Remote sensing techniques for geo-problem applications

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ABSTRACT

Geotechnical investigation involving failed structures can vary from open surface failures of roadside slopes to underground tunnel collapses. Remote sensing techniques naturally adapts to geo-problem investigation. This paper discusses innovative remote sensing technologies that are being developed for geotechnical investigations. Remote sensing refers to non-contact sensing from a distance away. Most remote sensing techniques such as satellite imaging and aerial LiDAR scans have been popular for geo-spatial analysis. More recently, close range remote sensing techniques have been developed into terrestrial or near-ground technologies. In this paper, focus is placed on remote sensing techniques that do not require surface treatments and techniques that can be used for quantitative measurements. Four techniques are described herein: terrestrial LiDAR scan, rapid shooting camera (RSCS) system, small format aerial photography (SFAP) and unmanned aerial vehicle (UAV) imaging.

Keywords: remote sensing, laser scan.

1. INTRODUCTION

After the collapse of the Minnesota I-35 bridge, there is a renewed interest in US to enhance bridge infrastructure monitoring. Other than developing traditional inspection and material testing techniques, there is also increased discussions about possible applications of commercial remote sensing (CRS) technologies for civil infrastructure monitoring.

Remote sensing is broadly defined as the collection and interpretation of information about a target without physically contacting the object (Sabine 1986). Remote sensing techniques can be optical or electro-magnetic. Nuclear-based method, although non-destructive, is intrusive and hence is usually not identified as remote sensors.

Robust remote sensing technology developed under the US TEA-21 legislation and continued with SAFETEA-LU resulted in several CRS technologies for wide-bandwidth spectral information sensing, including remote sensing techniques developed integrally with satellite surveillance platforms such as IKONOS, Quickbird and OrbView-3. Additional airborne sensors including ADAR 5500, Intermap STARS-3i, TerraPoint, and powerful LIDAR remote sensing systems including LandSat, SPOT and AVHRR, are technically-proven and available commercially (Birk et al. 2003). Several of these CRS-SI technologies have been extended to infrastructure monitoring.

Geotechnical forensic investigations can vary from finding the cause of open surface failures of roadside slopes to the collapse of underground tunnels. CRS technologies naturally adapts to geo-problems since they typically covers a spatial surface - the use of remote sensing allows widened viewpoint of a physical system - an advantage for large structures such as bridges, buildings, landfills and roadways. Obvious disadvantage of CRS technology is the loss in measurement accuracy and resolution as a function of distance. More recently, close range remote sensing techniques have been developed for terrestrial or near-ground sensing.

In this paper, four techniques will be introduced: terrestrial LiDAR scan, rapid shooting camera system (RSCS), small format aerial photography (SFAP) and unmanned aerial vehicle (UAV) imaging. A common denominator of these four techniques is that they do not require surface treatments and the products can be used for quantitative measurements.

2 LASER SCANNER

Terrestrial 3D laser scanners operate on the same basic principles as microwave Radars (radio detection and ranging), but at a much shorter wavelength (10 μm to 250 nm). They often operate in the ultraviolet, visible, near infrared, mid infrared and far infrared regions.
Laser scanners can also be considered as LiDAR (Light Detection and ranging) or LaDAR (Laser Detection and ranging) systems (Jelalian 1992).

Terrestrial laser is based on the transmission and receiving of pulsed lights. Using a moving-iron galvanometer, LiDAR can become a scanning device (Chen 2013). By determining the heterodyne laser beam phase shifts, scanning LiDAR can detect the distance information from a plane of data points, called point cloud. The point cloud information, which basically consists of the physical positions of any surface that the laser “sees”, can then be used to detect useful critical information about surface defects (damage quantification) and deformation under loading (deflection measurements), etc.

A basic LiDAR system consists of a transmitter, a receiver and a signal processing unit. A pulse or a series of light is emitted from the transmitter and part of the scattered energy is reflected back to the receiver after reaching the object area (Figure 1). The time the light traveled between the scanner and the object, can be measured. By multiplying the speed of light with its travel time, the two way distance between the scanner and the object can be calculated (Liu, 2009).

Ground-based LiDAR was first introduced for bridge displacement measurements (Fuchs et al. 2004), and has been used for damage detection on building structures (Girardeau-Montaut et al. 2005, Kayen and Pack 2006). Figure 3 demonstrates identified mass loss due to system instability on a bridge pile cap/floor beam using LiDAR scan and a damage detection algorithm. The bridge girder sitting has significant concrete mass loss due to uneven load distribution. Using the scanning laser, the volume and area losses under each girder can be computed.

Figure 2 shows a scan of a failed retaining wall, where separation between top soil and masonry block wall is detected and measured using LiDAR.

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3 RSCS (Rapid Shooting Camera System)

Photo imaging for crack detection is very useful for detecting pre-mature failures of tunnels. SmartSensys LLC developed a rapid scanning (RSCS) technique for tunnel monitoring. The image collecting system consists of 16 high-speed high cameras resolution (Resolution: 2 mega pixels (1624 x 1224) at 30FPS, shutter speed 1/4000, with focal lens distance: 12-35) surrounding a frame and can accommodate driving at normal traffic speed. Figure 4 shows the SmartSensys RSCS system scanning a tunnel for the Singapore MRT system.

The product of the RSCS system is an ultra-fine description of the cracking pattern on the tunnel walls. Figure 5 shows the stored digital information that...
distinguishes crack width, cold joint, water leakage, and many other condition information. The captured cracking information can be used for quantifying damaged state and for future references.

4 SFAP (Small Format Aerial Photography)

Boyle Consulting Engineering PLLC and University of North Carolina at Charlotte jointly developed a unique airborne imaging technique for providing sub-inch resolution images for condition assessments (Chen et al. 2011). Sub-inch aerial shots are captured from a height near 500 m and has many applications including construction monitoring, damage evaluation, event documentation and ground movement measurements. Figure 6 shows a typical shot of a bridge under construction. The image allows project managers to monitor the progress of the bridge construction and identify potential problem sites.

5 UAV (Unmanned Aerial Vehicle) IMAGING

SmartSensys LLC developed a UAV (MK-8 UAV) system to carry a GPS-based Remote Optical Monitoring system by integrating: (i) Advanced HD camera capturing technology; (ii) digital image processing technology; and (iii) advanced GPS navigation system. Figure 8 shows a picture of the MK-8 UAV. The UAV is mission-programmable where the waypoints were set with GPS data to allow automatic navigation to the target positions on a structure. The UAV can return back to the original location after mission at an accuracy of several millimeters. Integrating with advanced HD camera and 3D orthogonal digital image processing, crack widths on a bridge component can be measured with an accuracy of 0.1 mm.
bridge was constructed in 1997. The crack distribution including estimate of crack width along tower height (from road surface to altitude of 50m) was evaluated. Figure 9 shows the sequential images taken by MK-8 UAV. A total of 29 images are shown. Number of images can be pre-established and programmed with waypoint GPS positions. The UAV was flying in close vicinity of the bridge component, providing high resolution crack images. Similar imaging would be very challenging and time-consuming by bridge inspectors with a cherry picker.

6 DISCUSSION

The CRS technologies presented in this paper represents a small fraction of several actively researched technologies for condition monitoring/failure evaluation of civil structure/geo systems. Before the infrastructure industry catch on with CRS technologies, however, there is a need to carefully evaluate remote sensing technologies and identify the best technologies available for failure analysis or condition assessment. Because of the capability in providing high resolution spatial information from a distance, commercializing remote sensing technologies poses issues different from other sciences and technologies including issues of privacy and security (Hitchings 2003), critical information extraction issues such as differentiation between redundant imaging and actual information (Hernandez 2005), and apparent legality and technology relevancy issues related to commercialization (Johnston et al. 2003 and Williamson et al. 2004). Hence, a critical issue is how to retrieve useful and legitimate information from multi-variant imaging and data sources. This situation is further complicated by the presence of high data redundancy, which translates to computational complexities that require sophisticated inverse engineering algorithms.

Because remote sensors are image (optics) based, the techniques are light wavelength critical. It is important for the users to understand the sensor limitations and also the influences from the shooting environment. For visible light, the influence of color contrast and light reflectivity of the target surface and the damage should be carefully evaluated. This can have critical effects on damage quantification such as crack size measurements.

Another issue associated with imaging technique is the skew introduced in an image due to the optical lens geometry. This is usually described as the orthogonality between the imaging instrument and the target surface area. Fortunately, several image processing algorithms can be implemented to rectify any artifacts that may be introduced in an image due to the imaging technique (Gonzales and Woods 2001).

Despite these complex issues, transfer of high tech CRS technologies from space applications to civil structure monitoring opens an exciting opportunities for efficient, large area monitoring that cannot be achieved by conventional contact or embedded sensors.

10 CONCLUSIONS

In this paper, four different remote sensing technologies for geo-problems are presented. Other than the fact that none of the techniques reply on surface treatment of the target surface, the techniques represent a wide spectrum of different measurement platforms: stationary terrestrial LiDAR, aerial imaging using both fixed wing airplane and UAV and truck-mount rapid scans. It should be noted that the presented techniques are not the only available technologies, other methods such as truck-mount or airborne LiDAR scans are also available.

The following generalized remarks about remote sensing technology can be summarized:

1. Remote sensing provides full field optical monitoring, which is not possible with contact or embedded sensors.
2. Remote sensing is visual-based and is consistent with current field inspection techniques.
3. Remote sensing technique requires knowledge about the optical characteristics about the target and its environment.
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