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Digital image reasoning for tracking excavation activities

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Abstract

Efficient and safe construction of underground space is a key aspect in the development of infrastructure within densely populated urban environments. Construction processes are usually adjusted, based on information collected from field monitoring, to control induced ground movements such that the impact on nearby structures and utilities is minimized. An important component of field monitoring includes the development of a detailed timeline record of various construction activities especially soil removal. This paper explores the use of two image based techniques – Close-Range Photogrammetry and Image Reasoning – to perform semi-automated tracking of excavation activities. A new image reasoning algorithm, enhanced pattern detection and comparison (EPDC), is introduced to quickly identify changes in poor contrast excavation surfaces. EPDC is illustrated using laboratory and field trials. The proposed image reasoning algorithm paves the way for new uses of large numbers of digital camera and webcam images now available at many construction sites to acquire detailed construction staging information.

Keywords: Image reasoning; Urban excavations; Construction control; Remote sensing

1. Introduction

During the design stage of an urban excavation project, geotechnical engineers rely on the use of semi-empirical and numerical models to predict the magnitude of induced ground movements [6,7,19]. However, given the complex behavior of soils and the uncertainties introduced by factors such as construction method, support system, and ground water control, some degree of uncertainty is to be expected in these predictions. In order to control the excavation induced deformations and subsequent impact on nearby structures and to verify design assumptions, engineers employ extensive monitoring programs to observe ground response during construction.

Traditionally, monitoring programs have focused exclusively on the acquisition of quantitative information such as lateral wall deflection and surface settlements. However, it is essential to relate the occurrence of movements to specific construction activities, thus establishing a cause–effect relationship. Engineers often rely on hand written field records to develop a timeline of construction activities. These records can often be incomplete or inaccurate and lack sufficient details to establish a clear relationship between specific construction activities and measured response. More recently new imaging technologies are being employed at construction sites to develop a construction record, taking advantage of digital imaging equipment such as digital cameras.

This paper focuses on the development and implementation of new image manipulation techniques to capture the construction sequence of an excavation based on the analysis of still images such as those obtained by means of a webcam.

2. Imaging technologies in construction

The use of imaging techniques in civil engineering practice has experienced a substantial increase with the advent of digital cameras and three-dimensional laser scanners. So far the use of these procedures can be categorized into the following groups:

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1. Characterization and diagnosis: Efforts in the first category have been particularly successful in mining and blasting operations, where digital image analysis is widely used as a tool for rock mass characterization including geometry, grain size distribution and joints distribution [1,9,22,29]. It also includes the use of laser scanners [13]. Other efforts in this category have been made in the recognition of linear patterns for the diagnosis of pavement cracking [5] and the identification of road features from aerial images [33]. New developments in this area also include image analysis techniques to identify bridge coating and painting defects and rust development [4,24,25] and sewer and water pipe inspection [10,11,28].
2. Monitoring of engineering activities: Applications in the second category have been associated mainly with tunnels, where convergence measurements [21] and mapping of excavation faces [26] have been reported. Webcams [15] and laser scanners [18,31] have also been used to track urban excavation construction. Likewise, image based technologies (e.g. Close-Range Digital Photogrammetry) have been widely used for the documentation and visualization of archaeological finds [2,3,16,23,34].

A common factor shared by many of the imaging technologies currently in use is that the qualities or properties recognized in the object are evaluated from a static point of view (e.g. they are evaluated at one particular moment in time). Likewise, the focus of image analysis techniques has been limited almost exclusively to the recognition of linear features (e.g. joints, edges, etc.). On the other hand, the applications for bridge coating evaluation and sewer and water pipe inspection use a set of initial images to establish a database; thereafter images at different points are compared to statistical parameters of intensity content and features established in the database.

Recently three-dimensional laser scanning (3DLS) technology has been successfully used to acquire the as-built geometry of urban excavations [14,18,20]. 3DLS is a technology based on the use of LIDAR – Light Detection and Range, analogous to RADAR but using laser instead of radio waves – to produce accurate 3-D representations of an excavation site. One of the main advantages of this technology is that it captures a detailed 3-D to scale image of an open cut excavation at a given snapshot in time. The results associated with these measurements have been successfully used for the following tasks: i) input for numerical modeling, ii) calculation of indicators regarding task performance and efficiency and iii) calculation of construction quantities (e.g. excavated or filled cubic meters) [20].

Fig. 1 shows two 3DLS images taken 1 week apart at an excavation site in the Chicago area [18]. The images provide a detailed to-scale image of the construction site at these two snapshots in time. The images provide detailed information on changes at the construction site during that week. For example the increment of soil removed can be readily identified and quantified by superimposing the two 3-D images. During that week soil was excavated, berm for haul ramps was moved around the site and bracing was installed. The 3DLS images do not provide information on the specific dates corresponding to these activities. It is possible to perform laser scanning at the site on a daily basis, but this is currently impractical and costly given that the 3DLS image requires several hours to acquire on site. While instruments such as surface settlement points and inclinometers are read several times a week, there is a lack of a corresponding record of construction. This one week gap results in a significant loss of information over the period between scans that impairs the ability of the monitoring program to provide a clear picture of the behavior and status of an excavation. On the other hand webcam images and other digital images are readily available for the site as shown in Fig. 1. Of course, the user can manually examine the photo records on various dates to identify when a given activity has occurred. This is a time consuming effort. It is desirable to have a semi-automated procedure whereby the possible changes in an image can be quickly identified. The user can then readily correlate those changes to changes in measured response of the excavation (e.g. wall deformations and surface settlement) or to the changes identified over a week from 3DLS. This will provide a greater resolution in the information available from excavation monitoring which will be very helpful in urban excavation areas where the demands for strict control of deformations continue to increase.

In addition, advances in information technologies will bring new approaches to site monitoring and control. In the near future, with sensors and other advanced information devices, the time intervals of site information gathering will decrease. As a result, automated data collection and intelligent data-processing tools will play a critical role in providing the project control team with up-to-date information that do not only document accurate and detailed data for construction claims and dispute, but also detect problems and errors before engaging costly resources and rework.

The following sections examine the use of two image manipulation techniques, Close-Range Digital Photogrammetry and Image Reasoning, to identify changes at an excavation site. The image manipulation tools considered in this study are semi-automated (human-assisted) techniques able to extract data and recognize patterns out of static images. The aim is to evaluate potential image manipulation techniques to supplement the information obtained from 3DLS measurements, thus helping to fill in the gap of information between two 3DLS scanning sessions. This ultimately results in a hybrid imaging approach such that the laser scanning data (obtained at relatively long intervals of time, e.g. weekly measurements) could be used as boundary conditions, while the data obtained by digital camera (obtained at relatively short intervals of time, e.g. daily or hourly measurements) could be used to describe the singularities in-between (Fig. 1). The remainder of the paper is focused on developing appropriate image manipulation tools.

3. Close-Range Digital Photogrammetry for tracking excavation activities

Close-Range Digital Photogrammetry (CRDP) is a technique that uses digital photographs as the fundamental medium to create three-dimensional models [27]. As in traditional