Optik - International Journal for Light and Electron Optics 171 (2018) 658–671

Contents lists available at ScienceDirect

Optik

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

Original research article

Displacement monitoring for slope stability evaluation based on binocular vision systems

Sizeng Zhao[a], Fei Kang[a,*], Junjie Li[a,b]

[a] School of Hydraulic Engineering, Faculty of Infrastructure Engineering, Dalian University of Technology, Dalian 116024, PR China
[b] School of Engineering, Tibet University, Lhasa 850012, PR China

ARTICLE INFO

Keywords:
Binocular vision
Slope
Displacement monitoring
Measurement distance
Baseline distance

ABSTRACT

Landslide monitoring systems play an important part in slope engineering, and effective monitoring techniques can ensure the safety of slopes. This paper proposes an accurate and stable slope displacement monitoring method based on binocular vision systems. In the binocular vision system, Zhang's calibration algorithm is used to calibrate the camera parameters, which are critical for gathering accurate motion measurements. Measurement accuracy analysis is performed by adjusting the baseline distance from 0.2 m to 3.6 m and measurement distance from 1 m to 10 m during calibration and measurement, and the error curves for measurements are obtained. The results obtained illustrate that the accuracy is affected by the ratio of the baseline distance to the measurement distance. Displacement monitoring of a slope model is performed to demonstrate the practicality of the system and verify its accuracy. Results show that the proposed binocular vision based approach is convenient and accurate for slope displacement monitoring.

1. Introduction

1.1. Background

The scope of human activities has expanded further with the rapid development of technology and the economy. Geological disasters, particularly landslides, always seriously affect people life and their property. In this way, many landslide areas need to be reinforced and monitored. Despite the fact that landslides occur often, a fundamental understanding of landslides based on effective theoretical calculations and accurate predictions is lacking. There is still has no easy method to directly capture slope deformation until a large landslide is imminent [1]. Thus, accurate and effective methods for slope monitoring are essential in slope engineering.

Traditional landslide monitoring systems are based on contact monitoring systems [2], and non-contact systems have begun to flourish recently [3,4]. Traditional displacement sensors, such as linear variable differential transformers, are accurate for measuring one-dimensional displacements, but the installation processes are very inconvenient [5]. The accuracy of total stations is very high and reliable [6]. However, the working efficiency will fall with large spatial area, and the accuracy of these systems can-not be guaranteed. The using of global position system (GPS) technology can be used to obtain three-dimensional (3D) coordinates, and GPS is a completely independent system. However, this method has some problems, namely that satellite signals can be easily blocked in mountainous areas [1,7]. InSAR (Interferometric Synthetic Aperture Radar) and remote sensing are suitable for regional disaster monitoring, and have been widely used in disaster areas. However, image recognition and analysis procedures still need to be optimized [8,9]. Fiber optic sensing has proven to be a suitable and useful technique for monitoring and providing early warnings for

* Corresponding author.
E-mail addresses: zhaosizeng@mail.dlut.edu.cn (S. Zhao), kangfei@dlut.edu.cn, kangfei2009@163.com (F. Kang), lijunjie@dlut.edu.cn (J. Li).

https://doi.org/10.1016/j.ijleo.2018.06.097
Received 27 February 2018; Received in revised form 20 June 2018; Accepted 21 June 2018
0030-4026/

infrastructure engineering in laboratory tests and in practical projects due to its unique functions, such as long range distribution and immunity to electromagnetic interference. However, fiber optic equipment installation is hard and has low resistance to shearing [10,11]. Electro-optical laser scanner, X-ray computerized tomography, and photogrammetry can be applied to measure the total and local deformation changes of physical models, but the precision can not meet the requirements for landslide monitoring [12–14].

Research on binocular vision technology has increased dramatically in the past few years. Binocular vision can serve as a precise and reliable technique, which is widely used for non-contact displacement measurement over large areas [15,16], such as bridge monitoring [17], open pit displacement monitoring [18,19], pose measurement [20,21], and vibration monitoring [22]. Many camera calibration methods are proposed to obtain the relationship between 2D centers in an image and 3D curves in space [23,24]. Two representative methods are the Tsai calibration approach [25] and Zhang Zhengyou calibration approach [26]. Tsai's method has high precision, while Zhang's method is famous for its convenience. The accuracy of a binocular vision system depends on many factors, including the quality of the cameras and their resolution, the accuracy of stereo vision sensor calibration [27], extraction of feature points [28], sub-pixel detection [29], noise [30], baseline distance, and measurement distance [31,32].

In this paper, the binocular vision-based slope displacement approach is proposed for monitoring slope safety. The measurement accuracy and error is first analyzed in theory based on an existing coordinate system model. Using Zhang's calibration method, the effects of different baseline distances and measurement distances on accuracy during calibration and measurement are studied by experiments on motion measurements. The performance of the proposed approach is tested on a slope model with marking points. The results show that the proposed method is practical to capture the motion of a slope.

1.2. Slope monitoring system

In order to master the trend of slope stability and ensure safety in the vicinity of a slope, it is necessary to carry out slope safety monitoring and detect the development of abnormal phenomena over time.

Slope monitoring systems are usually composed of monitoring equipment, a power supply, and data transmission equipment [33]. Displacement, tilting, stress and strain, and rainfall can be monitored using these systems. The present method in this paper will focus on the surface displacement measurement because it is efficient and intuitive for slope safety monitoring.

Under the action of gravity, the slope deformation phases can be divided into initial, isokinetic, and acceleration stages according to the cumulative deformation-time curve for a slope. Landslides usually occur at the acceleration stage. The daily displacement and velocity of the slope can be obtained from surface displacement measurements, and these measurements are used to judge signs of slope failures over time.

2. Principle and theory of binocular vision

2.1. Camera imaging model

The camera imaging model [22] follows the pinhole model. There are four coordinate systems involved in the camera imaging model, which are physical coordinate system (o_1, u, v), image coordinate system (o, x, y), camera coordinate system (O_C, X_C, Y_C, Z_C), and world coordinate system (O_W, X_W, Y_W, Z_W). The camera imaging model and the relationship between each coordinates system is shown in Fig. 1.

The position p in the image coordinate system is the projection of P in the world coordinate system. O_C is the optical center and the Z_C direction points along the optical axis. o is the center of the picture captured by the cameras, and the O_C-o length is the camera focal length. u and v are the two coordinate directions in the physical coordinate system, and x and y are the two coordinate directions in the image coordinate system. X_C and Y_C are the two coordinate directions in the camera coordinate system and are

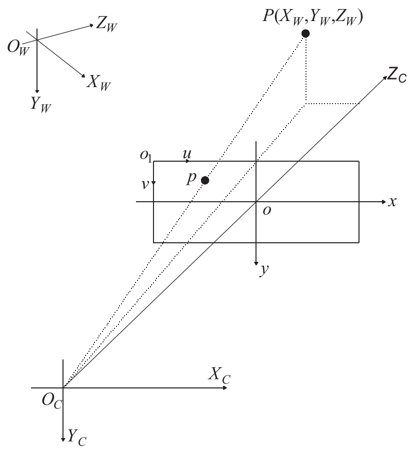

Fig. 1. Camera imaging model and four coordinate systems.