An analysis of the properties of targets used in digital close range photogrammetric measurement.

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ABSTRACT

It is common to use some form of targeting in close range photogrammetry as there are seldom enough points on the surface of an object with sufficient contrast. Targets which have been used include: light emitting diodes; black circles on a white background; retro-reflective film; projected laser beams; projected "white light" slides; feature encoded targets; and colour targets. This paper discusses the characteristics of targets. In particular the established retro-reflective target and the promising projected laser target are considered as they both offer high signal-to-noise ratios together with optimum target sizes. The performance of the targets are analysed by use of laboratory tests, for example: (i) a retro-reflective target was placed on a rotating mount with the centre of the target located on the axis of rotation and the target monitored by a CCD camera under varying conditions; and (ii) a laser target was analysed by experiments which were designed to indicate the effect of speckle by moving a flat object in a direction perpendicular to the laser beam.

Keywords: Targets, laser targets, retro-reflective targets, digital photogrammetry, close range measurement.

1. INTRODUCTION

Targets are generally required only when it is not possible to accurately and reliably identify features on an object by any other means. Unfortunately, because of the requirement for subpixel accuracy of location and the low resolution of typical electronic sensors, suitable features do not often occur in practice. Furthermore, the relationship between the illumination and natural features will often mean that the computed subpixel location of the feature in differing viewpoints will not necessarily be collinear with the same location on the object. In fact many objects have limited contrast features which differ in appearance with viewpoint and have large areas with no identifiable features at all. Hence, for the highest precision and for a full spatial description of an object, natural targets will generally prove inadequate and so are not considered further in this paper.

The use of targets in digital photogrammetry will often require techniques that are different to those used in film based photogrammetric measurement. This is because of the opto-electronic sensing process and the limited spatial and radiometric resolution of the sensors. With film the target location accuracy limit results from a combination of: target design; the properties of the photographic film used; comparator characteristics; and the operator ability or automated system used. With solid state sensors the limitations are in: the sensor resolution; the target characteristics; and the sensors radiometric, geometric, and electronic characteristics. This paper discusses the issues involved in optimising the resolution of the sensor using targets whose primary role is to provide a high contrast object that can be differentiated from the background illumination.

2. TARGET CHARACTERISTICS.

2.1 Target requirements for digital photogrammetry.

The high precision measurement of 3-D surfaces using digital photogrammetry generally implies the high precision location of target images which has to be achieved using a low spatial and radiometric resolution CCD sensor where the target may only occupy a region of 5x5 to 10x10 pixels. It is therefore necessary to improve the location of the target image beyond what would be conventionally expected from film by using subpixel methods which are now common and well tested (West & Clarke, 1990). The use of bundle adjustment techniques with digital images will often reveal standard deviations in the image space between 0.1 and 0.01 of a pixel. The source of the precision of location of target images is not easy to estimate from acquired images as it is dependent on a number of factors from electronic noise to A-

D converter quantization errors. An analysis of the effect of quantization errors alone has been conducted (Clarke et al., 1993) which discusses this limit to the subpixel location of target images and offers some simple rules which can be used to decide on the size and intensity requirements for target images. Several authors (Beyer, 1993; Dahler, 1987; Burner, et al., 1990; Robson, et al., 1993) have discussed limitations to target location precision due to the influence of: the frame grabber; electronic noise in the sensor; line-jitter; etc. Many authors have discussed the subpixel precision of the two common methods of target location: the centroid method (Trinder, 1989; West & Clarke, 1990); and the least squares method (Förstner & Gülch 1987; Gruen & Baltsavias, 1987). It is clear that typical results range from a standard deviation of 0.2 pixels to 0.005 pixels depending on the size and shape of the target and its intensity distribution. Brown, (1984) discussed the size and shape of targets for film based photogrammetric methods and recommended a white dot set against a black background where the background was of five times greater radius than the white dot. He suggested that, at magnifications of twenty to thirty times, the optimum diameter of the target on the film negative was between forty and eighty µm. With a digital image an optimum size and intensity maximum can also be determined to govern the size of the target used on the object. The optimum size is a diameter of six or more pixels (Clarke, et al., 1993)(Figure 1). The maximum intensity for such a target image also affects the accuracy of location, a doubling of target intensity will result in a doubling of target location precision if just quantization effects are considered (Clarke, et al., 1993)(Figure 2). A three dimensional view of a typical target image is illustrated in Figure 3.

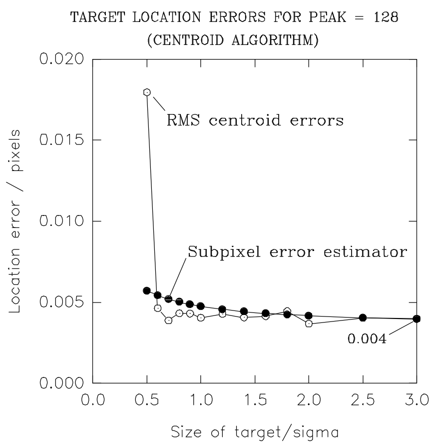


Figure 1. Location errors with size variation.

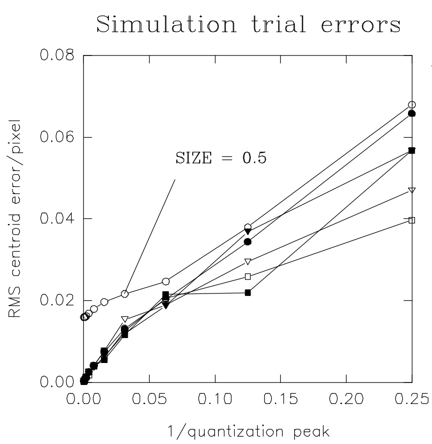


Figure 2. Location errors with intensity variation.

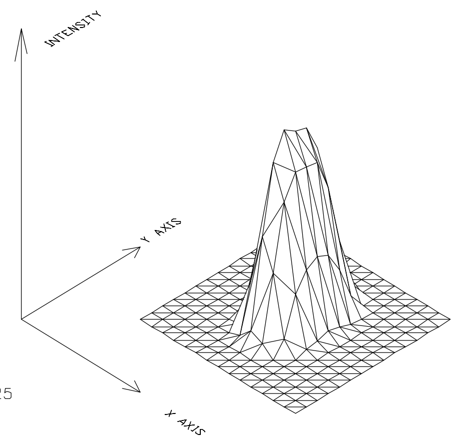


Figure 3. A 3-D view of a typical target image.

2.2 A survey of targets used for digital photogrammetry.

There are two forms of man-made target which may be used to signalise an object: projected light spots, and those which are manually fixed to the object. Both types of target can be further subdivided. A short survey has been conducted to illustrate the range of targets that have been used in digital photogrammetry. It is not intended to be exhaustive.

Spherical balls. Huang & Trinder, (1993) discussed the use of white spherical balls to obtain target features which have invariant features under rotation. With correct lighting the location becomes limited to recognition of circles. Jansa, et al., (1993) discussed the effect of lighting variations and least squares circle fitting, binary target image centroiding, grey scale target image centroiding, and edge detection. Aw, et al., (1993) reported the use of spherical beads which were attached to vertical strings in the measurement of a three metre diameter satellite dish.

Black on white naturally reflecting targets. Many researchers have used black dots on a white background for digital photogrammetric measurement. Beyer, (1992) performed many experiments using black on white targets. He discussed such factors as the precision of location of various size targets, and the influence of background illumination.

Crosses. Mikhail & Cantiller, (1985) discussed the use of cross targets found in digital images of terrain and their location using various algorithms with an accuracy of 0.02 - 0.03 of a pixel.

Particles. The use of neutrally buoyant pliolite particles with diameters of 50 microns was investigated by Mass, (1989) for the determination of turbulent flow in sequential images. Later work conducted by Mass, (1993) used Fluorescein, a liquid that fluoresces under laser light stimulation.

Feature encoded targets. van den Heuval, (1993 & 1992) described the use of targets which can be uniquely identified by a circular bar code which surrounds the target. Wong, (1988 & 1990) discussed the use of binary bar coding or the use of shapes such as a black rectangle to represent a one and a black square to represent a zero. Knobloch, (1992) discussed the use of targets with binary encoded segments, the white centre of the target (which is used for ellipse detection) is surrounded by black binary encoded segments at two different radii to give 512 different target identities.

Retro-reflective targets. Brown, (1984) discussed the use of retro-reflective targets in film based photogrammetric applications. The use of such targets has become widespread because of the advantageous characteristics of the high return of light in the direction of illumination.

Light emitting diode (LED) targets. Bayer, (1988) described the use of LED's and Position Sensitive Detectors to monitor the trajectory of a robot. Leder, (1990) described the use of LED's to monitor respiration by fixing them to the chest of a patient.

Laser light projected targets. Lasers have been used to signalise surfaces in: optical triangulation systems (Clarke, et al., 1990); light stripe systems (Heckel, 1992); and theodolite systems (Teskey, 1993). However, they have only recently being used in digital photogrammetric measurement due to the integration of the drive electronics with the diode laser and collimator in a small package at an affordable price (Clarke & Katsimbris, 1994). Yamashita, (1988) described the use of a double layer of optical fibres arranged so that each layer was perpendicular to both the laser light source and each other. This system was able to produce a regular grid of light spots which were used in an endoscope. Peach, (1994) reported on the use of a high power laser that was scanned by high speed galvanometer mirrors onto a red hot bearing to measure tolerances. The adjustment of the power of the laser as it scanned resulted in the production of up to five hundred spots in as little as 10 ms.

White light projected targets. An object may be signalised by the projection of white light. Baj, (1988) developed a "metric projector" with a precision of projection similar to the precision of imaging of a metric camera. Further experiences were described in Baj, (1990) where the use of the projector allowed a single camera to be used to obtain measurement. Claus, (1988) described the projection of random texture onto the surface of car parts such as a car bonnet and the use of correlation for 3-D object reconstruction. Mitchell, (1994) used a modified slide projector to cast a regular grid onto the back of a patient. Stahs, (1990) discussed the projection of **n** striped patterns onto the surface of an object to determine the 3-D shape of an object with the addition of a single camera. Maas, (1992) described the use of projected regular dot patterns of high density (approx. 10,000) to measure a bust of Beethoven. Vuylsteke, (1990) described the use of binary encoded light patterns to perform three dimensional measurement using a commercial projector and a single CCD camera. As LCD projectors achieve better contrast these are also likely be used to provide real-time changes in the projected patterns in synchronisation with frame grabber acquisition.

Fibre optic targets. Amdal, (1990) made use of fibre optic targets to produce a test field for camera calibration. In this case the test field was constructed of two target planes which could be switched independently.

Colour targets. The use of a colour camera and unique identification of targets by their spectral characteristics has seldom been used but would appear to offer some advantages albeit at the disadvantage of a loss of spatial resolution. However, a significant problem that would need to be addressed is the fact that the colour recorded by a sensor is dependent on the strength and spectral nature of the illumination.

2.3 Summary.

A large variety of targets have been used for 3-D measurement. For many applications the retro-reflective target offers the best overall performance of the manually applied types and is further investigated in section 3.0. Of the projected targets, the use of white light is popular due to its wide availability and ease of use. However, white light projectors cannot easily be used as a replacement for retro-reflective targets as it is difficult to achieve the same signal to noise ratio. Laser targeting is a possibility and so is investigated in section 4.0.

3. RETRO-REFLECTIVE TARGETS

3.1 Retro-reflective target characteristics.

Retro-reflective targets are constructed from sheets of film manufactured by 3M called Scotchlite. The film consists on one side of a sticky backed adhesive sheet the opposite side of which is a single layer of small spherical balls of approximately 50µm diameter (Figure 4). Each ball acts like a cats-eye or a retro-reflecting prism in that the predominant direction of the returned light is along the direction of incidence (Figure 5). To obtain such a characteristic the refractive index of the balls must be approximately 1.9. Because of imperfections in the shape of the balls and variations in the angle of deviation for differing wavelengths the returned light will not be perfectly parallel with the incident light but will emerge at varying angles (Figure 6).

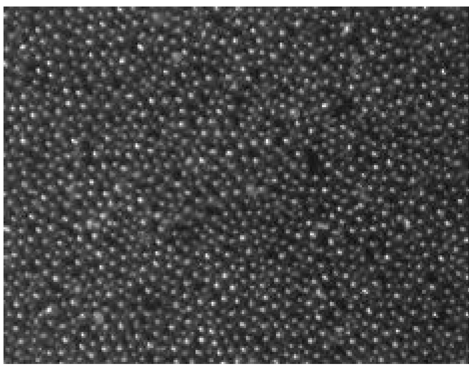


Figure 4. A close up view of retro-reflective target film.

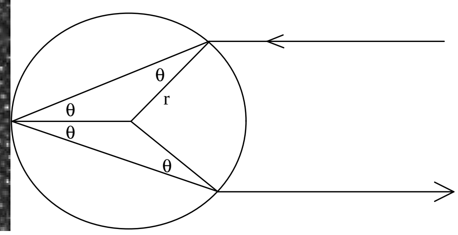


Figure 5. Mode of operation.

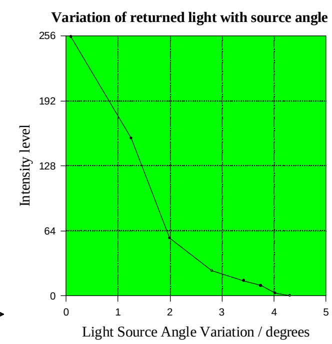


Figure 6. Dependence on incident light angle with respect to sensor.

This graph illustrates that to optimise the returned light to the camera the light source should be positioned within a cone of about one degree from the camera, a more precise graph than the one collected in the laboratory is given in Appendix 1. Determining the form of lighting to be used is of importance in ensuring that each of the targets in the image will have an equal opportunity of returning its fair share of light to the camera. The geometry of the balls will also affect the quantity of returned light. As the angle of incidence is increased from perpendicular to the target surface the return path will increasingly blocked by adjacent balls. This situation is illustrated for light rays which impinge at varying angles on two balls in Figure 7. In three dimensions the situation is slightly more complex and light will be returned at angles of incidence higher than shown in Figure 7. This is confirmed by experiment by measuring the returned light for differing incident angles (Figure 8) where a significant return of light beyond sixty degrees was measured.

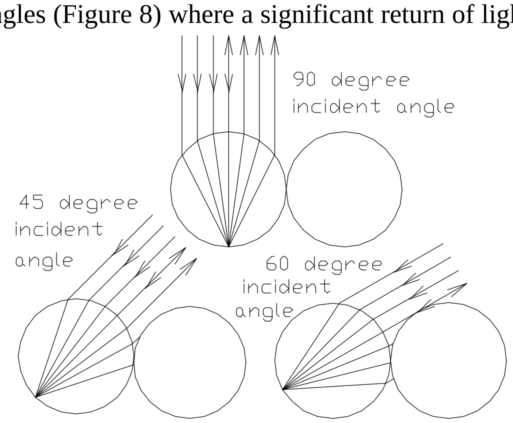


Figure 7. Return rays for two balls.

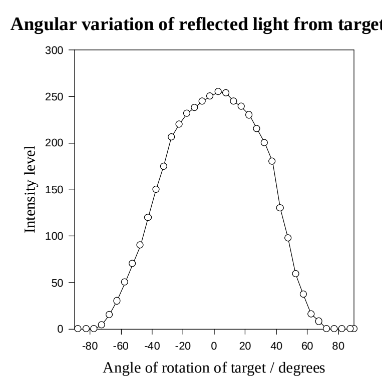
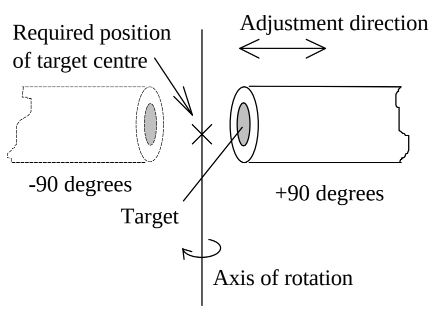


Figure 8. Reflected intensity at differing angles.

This intensity profile reveals that for a target with an angle of incidence of about forty five degrees the returned light will be about half of that obtained for targets with an angle of incidence of about twenty degrees. The realistic range for good subpixel target location is thus between approximately plus and minus fifty degrees. It is noted that if the illumination level is adjusted then the lower intensity targets can be measured more precisely at the expense of saturating other targets. Furthermore, the mechanism can also be used to segment targets into groups at various angles to the camera provided: the targets are of identical size; they occupy a relatively small depth with respect to the camera; and the illumination is constant. When there is redundancy of viewpoints and high precision is required this may be of value, but an analysis of the point at which the error of location due to quantization and the target size becomes larger than the errors due to other sources is required.

3.2 Experiments to investigate the properties of retro-reflective targets.

Retro-reflective targets will generally present a wide range of angular orientations to the camera viewing them. It is often assumed that when targets are viewed from an angle there is no bias in the computation of the target location. As part of a programme of fundamental investigations into 3-D measurement techniques this assumption has been tested and is reported here. The testing apparatus consisted of a stepper motor controlled rotation stage and a means of adjusting the retro-reflective target in two perpendicular directions so that the target could be located precisely on the axis of rotation. Initially the target was adjusted by monitoring the position of the edges using a travelling microscope to measure the location of the centre. Unfortunately this method proved too time consuming and not accurate enough so another method was devised. A camera was positioned at 40mm. from the target and a number of extension tubes used to focus on the target. Under these conditions the target occupied most of the image format and so the position of the two sides of the target could be monitored with respect to pixel co-ordinates. The first step in the set up procedure was to ensure that the target was positioned with the plane of the target in line with the axis of rotation. This was achieved by rotation through plus and minus ninety degrees and adjustment of the target so that the front surface remained in the same place with respect to the camera (Figure 9). The second step was to ensure that as the target rotates from being perpendicular to the camera it does not move from side to side under rotation. This was adjusted by monitoring the right and left hand side of the target image under rotation (Figure 10).



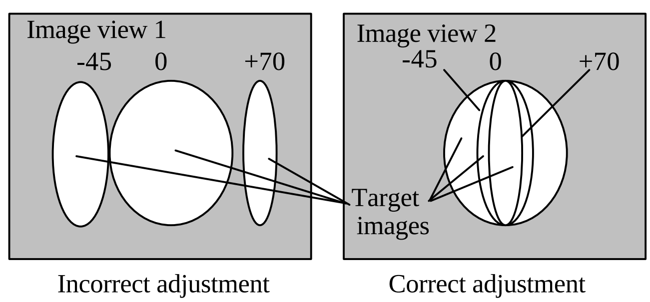


Figure 9. Setting up one axis of the test apparatus. Figure 10. Setting up the other axis of the test apparatus.

It was found that the maximum error in location was 3 pixels with a 3.5 mm. diameter target occupying 200 pixels in the image (Figure 11). This equates to an error of about 50 microns which was considered sufficiently precise not to cause an error in target location at the distances that the experiments were going to be carried out at (2-3 metres). Because of known warm up effects and line-jitter of CCD cameras (Robson, et al., 1993) the camera was arranged so that the change in location of the target centroid would be in the **y** direction. A program was written to repeatedly compute the centroid of any target within the camera's field of view. The camera was set up at about two metres from the target and a static test conducted by computing the centroid more than two thousand times. Figure 12 is a plot of target position relative to the selected window against computation number. The standard deviation was found to be 0.007 for the **y** direction and 0.017 for the **x** direction. This value in the **y** direction is close the theoretical limit for a eight bit quantized target image (Figure 1) and hence could be used as a reference for subsequent experiments. The initial tests to check the position of the target location under rotation indicated a large shift in the target image co-ordinates (Figure 13)

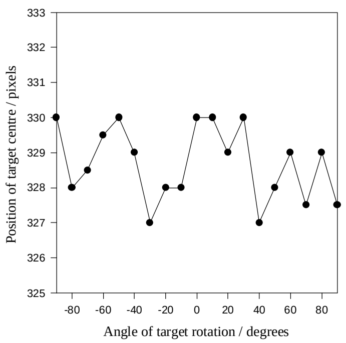


Figure 11. Variation in the target location under rotation.

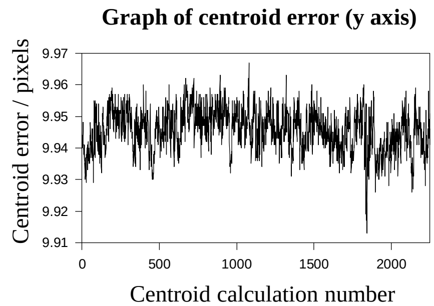


Figure 12. Graph of static variations in the computed y co-ordinate using the centroid method.

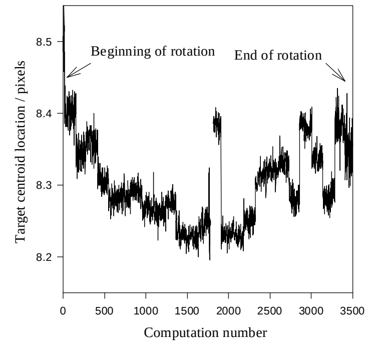


Figure 13. Initial test of target location under rotation.

The target varied in location by as much as 0.1 of a pixel, much larger than would be expected unless a systematic effect was being caused by the retro-reflective target. As this was considered unlikely further experiments were devised to improve the reliability of the target location process. One of the problems that could have contributed to the target location error was the variation of the target intensity when rotated. Hence, the location precision would not be expected to be the same when the intensity of the targets was reduced. The Pulnix TM6CN cameras have a shutter control which varies the exposure time from the normal 1/60 of a second to 1/10000 of a second. Control of the exposure time was effected by use of a parallel interface card described by Clarke, et al., (1994). The static test was repeated with the exposure time adjusted to three levels (Figure 14). In this test an unexpected change in target location was measured at each change in exposure level. As a result of a number of observations reported by Clarke, (1994) further experiments were conducted to trace the cause of this apparently systematic effect. A program was written to test the location of the centroid of a straight line used in lens calibration. A feature of the program was the real time computation and display of the residuals of a least squares best fit of straight line through the centroid co-ordinates. The residuals plotted against pixel position are illustrated in Figure 15. This effect was considered to originate from the same fundamental source as that highlighted by the exposure time control changes caused by a thresholding happening within the frame grabber. This was confirmed by Clarke, (1994).

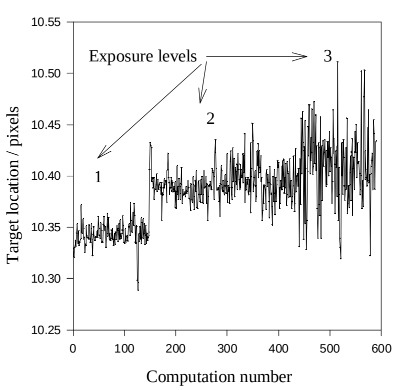


Figure 14. The effect of varying the exposure time.

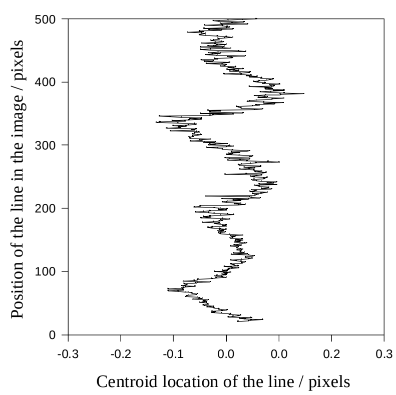


Figure 15. The residual from a least squares straight line fit plotted against pixel position.

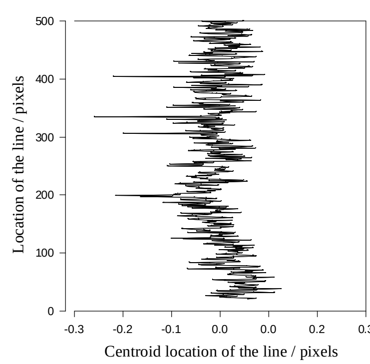


Figure 16. The residual from line fitting after careful adjustment of the frame grabber.

The frame grabber was adjusted to minimise the sinusoidal oscillations using the straight line and dynamic analysis programme and the static test conducted again with three exposure levels, the results are illustrated in Figure 17.

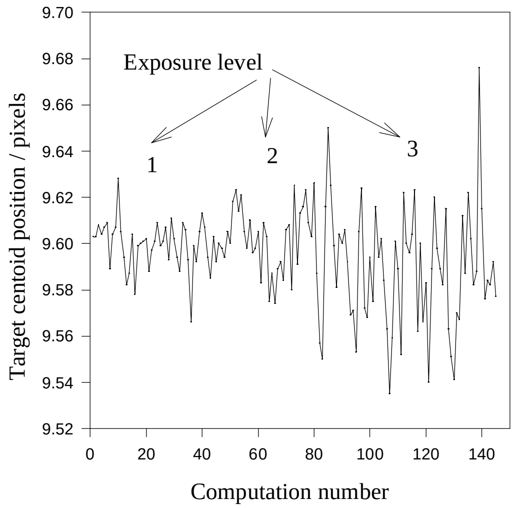


Figure 17. The stationary target location error with three changes of exposure level with correct frame grabber adjustment.

By analysis of Figure 17 it can be seen that the exposure time variation does not result in a target location change and the location error is improved to the levels obtained from static target location tests with a single exposure level. The standard deviation of this test was 0.02 of a pixel in the **y** direction which is comparable to the static test if the addition of noise due to the lower intensity of the shorter exposure times is taken into account. Hence, the systematic effect caused by the incorrect frame grabber adjustment was removed and the tests on the retro-reflective target were then possible. A series of tests were conducted whereby the centroid of the target was monitored as the target was rotated through its realistic operating range of plus or minus sixty five degrees. The location of the target was estimated to vary in position by approximately fifty microns which, using the standard deviation of target location as assessed by previous tests, would equate to eight microns in the image at 2.5 metres so tests at various distances were conducted. The results of these tests at one, two, and four metres are illustrated in figures 18, 19 & 20 respectively.

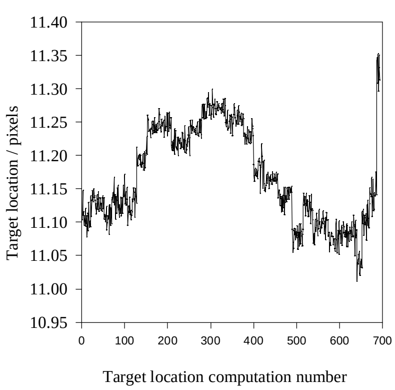


Figure 18. Rotation tests at 1.0 metres.

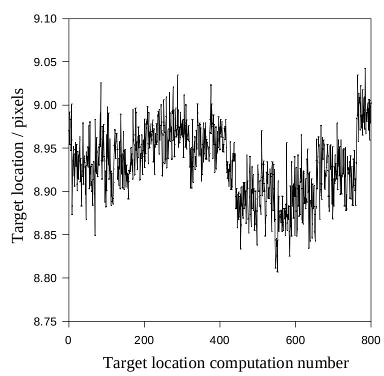


Figure 19. Rotation tests at 2.0 metres.

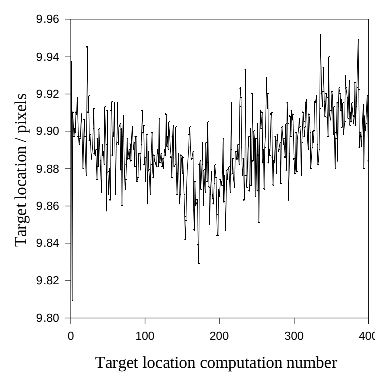


Figure 20. Rotation tests at 4.0 metres.

By observation of these graphs there appears to be a systematic effect that is reduced with distance. This is entirely consistent with the sensor picking up the residual eccentricity of the target. Such eccentricity would be amplified at closer distances. It may therefore be concluded that there is no significant systematic change in the position of the centroid of a target image under rotation. While this result may have been anticipated the errors that were identified in the measuring system were not which shows the benefits of fundamental analysis of each component within photogrammetric measuring systems. A further point is the high level of angular sensitivity available with CCD cameras and retro-reflective targets.

3.3 Conclusions.

Retro-reflective targets provide excellent means of signalising an object. The characteristics of the targeting film provide a signal significantly greater than the background illumination or the reflected target illumination. However, to achieve the highest returned light the light source should radiate from within a cone of 0.5 degrees from the camera axis, furthermore, the targets should present an angle of less than forty five degrees to the camera to obtain sufficient light return for consistent high precision target location. The results of the tests carried out for this paper confirm that the computed location of the target does not vary under rotation. However, as with all methods that aim to extract performance near the limit of what is physically possible, care must be taken to understand all of the effects that can contribute to errors.

4. LASER TARGETS

Laser targets have numerous useful advantages over projected white light targets they: are highly intense; have a Gaussian intensity distribution; have minor depth of field problems; and have stable power and pointing characteristics. However, it is only recently that small, self-contained, low power, diode laser collimators have become available at a reasonable price. An example of a typical laser diode collimator is given in Figure 21.

Figure 21(a). A typical laser diode collimator LDA 1000 from ILEE.

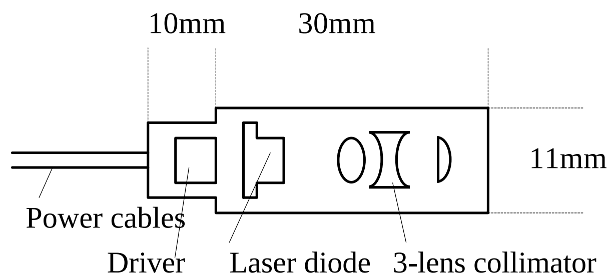


Figure 21(b) Dimensions of the laser diode collimator.

4.1 The characteristics of lasers.

Lasers have many characteristics, some of the important ones for use as targets are: **(i) Narrow spectral bandwidth.** Because of the mechanism of laser production, laser light has an extremely narrow spectral bandwidth which allows the use of filters on cameras to cut out extraneous light. **(ii) Gaussian intensity distribution.** The laser beam has a Gaussian intensity distribution which remains even as the beam is propagated in space. The intensity distribution is useful in the context of targeting surfaces as it avoids the flat top problems often encountered with retro-reflective targets or natural reflective targets which are above a certain size. **(iii) Directionality.** The output power of a laser beam suitable for targeting is far less than that of a domestic light bulb, however, with the laser all of the light is concentrated within a small, almost diffraction limited, diverging beam. This ensures that a laser spot is generally visible above the background illumination in most indoor environments. For a particular laser the laser beam size was measured (Figure 22(a) & 22(b)) for two mutually perpendicular directions across the beam at differing distances.

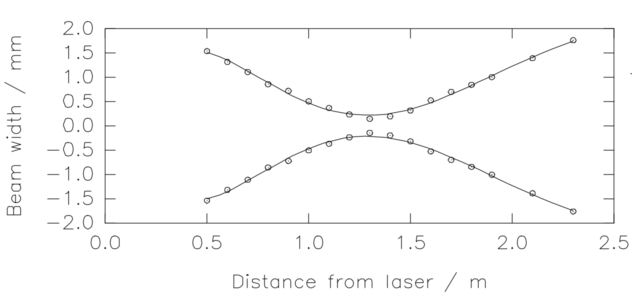


Figure 22(a). Laser beam 1/e² dimensions measured at discrete points, x axis.

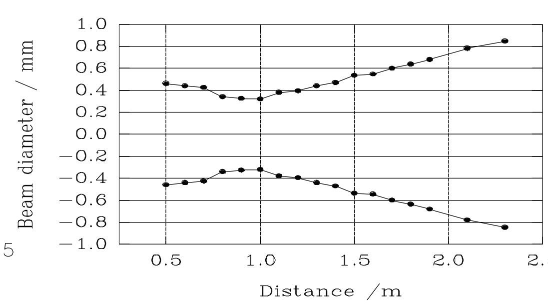


Figure 22(b). Laser beam 1/e² dimensions measured at discrete points, y axis.

By inspection of these graphs it can be seen that the output power of the laser can be concentrated in a spot size of approximately 1mm² for a distance of about a half a metre. **(iv) Pointing instability.** Due to thermal expansion within the diode laser can and within the collimator many lasers will exhibit a pointing instability. However, the change in output angle is relatively small, typically 0.1mrad/°C but 0.005 mrad/°C, and occurs mostly during initial warm-up. **(v) Speckle.** The major limitation to the use of lasers for targeting object is due to speckle caused by the coherent nature of laser light. A more detailed description of the fundamentals of diode laser collimators can be found in Clarke & Katsimbris, (1994).

4.2. The properties of laser targets.

At a distance of two to three metres with a diffraction limited spot size a laser target produced by a laser diode collimator of modest power output (2.0mW) will require a minimum lens aperture size and a short exposure time to reduce the peak intensity to an acceptable level. This characteristic is highly desirable as it can remove the background illumination from the image. Under these circumstances the problems caused by background illumination are eliminated and target recognition and location are optimised. However, the disadvantage is that the power output is marginally higher than the recommended safe levels for accidental intra-ocular viewing.

The problem of speckle has been noted by Clarke & Katsimbris, (1994) and Dorsch et al., (1994). The visual effect can be minimised by arranging the speckle size to either be small in comparison with the sensor pixels size, or by not allowing speckle to be formed. The first condition is arranged by a large aperture size which unfortunately means an unacceptably narrow depth of field, and the second condition by using a small aperture. However, Clarke & Katsimbris, (1994) have shown that even with an extremely small aperture this method will still cause significant errors in target location. These errors are introduced because the computation of the centre of the laser target spot will change when viewed from different directions (Figure 23). Given that the main problem with laser targets is the coherence of the light generated by the laser diode it is sensible to look for alternative light sources or laser diodes with less coherence. Unfortunately it is not easy to replicate the characteristics of high intensity and small beam sizes of lasers with incoherent sources. The main problem encountered with low coherence sources, such as light emitting diodes, is their relatively large emitting area compared to the size of a laser diode where the emitting area may be just a few microns making collimation of a small beam efficient. A possible solution, which may improve the usefulness of laser targets, is the use of lower coherence laser diodes. For example laser diodes vary in coherence length from several metres for laser designed for interferometric uses to about one millimetre for lasers designed for compact disk players. The former laser would normally have a single frequency mode while the latter would have many modes. Hence, it would be expected that the effect of speckle in reducing the accuracy of target location would be reduced by a multi-mode, low coherence length laser.

Tests were conduced to evaluate the lasers with various characteristics to see whether the expected improvement could be achieved in practise. Each of the lasers was mounted with the projected beam approximately parallel with the optical axis of a CCD camera. A plane paper surface was mounted at about two metres from the laser which could be moved in a direction perpendicular to the laser beam under the control of a stepper motor. The maximum error of location of the target was noted for each of the lasers in the **y** direction to avoid warm up effects (Table 1). For consistency the camera focal length and aperture were left untouched throughout the experiment and the electronic shutter used to obtain approximately the same peak intensity in each case.

Light source	**Type**	**Power output/mW**	**Max error/pixels**
LDA 1011 (670nm)	Single-mode	2.1	0.604
LDA 1000 (670 nm)	Multi-mode	0.97	0.497
He Ne (633 nm)	Gas	5.4	1.292
Toshiba 9200 (670 nm)	Multi-mode	1.6 (3.52)	0.625
" "	"	0.8 (1.76)	0.484
" "	"	0.2 (0.44)	0.183 (σ = 0.029)
Sharp 020MD (780 nm)	Single-mode	2.3 (4.05)	0.389
" "		1.0 (1.76)	0.867
" "		0.5 (1.05)	0.526

VLM (670 nm)	Unknown	2.03	0.772
White light	NA	NA	0.199 (σ = 0.028)

Table 1. The standard deviation of the laser target location for the lasers tested.
(x.xx)= internal power without collimator

It may be concluded from these experiments that the coherence of the lasers has a highly significant effect in degrading the location of the laser target. Only the Toshiba laser diode operated near to the lasing threshold produced a result that was comparable with that of a white light target. The error of location of the LDA 1011 laser target is plotted in Figure 23 for both the **x** and **y** directions. The arrow indicates the reported position for the first fifty percent of the measurements obtained with a static background after which the background was moved and the random wander can be clearly observed.

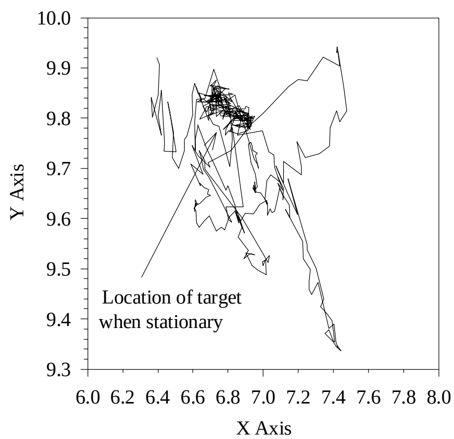


Figure 23. Graph of LDA1011 location errors.

Further tests were conducted to see whether the roughness of the surface would make any difference to the location accuracy. The materials were: two types of sponge material; planed wood; paper; and shiny black plastic. The LDA 1000 laser was used and the camera focus and aperture kept constant. The results were maximum errors of 0.42, 0.521, 0.365, 0.479, and 0.79 of a pixel respectively. No firm conclusions could be reached from these experiments and further investigations are planned.

4.3. Conclusions.

Laser targets provide comparable characteristics to retro-reflective targets in terms of signal to noise ratio. In the case of the laser target a high intensity beam impinges on the surface being measured with a inverse square law of returned light to the sensor. With retro-reflective targets a light source produces light which diminishes according to the inverse square law while the returned beam is a thin pencil of high intensity light which returns directly to the camera. An area where laser targets do have different characteristics is in the shape of the laser beam as it impinges on an oblique surface. If the spot is viewed from the a similar angle to the direction of propagation there may be no difference in observed target shape but the area of measurement will not be the same as for a retro-reflective target.

5. CONCLUSIONS.

In this paper a number of topics related to targets used in close range photogrammetry have been discussed. A survey of the various types of targets available has been performed in section 2. The properties of two targets have been chosen for analysis: retro-reflective targets in section 3, and laser targets in section 4. The performance of both types of target have been analysed and factors that influence the precision of target location such as frame grabber set up and speckle have also been discussed. The prime advantage of retro-reflective and laser targets over naturally reflecting targets is the high contrast that can be obtained. This contrast can be made great enough to cause the illumination of the background to be too small to be recorded by the sensor. Under these circumstances the variations in background intensity that can be a problem in affecting the precision of target location are removed. The major disadvantage of retro-reflective targets is that they have to be placed on the subject in convenient places to describe the object being measured. Often this process will be time consuming or the coverage may prove inadequate. The major disadvantages of laser targets are the cost and speckle. Whether low cost lasers can be produced with low enough coherence sufficient to be acceptable as targets has yet to be proven. In many situations the use of other targeting methods such as LED's or high quality white light projectors may prove just as acceptable. Further work is required in this area before many desirable tasks such as real-time measurement for automated inspection or dynamic monitoring can be achieved.

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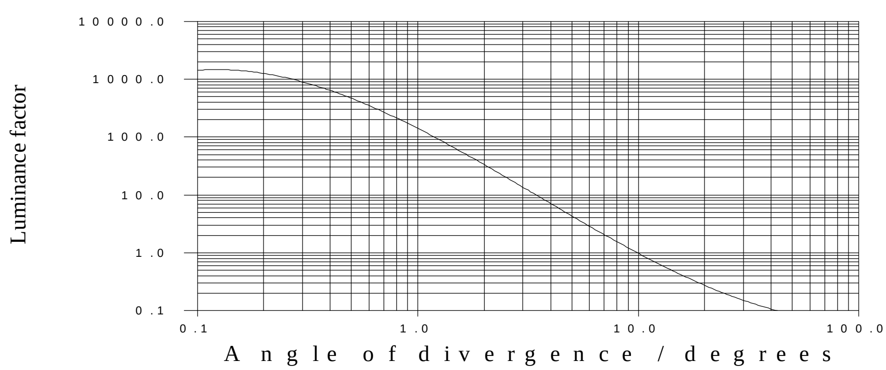
7. APPENDIX 1.



Luminance factor of 7610-retro-reflective film as a function of the angle of divergence (Brown, 1984).

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