THE SEQUENTIAL TRACKING OF TARGETS IN A REMOTE EXPERIMENTAL ENVIRONMENT.

T.A. Clarke, S. Robson, D.N. Qu, X. Wang, M.A.R. Cooper, R.N. Taylor.
Centre for Digital Image Measurement & Analysis, School of Engineering,
City University, Northampton Square, LONDON. EC1V 0HB. UK.
Email: t.a.clarke@city.uk.ac
Phone: +171-477-8000 Ext. 3817
Fax: +171-477-8568

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ABSTRACT

The application of digital image processing techniques within experimental apparatus from other academic disciplines is a recurring theme within photogrammetric research. For instance, H.G. Maas has applied 3-D measurement techniques to the mapping of turbulent flow (H.G. Maas, 1994). Such applications of photogrammetric techniques often produce new problems requiring solutions or improvements of existing techniques. Research has been conducted into monitoring the locations of targets within an environment subjected to high forces. Work to analyse video records is described which includes analysis of JPEG encoded sequences using a sensitive target detector and tracker as well as the use of *a priori* information concerning the initial target spacing to effect an approximate system calibration. An analysis of retro-reflective target properties has led to a redesign of the optics of the system for enhanced performance.

1. INTRODUCTION

In order to understand the detailed behaviour of geotechnical events and processes it is important to be able to observe how soils respond to load. Single element testing apparatus can be used to investigate the stress-strain behaviour of soil when subjected to particular stress paths. However, the response of geotechnical structures is the integrated effect of a large number of soil elements each following its own particular stress path. It is therefore of major importance to be able to measure displacements and hence strains during real geotechnical events. Instrumentation of prototype structures can yield valuable results, but much more can be learned from comprehensive test series on small scale geotechnical models.

The behaviour of geotechnical structures is dominated by self weight effects. The driving force is often the self weight of the soil (e.g. embankment loading, tunnels) and the strength is related to in situ effective stresses which are in turn related to the weight of soil. In order to study the behaviour of geotechnical structures using physical models, the main requirement is to be able to create in the model stress profiles corresponding to those in the prototype. This can be achieved by accelerating small scale (1:*n*) models to *n* times Earth's gravity using a geotechnical centrifuge. Thus a 10 m. layer of soil can be represented by a 10 cm. deep model of the same soil accelerated to 100 g because the reality and the model will then experience the same self weight stresses at homologous points. The development of centrifuge testing and its application to a wide range of geotechnical engineering applications are described by Taylor (1995).

Centrifuge testing allows the study of geotechnical processes in scaled models with properly established scaling laws relating the model to the corresponding prototype. It is a technique particularly useful in the study of mechanisms of collapse and deformation; in this context parametric studies are often undertaken. Centrifuge tests have proved to be a major source of high quality repeatable data which are essential for verification of numerical analysis. Particularly valuable data are the movements in vertical sections of plane models which can be observed through a perspex window in the side-wall of a model container. These subsurface deformations can be compared directly with those from finite element predictions and can be used to test and improve constitutive models of soil behaviour.

In order to monitor such movements, the technique commonly adopted is to place markers or targets in the soil face which is in contact with the window. A closed circuit television system allows these targets to be viewed during centrifuge flight. Thus, by measuring the position of these targets in video images, displacements in the model can be determined. A model width is typically of the order of 500 mm. which in an experiment at 100 g represents a prototype distance of 50 m.. The most useful measurements of displacement will need to have an accuracy of 0.01 - 0.1 mm. i.e. 1 - 10 mm. prototype scale. This paper describes the development of a system which allows such measurements to be made. It is illustrated by reference to a project investigating subsurface ground movements due to tunnel construction.

2. ANALYSIS OF THE CURRENT SYSTEM.

The centrifuge optical system consists of a Toshiba IK-M36PK miniature colour camera mounted approximately 400 mm. from the front face of a thick perspex block. The signal from this camera, which was mounted in the 100g environment, is sent to the camera interface unit mounted close to the axis of rotation and consequently subjected to low g forces. From there the signal is transferred via coaxial cables through a slip ring assembly manufactured by Pandect. Two of the 130 Silver Graphite contacts on Silver

Graphite rings were used. The video signal is then routed across several metres out of the environment of the centrifuge to a viewing station. The video signal was recorded by a VHS recorder, but now a SVHS recorder is used. The targets are illuminated by four Osram 5W fluorescent tubes which give an output of 250 Lumens each. Figure 1 illustrates a typical image.

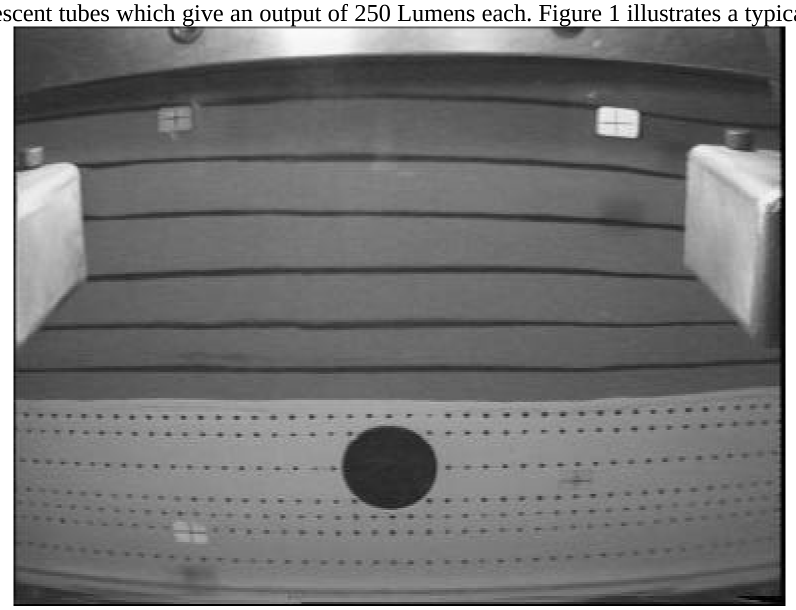

Figure 1. An example of a centrifuge image.

The camera distortion can be clearly seen in the image which consists of a sand section in the top half of the image and a soil section in the bottom half of the image. The black circle is the model tunnel. The experiment examines the effects on it of dynamic loading. The photogrammetric quality of the video tape images was initially very poor because the video had been originally chosen only for visual inspection, rather than for target recognition and measurement (Figure 2 & 3).

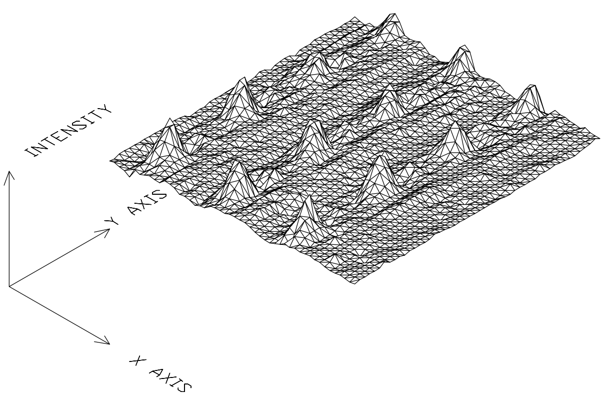

Figure 2. Poor contrast targets.

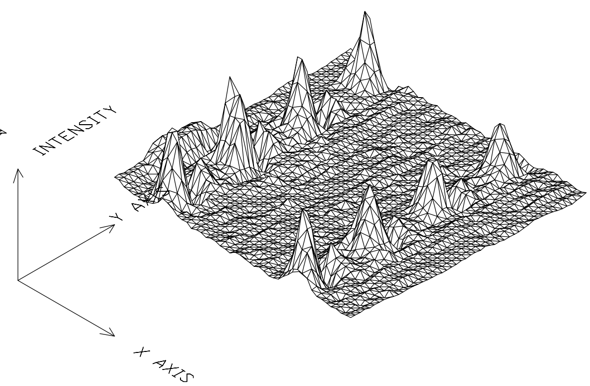

Figure 3. Reasonable contrast images but with evidence of ringing.

The layout of the centrifuge is illustrated in figure 4.

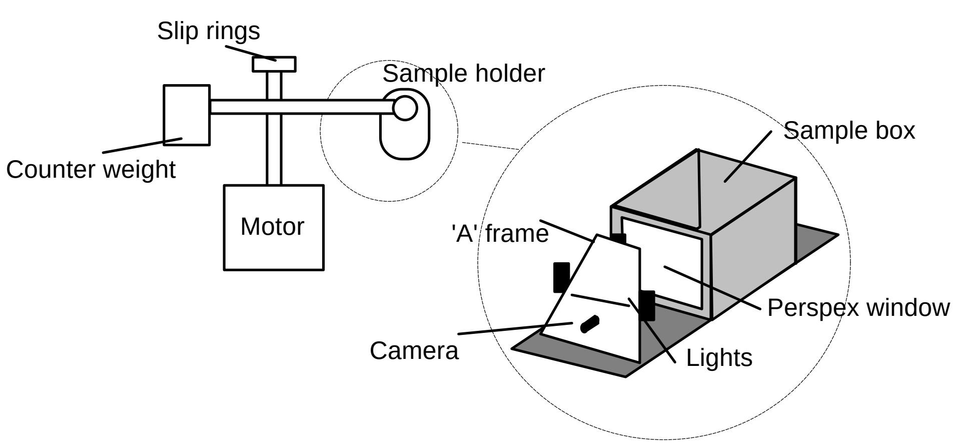

Figure 4. The layout of the centrifuge.

To obtain sequential information from video tape requires very fast storage of data. A means of obtaining such information is to encode the digitised images in JPEG Movie format and then sequentially extract them for processing. A frame-grabber with these capabilities was used to store sequences from past tests. A JPEG movie viewer was created for use in the X Windows environment to allow for sequential playback of individual frames from the JPEG movie sequence. Each image was then processed in the following manner.

(a) The target image locations were detected using a intensity feature based method. The poor quality of the target images and the variable background illumination meant that reliable location of the targets was difficult using conventional methods. Hence, a simple but effective algorithm was written in which a 5x5 mask was moved around the image and the characteristics of an intensity peak caused by a target were found. A target was located by taking the intensity of the point in the image at the centre of the mask and searching for pixels in the eight locations surrounding this point. If the average of their differences was around seven or greater grey values then this point was considered a candidate target. The sixteen pixels surrounding the previously used eight were then checked to establish whether their average difference from the eight was around five or greater. By combining both criteria it was possible to detect the majority of the targets in the video images. The advantage of this method is its independence from the background level at a relatively modest computational cost.

(b) After shape analysis and threshold determination the centroid of the target was computed and the locations of the targets from the first image passed to the second image where the centroid of the target was again computed and passed to the next image, and so on. In this way targets were tracked from image to image with minimal errors. The use of this procedure meant that no new targets could be added in subsequent images and there is a possibility of targets deteriorating and causing misidentification. However, tracking of targets with few errors of any consequence proved possible.

The current method of data collection suffers from two important limitations: poor image quality and the fact that analysis of images has to be made after the end of the experiment. Hence, further investigations were required to improve the operation of the system which are described in the next section.

3. IMPROVEMENT OF THE ORIGINAL SYSTEM.

3.1 Calibration

Any transformation from image measurements to 2-D object co-ordinates within the centrifuge is subject to two major sources of error. First, the sample box and the camera can move as the centrifuge is spun up to speed and second, the camera has an optical system which, by virtue of its short focal length, was subject to gross barrel distortion. The original video image did not contain any control points. Consequently no physically appropriate model for positioning could be directly applied to the data without more information. Calibration, based for example on the plumb-line method, was considered but no suitable colour frame grabber was available to obtain images directly. The only dimensional information available derived from the fact that the targets were positioned in the soil using a template. Comparisons between the target template locations and image data obtained once the centrifuge was at test speed, but before the test itself had started, could be used to generate a deterministic mathematical model. The statistically significant parameters of a third order polynomial were used to model the data by the method of least squares. The polynomial could then be applied as a rudimentary system calibration to correct subsequent target image measurements. Whilst giving no better than 1mm. standard deviations for object space positions, the procedure could at least be used for extracting photogrammetric data from tapes obtained before the use of photogrammetry had been considered by the geotechnical engineer. These computations have nevertheless allowed useful results (Figures 5 & 6) to be obtained from the archive tapes. Once the imaging system has been redesigned, a full component calibration will be carried out, based on physical and photogrammetric principles, and then used as an integral part of the geotechnical experiment.

Figure 5. Before correction.

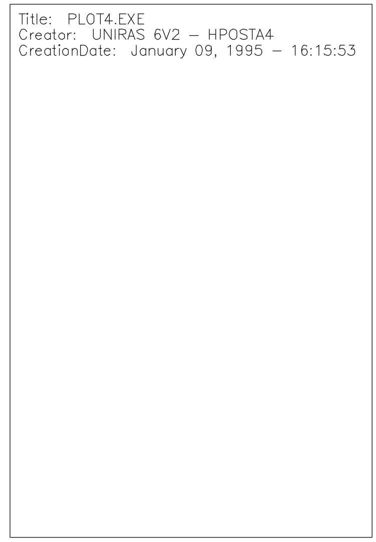

Figure 6. After correction.

3.2 Consideration of retro-reflective targets.

3M have been manufacturing retro-reflective sheeting for many years. The main volume use of this material is for road traffic signs, many of which are a few square metres in size. A minor use, by comparison, is for safety clothing, and an even smaller use is for photogrammetric measurement targets. These materials are optimised for the main market, but requirements for photogrammetry and other uses appear to be very similar, all involving a light source that is close to the viewer (CCD or film cameras in the case of photogrammetry). Although photogrammetrists have largely used just one material (of a type used for projection screens) for targeting there are three different materials used for traffic signs, each with a number of variants which could be useful, but little appears to be known about their photogrammetric characteristics.

In the environment of the centrifuge it was initially thought that it would be difficult, if not impossible to use retro-reflective targets. This was because the surface of the 3M 7610 series material cannot be wetted - a likely occurrence in the centrifuge. However, the advantages of these targets are such that an investigation of other retro-reflective materials was started. The main benefit in this case is the ability to use materials of differing reflective characteristics i.e. black or white, with the same set-up and targets.

3M products use two means of obtaining the retro-reflective effect - miniature balls and miniature prisms. The prismatic material is divided into two types, Diamond Grade and VIP Diamond Grade, while the balls type are divided into High Intensity and Engineering grade. For use in traffic signs the least effective of these materials is the Engineering grade and the most effective is the Diamond grade. This investigation concerns an evaluation of what is most useful for photogrammetry and what in particular can be used in the centrifuge. The information that is required for each material is: surface type; angular reflectivity characteristics; orientation characteristics; and physical properties. The angle of return is of importance in defining the camera angle of view to avoid light fall-off and the angular reflectivity must be known to determine the location of the illumination with respect to the camera. As the camera cannot easily be mounted far from the test specimen, a knowledge of these parameters is of paramount importance.

An apparatus was designed to enable a comparison to be made between materials and, if possible, between other surfaces such as mirrors or plain paper. Measurement over a number of orders of magnitude is required so the methodology used in previous work (Clarke, 1994) could not be used. The first requirement was for a light source of suitable power and stability. A tungsten filament system used for microscope illumination and a high intensity fibre-optic system were investigated, but considered inappropriate due to mains electricity intensity modulation and insufficient output. A 5mW. HeNe. laser (633 nm.) was used. The laser provided the necessary intensity of illumination whilst guaranteeing the delivery of the light to a known location on the material. The output stability of the laser is also very high. The other reason for using the laser was the avoidance of the requirement for a phase lock amplifier and light chopper to separate the illumination of the target from other sources of illumination. The disadvantages are the use of coherent illumination and an investigation at a single wavelength. However, as a first approach to characterising the performance of the materials it was considered adequate.

The apparatus consisted of the laser which was directed via an aperture through a beam splitter. One part of the beam was reflected inside the beam splitter through 90° and then reflected again by another mirror to avoid any further influence on the experiment. The remaining beam passed through the splitter to impinge on the surface of the retro-reflective material. The returned illumination from the retro-reflective material was then partially reflected, in the opposite direction to the useless beam, to a detector. The test material orientation was adjusted by rotation and by a further three degrees of freedom to allow correct alignment. The beamsplitter itself was also mounted on a similar rotation and alignment stage. The materials tested are given in Table 1.

Type	3970 series	5870 series	3990 series	2290 series	7610 series
Name	Diamond grade	High Intensity grade	VIP Diamond grade	Engineer grade	High Intensity grade
Construction	Prisms	Spherical balls	Prisms	Spherical balls	Spherical balls

Table 1. Retro-reflective materials tested.

To gauge the relative response of the various materials used the apparatus was set up for maximum light return to the detector and the light returned by all of the materials measured. In one set of measurements all of the returned light was collected by a lens and focussed onto the detector (row 2) while in another set of measurements (row 3) a small aperture was used. Care was taken to establish the level of returned light, with no material in the field of the test beam, due to imperfect surfaces on the mirror and beam splitter. The responses are given in table 2. It is interesting to note the difference between a front surface silvered mirror and the best material and the differences between the materials themselves. The material usually used in photogrammetry is the 7610 series which is mainly used for projector screens.

Type	Silvered mirror	3970 series	5870 series	3990 series	2290 series	7610 series
Relative total response	380	385	175	310	60	126
Relative sampled response	Not measured	6.04	1.58	3.9	0.5	2.57

Table 2. Relative peak responses of each material.

To measure the relative response of the materials at differing observation angles from perpendicular to the material a detector was mounted to measure the light returned at varying angles of the beam splitter. This method allowed the precise measurement of the return beam even perpendicular to the light source itself. Care was taken to use an aperture which was large enough to contain a significant number of objective speckles caused by the coherent radiation and to take into account the Airy disk pattern produced by interference with the regular pattern of the spherical balls. The results for the test materials are illustrated in figure 7.

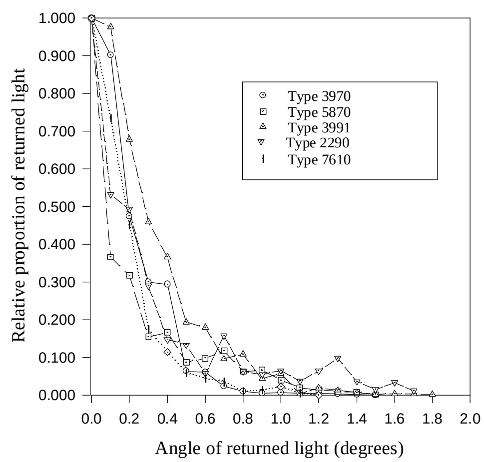

Figure 7. Graph of returned light against angle of return.

All the materials exhibit a similar characteristic - a rapid fall-off of returned light as the sensor is moved off axis. To obtain the best use of the retro-reflective material it is necessary to place the light source very close to the optical axis of the sensor which is generally a camera. As many cameras have a significant physical size it would appear that it is difficult to achieve the necessary conditions to make optimum use of these targets unless the targeted object is many metres from the sensor. However, even using the material at less than optimum efficiency a significant signal to background noise is still obtained. The light return from a white diffuse reflecting sheet of paper, for instance, provided a signal that was barely detectable. There appears to be a modest difference between the materials which could be exploited if it is difficult to arrange for the light source to be as close to the sensor as required.

To measure the response of each material to change in angle of incident light the sample was rotated and the response at each angle noted. The important information required from these tests is the angle at which the material response is about a tenth of its maximum value. At less than this angle the signal is likely to become difficult to locate if background noise is present. The 10% angle for each of the materials is given in table 3.

Type	3991 series	3970 series	5870 series	6710 series	2290 series
10% point (degrees)	40	50	55	55	40

Table 3. The 10% response points for the materials tested.

A possible redesigned optical system using the information obtained in these tests is illustrated in figure 8.

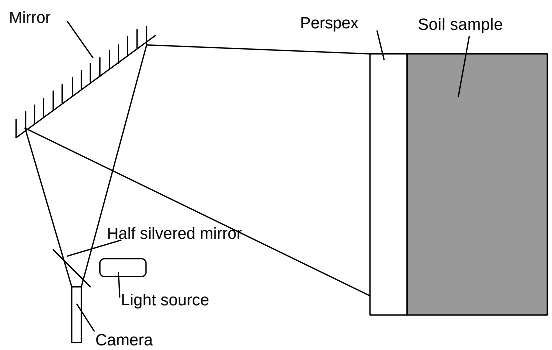

Figure 8. A possible redesign of the centrifuge optics.

The reasoning behind this design is as follows. The mirror is necessary to obtain a path length long enough to keep the angle of view within the 10% fall-off point for the material chosen. The half silvered mirror is required to get the lighting close to the camera axis, and hence to ensure a high signal to noise ratio. The offset of the angle of view to avoid being perpendicular to the perspex inspection window is to stop specular reflection from the surface. This arrangement to realise the potential of retro-reflective targets for the centrifuge is in the process of bench design and testing. The information obtained from the retro-reflective material tests will provide the specifications of the light source spread and power to be defined. It is hoped that the final design will allow successful monitoring by photogrammetry during centrifuge testing, and by virtue of the relative strength of the retro-reflective targets compared with the normal lighting, to allow for simultaneous viewing of the test model.

4. CONCLUSIONS

This paper has described a number of steps in a continuing optimisation of the experimental information obtainable from a centrifuge. Retrospective photogrammetry of archive video tapes has been described. Issues such as: target location in a noisy environment; target tracking; lens calibration after the event; JPEG encoding of image sequences; and the production of displacement vectors have been covered. Finally, the use of retro-reflective targets in this context have been studied and a redesign of the optical system has been outlined. Further work will consider real time target location and tracking as well as an investigation of the effectiveness of retro-reflective targets under these circumstances.

5. ACKNOWLEDGEMENTS

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