Deformation Monitoring and Analysis of Structures Using Laser Scanners

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SUMMARY

Laser Scanners are relatively new technology, allowing rapid and very dense surveys of structures within an hour or so. Laser Scanners allow millions of angles and distances to be gathered onto a structure, creating a point cloud. This point cloud can then be linked to another of the same structure but scanned from a different location, allowing a 3D image of the structure to be created. This is made possible through placing targets on or adjacent to the structure and matching these in various point clouds. The draping of digital photos of the structures on the point clouds allows the final image to look realistic; allowing the user to be able to interpolate the point cloud easier.

Research is underway at The University of Nottingham investigating the use of laser scanners to aid deformation monitoring of structures over a period of time. The research investigates the resolution of the laser scanner, and determining the minimum deformation that can be detected through such a system. Trials underway at The University of Nottingham include monitoring the deformation of concrete beams during loading trials. The truth for these trials is provided through accurately surveying targets upon the beam before and after the deformation occurs. Furthermore, a trial upon a historic cathedral is also discussed.

One of the main areas of interest is the location and numbers of targets required for a successful trial.

The following paper outlines the work underway at the University of Nottingham, identifying the trials that are planned as well as the outcomes expected and their implications.

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1. INTRODUCTION

Work with terrestrial laser scanners has been performed seriously in the past five years. A number of scanners are available on the market and are used by both commercial and private sectors. As a new technique the scanners are currently being tested for their accuracy and precision in comparison to more traditional techniques. Also, various applications including deformation monitoring and cultural heritage are currently being investigated.

Schulz T and Ingensand H [2004], have performed a number of benchmark tests using a calibration track line, focusing on the distance accuracy.

Work has also been conducted by Lichti et al [2002], using a EDM calibration baseline with known measurements and a dam with known GPS co-ordinates.

Laser scanners use the time of flight of the laser to measure the distance to each point in the scanners range. The surface material will affect the signal that the scanner receives back and can cause problems with the strength of the signal. Results can therefore be affected, so research into the effect of the materials is currently occurring. Several different materials can be tested, although those most associated with structures are of most interest, i.e. concrete, wood, rock. Reference to this is the work done by Lichti and Harvey [2002] who have used various materials and scanned them at close (3m) and medium range (53m).

Work has been conducted at the University of Nottingham [Cridland, 2004] into materials and the scanners ability to detect movement using various materials.

Archaeological work in Athens [Ioannidis C, *et al* 2004] has laser scanned an excavated site found during construction work and used photogrammetry techniques to get the required data for comparison before the site was built upon. An example of the speed and effectiveness of the technique if data is required in a short space of time.

Other work [Mills J and Barber D, 2004] where laser scanning, total station and photogrammetry techniques have been compared on the South Façade of the Hastings Tower, Ashby Castle. Problems arising with the laser scanning were found here and conclusions made that traditional techniques still needed to be used until laser scanning improved. Some points made included the need for careful planning of target position and scanner position to eliminate error measurements.

Current deformation monitoring makes use of traditional surveying techniques including photogrammetry and total stations. Work at the University of Curtin [Gordon et al, 2004] has used a Leica HDS2500 scanner for the testing of loaded beams. Their work includes different beam materials and allowing the beam to be loaded in increments. The interest in laser scanners arises in the fact that they gather more data for the time given than traditional techniques. Data for all of the area of interest can also be taken as opposed to just specific chosen points or targets.

Cridland, [2004] in association with Greenhatch Ltd. Carried out deformation monitoring using concrete beam tests, where the results were reasonable for the scanner. Also, tests for the reflectivity of materials and the effect of this on results in comparison to a total station. The targets used here, however, were retro-reflective; ideal for the total station, but disastrous for the scanner.

The following paper will outline the work currently underway at the University of Nottingham; investigating the suitability and best practice for using a laser scanner for the deformation monitoring of structures. Due to the nature and timing of this project, the paper will outline the trials and expected results.

2. THE LASER SCANNER

A Leica Geosystems 3-D laser scanner, the Leica HDS3000 along with state of the art software package Cyclone 5.1, which gathers the data and can be analysed immediately after the scan. Leica Geosystems are a Swiss based company operating around the globe who specialise in the design and manufacture of laser scanners as well as other systems.

Figure 1: the Leica HDS3000 being set up at the University

The HDS (High Definition Scanning) 3000 is a new model in the Leica range which develops the ideas from the HDS2400 and HDS2500 models, Figure 1. The scanner includes additional features that the previous Leica scanner models the Cyrax 2400 and 2500 did not have. The features include a 360° horizontal field of view and a 270° vertical field of view as well as an internal colour camera for overlaying images.

Accuracy is said to be 6mm at 50m and 1.5mm at 50m for purpose built targets (Leica Geosystems website). Although the accuracy of these points will depend upon the reflectivity of the surface.

The scanner can scan up to 100m in ideal conditions. However, the manufacturers recommend a 1.5m to 50m range. The temperature range is 0-40°C and it is not advised to work in the rain. The scanner gathers data at 1 column of points per second, if the column contains 1,000 points. A windowing facility is available allowing the surveyor to choose the field of view and saving the time to carry out a full 360° scan. This is particularly useful in beam monitoring where it saves scanning time.

Many trials have been carried out using the Cyrax HDS2500 laser scanner of which several papers have been produced. Work carried out by the group from the University of Curtin, who are producing similar work with regard to deformation monitoring. Many of this work is conducted using the HDS2500 scanner and not new newer HDS3000. It appears to have less use probably due to its recent introduction to the Leica catalogue.

3. THE USE OF LASER SCANNERS FOR DEFORMATION MONITORING OF STRUCTURES

Laser scanners have the potential to gather millions of points in a relatively short space of time. Deformation monitoring up until now has been carried out using traditional surveying techniques and photogrammetry. The accuracy of these methods is generally very good, but the time to set up and performing the survey takes time. Data can also only be gathered for specific points, causing the very likely situation of deformations such as cracks being missed. The idea behind using the laser scanning technology is to gather data from the entire structure without the use of specific deformation targets being required. Targets are required for the registration of the structure, and can be set up away from the structure to tie in the various scans. No targets are required on the actual structure itself. Therefore a complete point cloud image of the targets can be produced and set up within a network coordinates system. Future trials can be carried out in the same way, set within the coordinate system and compared to initial tests. Therefore structural movement can be assessed. The idea of transferring the data into DTM (digital terrain model) for comparison is also a possibility.

Accuracy is therefore important and tests are being conducted at the University of Nottingham to determine whether this kind of surveying technique is feasible for deformation monitoring.

4. FIELD TRIALS

4.1 IESSG (Institute of Engineering Surveying and Space Geodesy) Building Survey

Initial trials are being performed to check the target choice for the scans. HDS targets supplied by the manufacturer were positioned on the front and back of windowpanes. Also, black and white paper targets already on the building were tested.

Three scans made were registered together using four free standing HDS targets, which did not move.

Results showed after registration that the black and white targets created large errors. Hence the proprietary targets have to be used and not a cheaper alternative. If these are taken out of the registration then the errors greatly reduced. The results obtained from the targets behind and in front of the glass showed little difference in results. Hence, glass does not appear to make any difference with the target acquiring.

Future tests on the IESSG building for precision are planned. The building will be scanned with independent targets and targets in window. The scan will be repeated at a later date and compare results for the precision of the scanner. There is a need to have known target points for the independent targets, so there is a need to incorporate GPS coordinates to the targets set up off of the building as a check. Tests will be conducted when weather conditions are significantly different, i.e the temperature. These tests will focus on the target rather than the accuracies obtained through deformations. In addition, however, the accuracies obtainable from the laser will be investigated through re-calculating the coordinates of any redundant targets upon the structure.

4.2 Beam Cracking

Concrete beams within the School of Civil Engineering are set up in preparation to be loaded. The trial is to be conducted using the laser scanner and total station as a comparison. The total station used is a Leica TCA2003. As the total station results should be more accurate than the scanner, these are taken as the truth and the laser scans results compared directly to them.

Three HDS targets are set up around the beam in positions where they will not move throughout the entire experiment, Figure 2. These targets are required to register the numerous scans together and to allow the two techniques to be compared. More targets are positioned on the face of the beam, these will be the points which are compared for the total station and scanner results. The scanner will be positioned in front of the beam and a scan taken. Each individual target can then be scanned with a finer scan to get the exact position. The scanner may be moved and more scans taken. This will be conducted before and after the beam is deformed.

Figure 2: the concrete beam before loading with targets attached.

The total station is required as a truth for the comparison of results. This will be set up with a reflectorless target on the other side of the beam, which will be the reference line. Each point on the beam and the three independent HDS targets will be recorded. Coordinates will be given to the total stations and hence they can be calculated for each of the three points and the positions on the beam. The coordinates of the three independent targets can then be put into the Cyclone software and a coordinate system for the data is produced.

Data is taken before and after the beam is loaded and broken. Therefore the change in positions will be calculated for each method and compared.

4.3 Lincoln Cathedral

These trials are real life scenarios. The project will use Lincoln Cathedral, which is nearly 1,000 years old, and taller than the Egyptian pyramids. It is an imposing tribute to medieval British architecture. It has been through a series of mishaps, including fires, re-builds and tower collapses. It is obvious that such a structure could be prone to long term deformations. The project will establish a point cloud and control to allow future deformation monitoring to take place. In addition, many cathedrals around the United Kingdom do not have adequate records of their general layouts or plans. The intricate details of some of the architecture within these cathedrals only have photographic records. If any damage occurred, it is possible that the recreation of such details would be impossible. The laser scanning equipment is a good answer to this issue, as it records a three dimensional image of the structure, allowing both the general outline plus the actual dimensions of each area of interest to be recorded.

A trial run for this use has been started at Lincoln Cathedral in conjunction with English Heritage. Two preliminary trails have been carried out to assess the feasibility of the scanners use within the cathedral space and outside it. HDS targets have been set up within the cathedral floor and scans taken of the entire space. Finer scans of stained glass windows and ornamental details have also been taken using a smaller grid of points for more detail.
The main issues that have arisen from these trials is the use of targets and how to tie in the points clouds using the registration facility within the Cyclone 5.1 software. As targets can not be placed on the cathedral walls, free standing targets must be used. This creates the problem of the public knocking them over and causing the scans to be invalid. Figure 3 illustrates a scan taking place at Lincoln Cathedral.

Figure 3: The laser scanner in action within Lincoln Cathedral.

Results from the first day have been tied together using the HDS targets and good results have been produced, Figures 4 and 5.

Trying to tie in the outside scan from the second day, to the registration of the first days data has been difficult. Cloud point registration problems using specific points in each image, rather than independent targets. Picking the same point on each scan is very difficult and the results have been bad. Therefore, there is a need to have HDS targets set up to register it all together rather than relying on using unique points on each scan. Results so far bring up a number of problems with the general scanning itself, not the data gathered e.g. targets have been moved by the public. The probing facility on the scanner has been used for a fine scan of a detailed part of the cathedral. This probes the average distance for the area required to be scanned and creates a grid of the specified scale to occur at that distance. This was tried with a 1mm by 1mm grid of points at approximately 5m away. The scan started, but would have taken almost 600 minutes, which would not have been feasible for the timescale. Therefore a less fine scan was taken.

Other results include the materials having different resolutions in the results, due to the strength of the signals returned. Possibly a means of not only recording the location, size and shape of the structure, but also the material it is made of.

Outside there have been weather problems, the wind being the major issue causing the scanner initially not to work. Cars and pedestrians also get in the way of the scan.
Batteries also create a problem, as scanner can not be run from the mains and the batteries will last for 6 hours. Therefore, if a very detailed scan was needed, each battery would have to be used in turn and recharged during the scan.

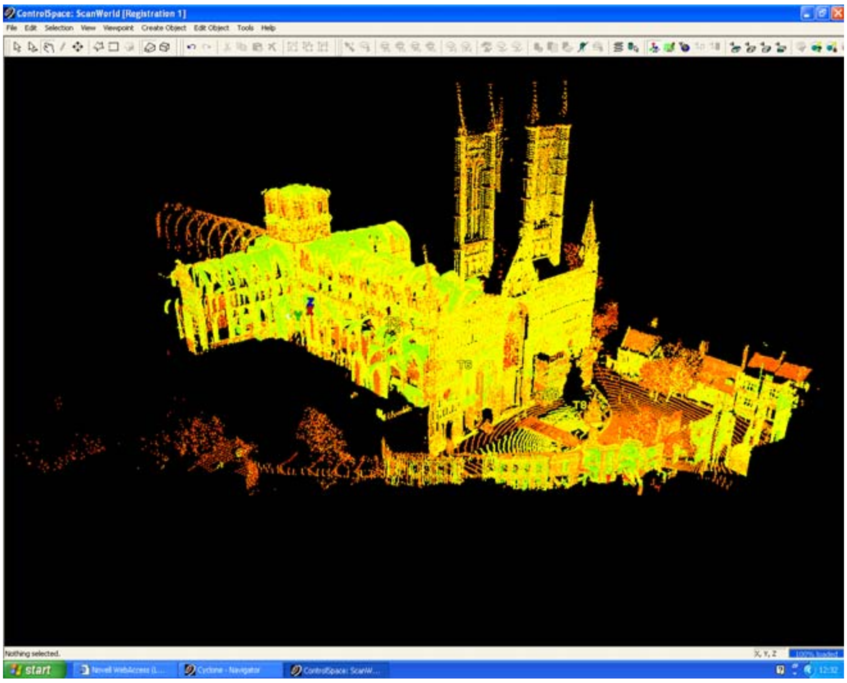

Figure 4 a point cloud of the outside of Lincoln Cathedral.

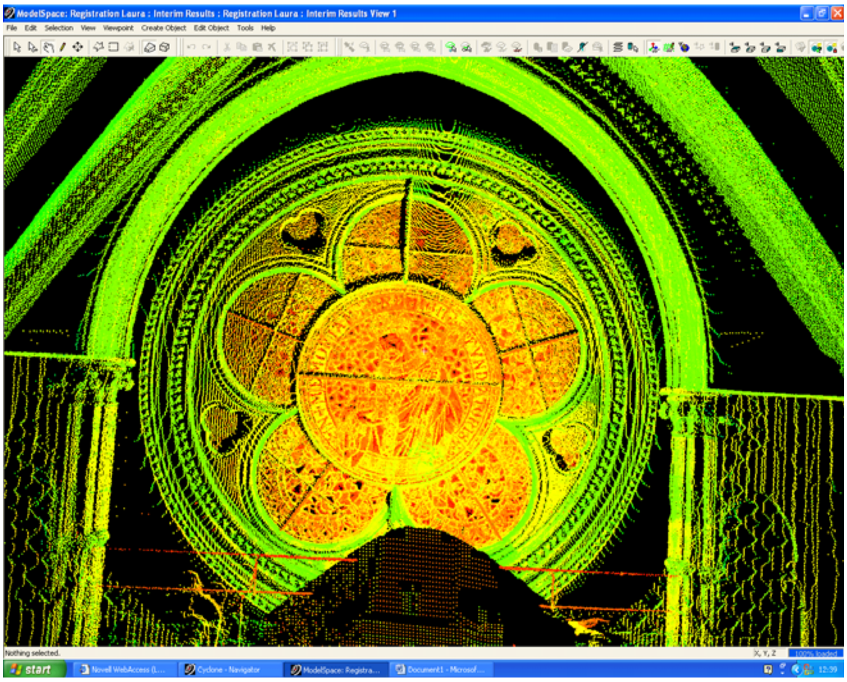

Figure 5, A point cloud of one of the windows within Lincoln Cathedral.

5. CONCLUSIONS

The work at Nottingham is underway and it is planned to assess the use laser scanners for long term deformation monitoring. Ideally, the laser scanners will also be able to identify and possibly measure cracks; this, however, depends upon the resolution of the scanner.

In addition to the deformation aspects of this work, the laser scanner's applications include the ability to record and document the structural architecture. This can be invaluable for historic buildings and for future renovation work.

Further trials are underway in order to identify the potential accuracies and hence the possible applications of such a laser scanner for deformation monitoring. In addition, the locations of the targets are being investigated.

REFERENCES

Charalambos Ioannidis, Maria Tsakiri and Sofia Soile, Rapid 3D Recording of Archaeological Sites Found During Construction Development, FIG Working Week 2004 , Athens, Greece, May 22-27, 2004

Cridland T. (2004), The Use of Ground Based Laser Scanners for the Monitoring of Building Deformations, MEng dissertation, the University of Nottingham.

Gordon S, Lichti D, Franke J and Stewart M, (2004). Measurement of Structural Deformation using Terrestrial Laser Scanners, FIG Working Week 2004, Nottingham, United Kingdom, 28 June – 1 July 2004

Leica Geosystems (2004), www.leica-geosystems.com

Lichti D and Harvey B, (2002) The effects of reflecting surface material properties on time-of-flight laser scanner measurements, Symposium on Geospatial Theory, Processing and Applications, Ottawa 2002

Lichti D, Stewart M, Tsakiri M, Snow A, Benchmark Tests on a Three-dimensional Laser Scanning System.

Mills J and Barber D. (2004) Geomatics Techniques for Structural Surveying, Journal of Surveying Engineering, p. 57-64

Schulz T and Ingensand H, (2004) Terrestrial Laser Scanning – Investigations and Applications for High Precision Scanning,

FIG Working Week 2004

Athens, Greece, May 22-27, 2004

BIOGRAPHICAL NOTES

Dr Gethin Roberts is a senior lecturer at the University of Nottingham. He is also the chair of the FIG's Working Group 6.1 "Engineering Surveys for Construction work and Structural Engineering". His research interests include deformation monitoring, GPS, GNSS and deflection monitoring through GPS and other engineering surveying methods.

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