Detecting Fire Damaged Concrete Using Laser Scanning

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SUMMARY

Concrete is the single most widely used building material throughout the UK and the world. A major advantage of properly designed concrete construction is its inherent resistance to the effects of unwanted fires. The detection and location of structural deficiencies in buildings is of vital importance from a health and safety point of view. In some cases the damage to these materials is easy to detect and identify. Materials such as wood and metal deform such that the deformation, such as twisting, bending, obvious changing in colour and obvious changes in size can usually be seen by eye and thus decisions on parts of a structure that need to be replaced when looking at these materials can be relatively easily made. Concrete on the other hand changes very little in shape and size when damaged, which makes it more difficult to detect when damage has occurred. One of the causes of structural deficiencies in buildings is fire.

In 2004 the cost of building fires in the UK was estimated to be in excess of £2 million a day. Consequently there has never been a greater need for structures to be assessed for fire damage to ensure safety and also to plan and carry out appropriate and cost effective repairs. Terrestrial laser scanners measure the 3D coordinates of any object automatically in a systematic manner in near real time. In addition to 3D coordinates laser scanners are able to measure the intensity value of the returned laser signal. Tests have been carried out to evaluate whether the intensity return values obtained via laser scanning can be used as a means of detecting the temperature to which concrete has been heated. The results of these tests will be presented.

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1. INTRODUCTION

Concrete is a widely used building material in the UK and throughout the world. One of the reasons it is widely used is because it performs well in fires. However if concrete is heated over certain temperatures it can lose its strength and become structurally unsafe. Current methods of identifying damage to concrete involve going into a potentially unsafe building to inspect the damage. This is not the ideal situation.

Laser scanners are widely used in surveying and deformation monitoring activities. Most laser scanners also recode the reflectance of the signal, known as the intensity return. This parameter is affected by many different variables one of which is the type of material being scanned. During a routine scan of a historical building in the UK it was noticed that repairs to a stained glass window that could not be seen by eye, where evident in the intensity return data. From this experience the University of Nottingham, in conjunction with the University of Edinburgh and Glasgow Caledonian University have undertaken some research to investigate whether the intensity return from laser scanning can identify concrete that has been heated above a certain temperature.

This paper presents some promising preliminary results of the research that show that it might be possible to indentify concrete that has undergone heating in a automated fashion using laser scanner data.

2. BACKGROUND

Concrete is the single most widely used building material throughout the UK and the world. A major advantage of properly designed concrete construction is its inherent resistance to the effects of unwanted fires. In the event of a fire, the concrete cover at the surface of a structural member (the thickness of which is often dictated in part by structural fire resistance considerations) provides an insulating layer which protects the internal steel reinforcement and the inner concrete core; this ensures that sufficient load bearing capacity is maintained and prevents structural collapse (Buchanan 2001, Concrete Society, 2008).

The key issue for concrete structures in fire is therefore maintaining the integrity of the concrete cover. However, evaluation of the effects of heating of the concrete cover during fire is by no means an easy task, and there are few scientific tools that can be easily applied to assess the physical or mechanical impacts of fires in concrete structures.

The detection and location of structural deficiencies in buildings is of vital importance from a health and safety point of view. In some cases the damage to these materials is easy to detect and identify. Materials such as wood and metal deform such that the deformation, such as twisting, bending, obvious changing in colour and obvious changes in size can usually be seen by eye and thus decisions on parts of a structure that need to be replaced when looking at these materials can be relatively easily made. Concrete on the other hand changes very little in shape and size when damaged, which makes it more difficult to detect when damage has occurred.

One of the causes of structural deficiencies in buildings is fire. In 2004 the cost of building fires in the UK was estimated to be in excess of £2 million a day (ODPM, 2006). Consequently there has never been a greater need for structures to be assessed for fire damage to ensure safety and also to plan and carry out appropriate and cost effective repairs. Fire causes damage to most materials used to build structures. One of the main reasons for choosing concrete for buildings structures is that it performs very well in fire as it doesn't burn nor does it produce smoke or drip molten particles. This makes concrete a very popular building material in many types of structures. Concrete also doesn't conduct heat well and therefore helps prevent the spread of any fire. Although concrete performs very well in fires any concrete that has been heated to over 300°C starts to lose its strength and is often removed and replaced.

Concrete heated up to between 500°C and 600°C begins to lose a considerable proportion of its load bearing capacity, and above 600°C it cannot function to maintain structural capacity (Khoury, 2000). Currently there are several methods used for determining if concrete has been damaged structurally and therefore needs to be repaired or replaced, these include visual examination as well taking core samples and using geophysical techniques (Concrete Society, 2008), impact echo techniques (Epasto, Proverbio and Venturi, 2009), thermoluminescence studies (Pei, Han and Sun, 1997), and more recently 'combined while drilling' techniques (Felicetti, 2009). However, these techniques all require a person to enter the fire damaged area before any assessment has been carried out. This is obviously a health and safety risk and would be best avoided if at all possible.

Some types of concrete change colour considerable when the have been exposed to fire. Previous research has looked at the possibility of using colour to assess the extent of damage to concrete (Short et al, 2001). This research showed that using colour as a method of preliminary assessment of fire damaged concrete is a more consistent and cost effective than the conventional method of preliminary assessment which is visual observation. However in some types of concrete colour change is minimal and is therefore difficult to assess either visually or automatically with cameras.

The research at the University of Nottingham is investigating the usefulness of intensity return values from laser scanners as a means of preliminary assessment of damaged concrete. Terrestrial laser scanners measure the 3D coordinates of any object automatically in a systematic manner in near real time.

There are several different makes, models and types of laser scanning technology available. Laser technologies record information regarding the return strength of the signal. This return signal is known as the intensity value and this value varies according to the reflectivity of the material being scanned.

3. ANALYSIS

The opportunity to use intensity return from laser scanners as a means of identifying difference became apparent during a laser scan of a stained glass window at Lincoln Cathedral, Lincoln, UK, where a significant difference was seen in the intensity value return of the laser to a section of the window that had been relatively recently replaced with a different type of glass (See Figures 1 and 2).

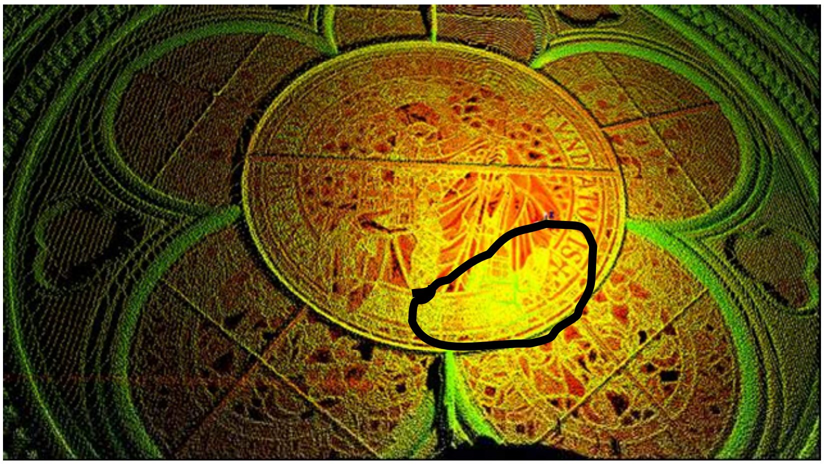

Figure 1 Intensity image of a stain glass window at Lincoln cathedral.

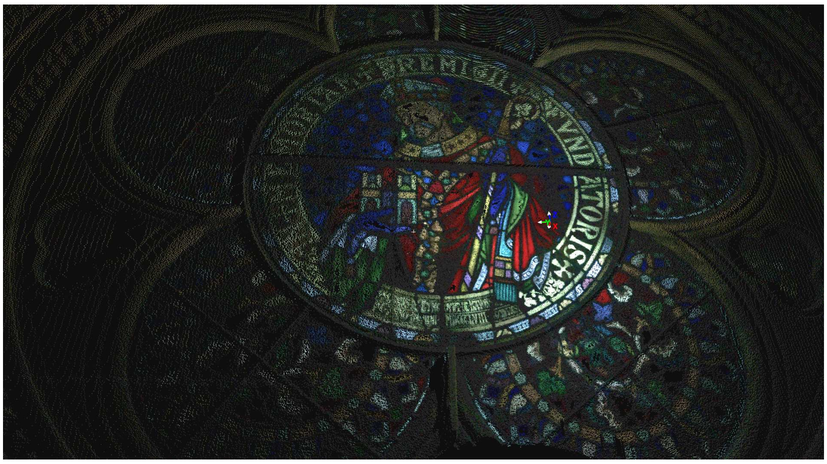

Figure 2 the same image as Figure 1, but with the digital photo draped over the scan.

The difference in glass type was not obvious by visual inspection alone but from Figure 1 it can be seen that this difference is evident in the data from the stained glass window. This evidence for detecting different materials using the intensity values from lasers led to some preliminary tests being carried out at the University of Nottingham to investigate the idea of using the intensity value returned from laser scanners to collect data about concrete and interpret that data with regard to the condition of the concrete.

Figure 3 shows four identical pieces of concrete. Three of these blocks have been heated gradually from a temperature of 200°C to a temperature of 990°C in a kiln for a period of three days. This meant that the heating of this concrete was very controlled. The block on the far left of Figure 3 has not been heated at all but has been kept at normal room temperature.

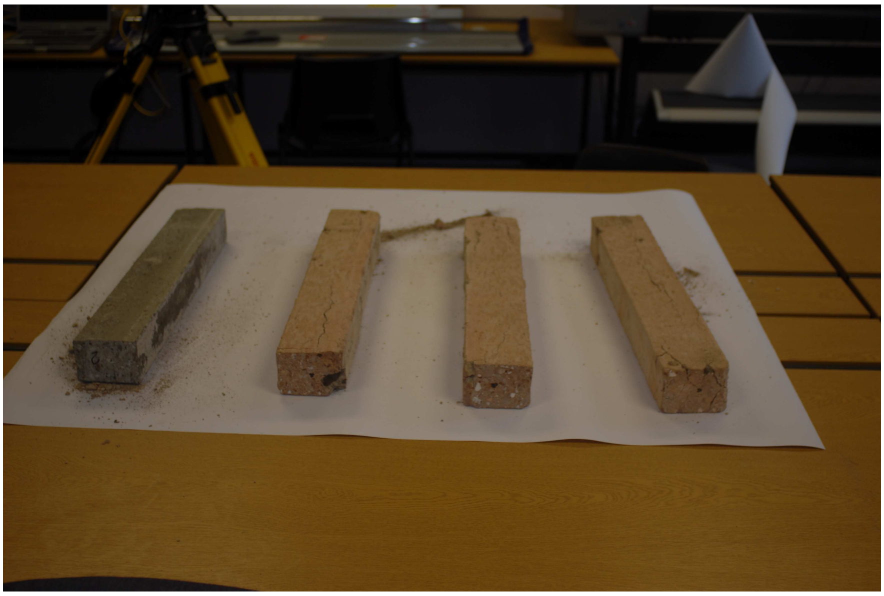

Figure 3: Four concrete samples, the three to the right have been heated to 990°C, the one on the far left has been kept at room temperature

The concrete blocks were then scanned user a Leica HDS3000 pulse laser scanning. The intensity value of the returned signal is shown below (Figure 4). Using the HDS3000 on its highest setting, approximately 90,000 points were collected. From Figure 4 there is a visible difference between the concrete that has not been heated (far left) and the heated concrete as the non heated concrete is more orange in colour compared with the yellow of the heated concrete. This difference however is not obvious.

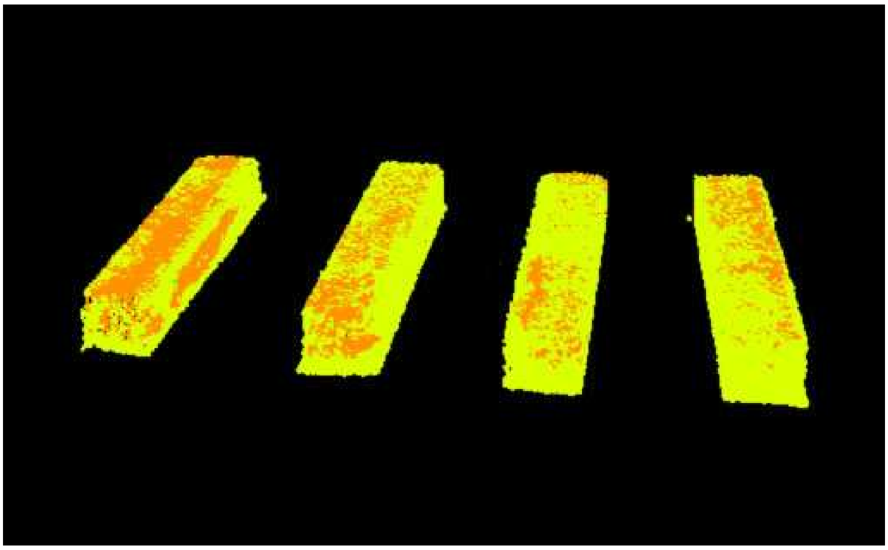

Figure 4: HDS3000 intensity return values for the four concrete samples

To investigate whether other types of scanner might give more promising results the same concrete blocks were scanned again this time using Leicas HDS6000 Phase scanner. The HDS6000 is capable of scanning at much faster speeds and at a much higher resolution. The results are shown below (Figure). Using the HDS6000 on its highest setting 9,000,000 points was collected.

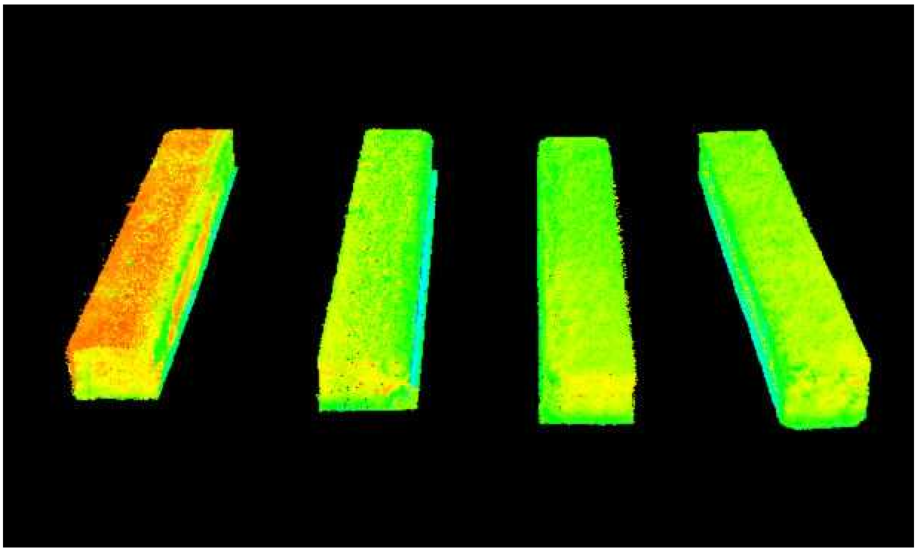

Figure 5: HDS6000 intensity return values for the four concrete samples

From Figure the difference between the intensity values returned from the heated and non heated concrete blocks is clearly visible, much more so than when using the HDS3000.

These experiments have shown that it may be possible to detect differences in materials by using the return intensity values from laser scanning, when using high resolution laser scanners. Recent research has shown that it is possible to derive algorithms to predict the reflectivity of certain materials but that there are many unknowns in this process (Höfle and Pfiefer 2008). Some of the parameters that have an effect on intensity are, angle, distance, ambient light, water content, humidity, type of laser, type of concrete etc. This is a very new area of research that has been investigated first from airbourne LiDAR (Wagner et al, 2006) and more recently from terrestrial based laser scanning (Höfle and Pfiefer 2008). To be able to effectively identify concrete that has been heated to certain temperatures then all of these factors need to be modelled in some way.

4. CONCLUSION AND FUTURE WORK

The results of these preliminary experiments have given promising results that show that it might be possible to identify to what temperature concrete has been heated too during a fire. This could aid in the decision making process when decided which parts o the building are safe to enter and also which parts of the building may need to be replaced due to not being structurally sound.

Experiments are continuing at the University of Nottingham investigating whether differences are noticeable when the difference in temperature is smaller. In addition to this, methods of modelling the variables that have an effect on the intensity value of the laser are being investigated.

REFERENCES

Buchanan, (2001). Structural Design for Fire Safety, Wiley.

Concrete Society, (2008). TR 68: Assessment, Design and Repair of Fire-damaged Concrete Structures.

Epasto, G., Proverbio, E., Venturi, V., (2009). *Evaluation of fire-damaged concrete using impact-echo method,* Materials & Structures, 43:235–245.

Felicetti, (2009). *Combined While Drilling Techniques for the Assessment of Fire Damaged Concrete Cover*, Applications of Structural Fire Engineering, Prague, 19-20 Feb. pp. 208-215.

Khoury, G.A., (2000). Effect of Fire on Concrete and Concrete Structures. *Progress in Structural Engineering and Materials* 2(4): 429–447.

ODPM, (2006). *Office of the Deputy Prime Minister's Sustainable Development Action Plan 2006-07*

Pei, J., Han, Y., Sun, X, (1997). Determining burn degree of fire-damaged concrete constructions by thermoluminescence, Chinese Science Bulletin 42(21): 1829-1833.

B. Höfle, N. Pfeifer, (2008) *Correction of laser scanning intensity data: Data and model-driven approaches*,ISPRS Journal of Photogrammetry and Remote Sensing, 62(6), 2008.

N.R Short, J.A Purkiss, S.E Guise, (2001) *Assessment of fire damaged concrete using colour image analysis*, Construction and Building Materials, Volume 15, Issue 1, February 2001, Pages 9-15.

Wagner, W., Ullrich, A., Ducic, V., Melzer, T. and Studnicka, N., (2006). *Gaussian decomposition and calibration of a novel small-footprint full-vaveform digitizing airborne laser scanner*, ISPRS Journal of Photogrammetry & Remote Sensing, 60 (2), pp. 100-112.

BIOGRAPHICAL NOTES

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