The Use of Surface Model in Area-Based Matching in Determining Deformations of Steel Structures

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ABSTRACT

In civil engineering, surface deformations of a structure, in particular steel, are useful indicators pertaining to its failure. Present laboratory methods employed in determining the deformations are through the use of transducers and strain gauges. As such, much time is spent in the preparation of the equipment and peripherals for a particular test. Furthermore, surface deformations can only be measured at points where gauges are fixed and in many cases would not cover the entire surface. This paper presents the use of close range digital photogrammetry to obtain a three-dimensional model of a structure's surface. Since, photogrammetry has always had the advantage of being able to provide measurements on a large number of points on the object of interest, the representation of the surface deformations would be better. Image correspondence is achieved by using an area-based image matching which makes use of simple surface models. Laboratory tests involving load test on steel I-beams were performed. Images of the steel beam under various load were captured using off-the shelf digital cameras that are relatively fixed and calibrated. Whilst the image matching process employs a revised area-based matching algorithm, the image coordinate refinements and the three-dimensional model of the beam's surface was acquired through elementary photogrammetric operations. Validation of the results was done by means of comparing the photogrammetric output against those obtained from the transducers and gauges. Initial results show that the differences between the photogrammetric and conventional approaches are not statistically significant. This indicates that the use of close-range digital photogrammetry in producing the surface deformations is a viable additional approach in determining the physical properties of steel structures.

1. INTRODUCTION

Steel structures, such as bridges, consisting of steel girders and decks, are designed optimumly with the intention of making full use of its mechanical properties. In order to guarantee safety, testing of steel beams and columns in terms of their distortions and deformations is salient to the structural engineers in determining the optimum design of steel structures. Furthermore, with the intention of a better understanding and an accurate numerical modelling of the steel structures, measurements, in particular the deformation, are indispensable. Present approach in measuring distortions makes use of suitably located electronic transducers or gauges to obtain the magnitude of displacements. The shape of the deformed surface is normally measured manually by hand at points of interest which are normally the nodes of a grid drawn on the steel surface. Such method, apart from being crude, is tedious and less accurate. A more practical approach to alleviate this problem is by using close-range digital photogrammetry technique.

2. DIGITAL PHOTOGRAMMETRIC MEASUREMENT

Photogrammetry has always had the advantage of being able to measure an immense number of points on the object of interest, which has usually been earth's topography. A once laborious exercise, if performed using conventional methods, can now be automated using digital images together with appropriate image manipulation algorithms.

In the case of aerial survey, "digital photogrammetric work-stations", which are, in effect, standard work-stations operating extensive and sophisticated photogrammetric software, available from a small number of manufacturers, are able to carry out relative orientations and digital terrain model generation with complete automation given digitised photographs of terrain meeting certain reasonable criteria for terrain undulation and radiometric texture. With assistance from the digital terrain models (DTM), orthoimages and contours can be automatically and quickly generated. Interior orientation and absolute orientation are partially automated. Generation of a DTM of satisfactory density and accuracy from a suitable pair of aerial photographs can be achieved at rates of order of 25 points per second. This is achieved through computer programs to carry out the equivalent of placing the "floating mark" on the surface, as operators need to do on analogue and analytical photogrammetric plotters

In non-topographic measurement, automation of measurement of those objects which have been marked with appropriate types of targets is now a highly

automated procedure. Examples of it being carried out are abundant in the literature, examples are given by Whiteman *et. al.* (2002) & Li and King (2002). However, this paper is concerned not so much with the finding of targets as with the measurement of surfaces, defined by numerous points found through the automated matching. Although this can often be carried out using the same work-stations intended primarily for aerial photographic use, the peculiarities of non-topographic measurement often mean that it is carried out using cheaper proprietary software loaded onto personal computers or work-stations or software developed in-house such purposes.

One of the most important aspects of carrying out automated measurement on either aerial or non-aerial imagery is the "digital image matching", or "image correlation" procedure. Over the last few decades, a number of approaches have been developed but generally these techniques can be classified into two main groups, feature-based and area-based matching. The former group is fast and reliable and capable of finding matches with poor initial values, while the latter approaches have the advantage of high precision. It is the latter group which is of interest here.

Area-based stereo image matching techniques make use of two small areas (windows) surrounding the point for which matching is needed within each image. A correlation technique, generally based on least squares estimation, selects the point of best match. Methods in area-based matching have developed since early significant, seminal work by Foerstner (1982) and Grün (1985). Further significant extensions of area-based matching were proposed by Grün & Baltsavias (1987); Rosenholm (1987a & 1987b) proposed a method of multi-point area-based matching technique in evaluating three-dimensional models, and area-based method was further extended by Baltsavias (1991) through the use of images from several viewpoints, i.e. with multiple images. Further developments of the area-based method was proposed by Wrobel (1991) and Heipke (1992) in which the matching integrates image matching and object surface reconstruction. Recent developments, among others, was proposed by Di Stefano *et.al.* (2002) whereby a fast area-based stereo matching algorithm was proposed.

3. AREA-BASED IMAGE MATCHING MODEL USING A SURFACE MODEL

Mathematical details of conventional area-based matching (ABM) are provided in many publications and are not given here. It may be sufficient to point out that ABM is based on least squares solution of a number of similar equations, one being written for each pixel in the selected "window" surrounding the point to be matched on one image. The equation for any pixel incorporates the image co-ordinates in one window and the image co-ordinates of corresponding pints in the other window, via a transformation equation. Conventionally, an affine transformation between the windows is adopted, (Foerstner, 1982). The unknowns to be determined in the least squares solution are the parameters defining this transformation - including parameters which define the

relative positions of the windows. In effect, these parameters represent what are conventionally called x and y parallaxes. The equations often also incorporate radiometric values but these are not significant to this brief explanation. No information of the object is taken into account in the matching process. Matching is solely based on the intensity values of the pixels and the assumed affine transformation.

An attempt has been made to improve the accuracy of the traditional area-based technique as offered by Grün (1985). The revision involves replacing the conventional model which is used to transform one window shape to the other to improve the mathematical description of the relationship between the windows in the least squares fit. The new transformation incorporates a simple model of the surface being measured, and replaces the assumption that the windows differ according to an affine transformation. It serves as a compromise between the traditional and the far more complex global area-based matching method. As with the conventional solution, the method proposed here solves, through an iterative least squares solution, for the corrections to image co-ordinates (x,y) of the search window. But, in addition, two 'new' unknowns, the gradients in X and Y directions on the surface at the point on the surface which corresponds to the centre of the search window and their second derivatives are introduced.

Since the transformation used is more rigorous than the affine, it is hypothesised that the improved functional model will allow the use of larger windows for matching and hence improve accuracy. It is also found that the use of a better functional model will converge more quickly to give a solution.

The mathematics of the refinement can be obtained from another more detailed discussion, (Mustaffar & Mitchell, 2001). It may be sufficient to point out that the model described above is extended by taking into consideration the shape of the object. The equations used to define the transformation now includes some information about the object's surface which needs an additional significant complication of using the known relative positions of the cameras.

4. EXPERIMENTS

Tests of the algorithms were carried out in the study of steel deformations under static loading, see Figure. Images were taken using a pair of Kodak digital still cameras which comprise of a DC290 and DX4900. The DC290 is fitted with a 6.0 mm lens and has a resolution of 3.1 megapixles. The lens and resolution for the DX4900 are 7.3 mm and 4.0 megapixels respectively. These cameras are mounted with a base distance of approximately 750mm and the relative orientations of these cameras has been determined. A projector was placed in between the cameras for the purpose of projecting patterns onto the object. The pattern used in this investigation was a diamond shaped mesh.
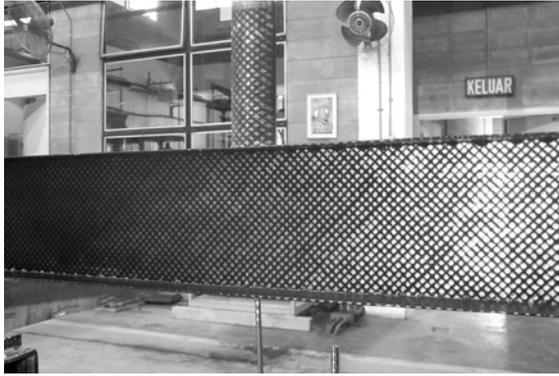
Figure 1 An image of the steel beam tested

The images used are shown in Figure 1, where the mesh projected is apparent. Points of interest in the image are the intersections of the mesh. The selection and pairing of corresponding points for precise matching was carried out manually but techniques for finding such points automatically can be achieved using epipolar approach. Two hunderd pairs of points were selected for matching and as part of the experiment, the size of the window chosen was 25×25 pixels.

5. SUMMARY OF RESULTS

Results obtained from the proposed method, were then used in a space intersection routine in order to obtain the shape of the deformed steel. Figure 2a and 2b show the contour and shape of the deformed surface obtained respectively. Closer inspection revealed that the difference between the highest point and the lowest point on the surface is 7.5 mm.
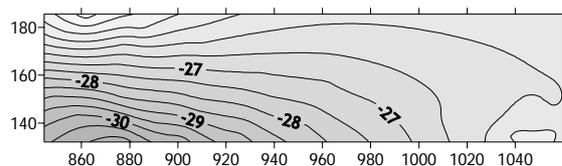
Figure 2a.   Contour plot of the deformed steel surface

The internal precision, which is indicated by error ellipses computed using the standard errors obtained from the least squares adjustment is found to be good. For example, at window size 25×25, the size of the semi-major axis of the error ellipse is 0.01 pixels.

6. DISCUSSION AND CONCLUSIONS

This experiment has shown that the ABM using surface models can be successfully applied to the measurements of surface deformations of steel structures. Nevertheless, as the results presented are those obtained under laboratory conditions, further tests are needed to arrive to a more thorough conclusion.

It is intended that the method employed serves as an avenue for structural engineers to obtain additional information in their analysis of steel structures.
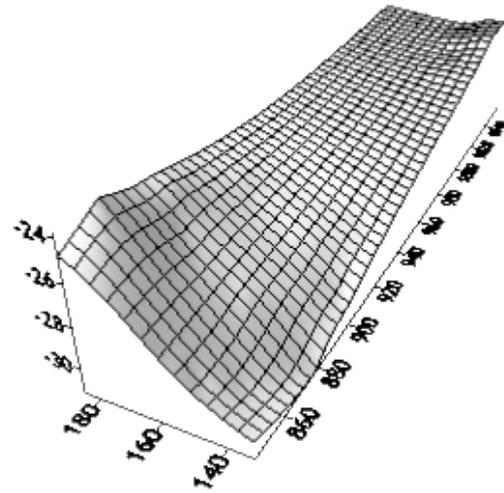
Figure 2b.   The three-dimensional surface plot of the deformed steel surface

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