzoni et al., 2003) or ground-based (Tarchi et al.,

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2003; Casagli et al., 2010), and laser scanning (LIDAR) — either airborne (Adams and Chandler, 2002; Corsini et al., 2007; Jaboyedoff et al., 2012) or ground-based (Teza et al., 2008; Baldo et al., 2009; Jaboyedoff et al., 2012). Depending on the technique used, successive data acquisitions can provide measurement of displacement vectors and/or difference calculations between digital elevation models (DEMs).

Aerial photographs have the advantage of providing a synoptic view of the landslide under study. They not only provide a metric model from which quantitative measurements can be obtained, but also give a qualitative description of the Earth's surface. A sequence of photographs captures morphological change, which can be unlocked by using appropriate photogrammetric methods. Comparing recent photographs with historical imagery offers the opportunity to examine the spatiotemporal evolution of the landslide back in time (Walstra et al., 2007). Recent advances in information technology have led to the development of automated digital photogrammetric techniques, allowing for rapid and cost-effective data collection (Chandler, 1999; Baily et al., 2003).

Although the last decade has seen many publications on the use of digital photogrammetry in landslide studies, most of these were conducted on rural sites. The aim of this research is to show the potential of such techniques for the study of unstable slopes in an urban context. Additionally, this study clearly demonstrates how photogrammetrically derived data, when combined with geological and geotechnical information, improves the characterization and understanding of the landslide mechanism and so enhances the definition of a mitigation solution. This paper describes the key steps of such a study and, using the example of the El Biar landslide in Algiers, shows the wide range of data that can be extracted from historical aerial photographs.

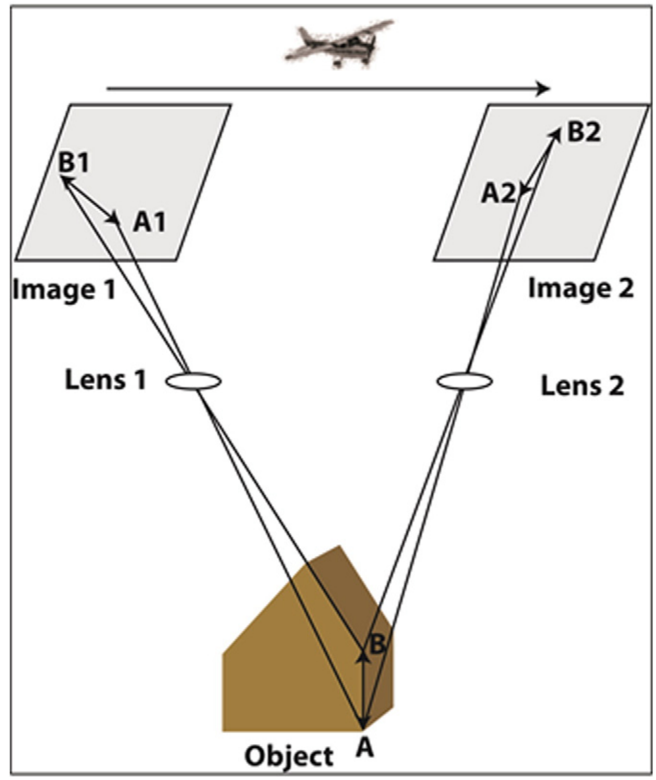

Fig. 1. Principles of photogrammetry: based on the concept of collinearity, 3D-coordinates can be extracted from a stereopair of photographs, provided that the geometry and position of the camera are known.

2. Methodology

2.1. Theoretical principles

Theoretical principles underlying photogrammetry were established over a century ago and further developed for map production in the 1930s (Slama, 1980; Wolf and Dewitt, 2000). The main concept of photogrammetry is collinearity, whereby an object point, the projection center of a lens, and its corresponding image point on the focal plane lie along a straight line (Fig. 1). Using this principle, 3D-coordinates can be extracted from any stereopair of photographs, provided that the inner geometry (interior orientation) and the position and orientation of the camera at the moment of exposure (exterior orientation) are known. As a bundle of light rays will never pass from the object through the camera lens system and onto the imaging device in a perfectly straight line, for accurate photogrammetric work corrections have to be made for lens distortion, atmospheric refraction and Earth curvature (Wolf and Dewitt, 2000).

Since the 1990s, significant developments in digital photogrammetry have allowed automation of large parts of the photogrammetric processing (Schenk, 1996). High-resolution DEMs and orthophotos can be created relatively easy using modern software packages and have become standard outputs of the photogrammetric workflow (Wolf and Dewitt, 2000). A DEM is a 3D representation of the terrain surface (Weibel and Heller, 1991). In an orthorectified photograph, image distortions caused by camera tilt and terrain relief are eliminated so that all ground features are displayed in their true ground position (Wolf and Dewitt, 2000).

2.2. Practical considerations

The working procedure adopted in this study can be divided into four general stages (Fig. 2): (1) acquisition of suitable imagery, (2) collecting ground control, (3) restitution of the photogrammetric model and data extraction, and finally (4) visualization and data analysis.

In Algeria, aerial photographs are produced and sold exclusively by the National Institute of Cartography and Remote Sensing (INCT) of Algiers. Selection of suitable images was based on a number of obvious considerations, including ground coverage, geometry and image quality.

Ground control points are required for establishing the photogrammetric model and referencing it to a common ground coordinate system (i.e. defining the geographic datum). Typical targets include the corners of old buildings and electric posts, distributed uniformly over the area of interest and fixed during the time interval under investigation. Rather than collecting in the field, control points (and orientation parameters) were derived from previous (analytical) aerial triangulations (based on the same imagery, calculated by PAT-M software) and subsequently entered into the digital workflow.

The photogrammetric processing was carried out on a standard desktop computer using Leica Photogrammetry Suite (LPS), version 9.1 (Leica Geosystems, 2005). Primary products from the photogrammetric workflow included high-resolution DEMs and orthophotos, which were extracted using automated image matching algorithms available within the software.

Combined with available evidence from inclinometer data, the DEMs enabled an estimation of the volume of the displaced ground mass. Multitemporal topographic profiles derived from the DEMs allowed differentiation between zones of ablation and accumulation (i.e. areas where the elevation decreased or increased, respectively).

Displacement vectors, indicating the magnitude and direction of surface movements, were obtained by interactively measuring the position of objects in the successive stereomodels, using a stereoviewing tool (PRO600 for LPS). Typical targets included the position of corners of buildings that did not experience architectural changes throughout the investigated time interval. The significance of these vectors was assessed by evaluating measurements outside the landslide area; any apparent displacements on stable ground were considered due to cumulative errors arising from stereomodels and the measurement procedure. Based on the covariance matrices of these errors, error ellipses