A frame-grabber related error in subpixel target location.

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Abstract

The accuracy of subpixel target image location is an important factor that contributes to the overall precision of three dimensional measurement when using CCD cameras. This shorter contribution reports the effect of an electrical adjustment of a frame-grabber that results in a significant and systematic error in the accuracy of target image location using some target location methods.

Introduction

The attainment of subpixel accuracy is of great importance in extracting the highest performance from systems using CCD cameras. However, while the theoretical accuracy obtainable from a subpixel algorithm such as the centroid method is very good (Clarke et al., 1993), this is of little consequence if it is swamped by other errors such as those caused by electronic noise, or line-jitter. During the course of research conducted into an optical triangulation tunnel profiling system (Clarke, 1991), an effect was noted that appeared to indicate a correlation between the reported subpixel location of a laser target and a measurement error. More recently, research conducted into the use of straight lines for camera calibration highlighted an error in subpixel location that was also linked to the pixel locations. Finally, in research conducted into the characteristics of retro-reflective targets (Clarke, 1994), an unexpected error in the location of targets was noted. This shorter contribution reports the probable cause of these errors.

Experimental results with an unexplained subpixel error

Subpixel errors that are related to pixel locations have been noted by: Maalen-Johansen (1993); Ge (1993) (who considered the effect was caused by the physical gap between pixels); and Beyer (1993) (who postulated instabilities in the frame-grabber's phase-locked-loop). A similar effect may be noted in the results given in papers by: Dahler (1987); Beyer (1987); and Beyer (1989).

Errors in subpixel target location in an optical triangulation system

Investigations into the accuracy of an optical triangulation distance measuring system included tests to check the effect of very small movements of a object. The recorded subpixel locations of the laser target image were plotted against distance measured using a laser interferometer (Fig. 1). A clear change in the location of the centroid of the target that coincided with pixel locations was noted. This correlation was observed in only a few experiments and at that time was considered coincidental, or due to other effects such as laser pointing instability, so was not investigated further.

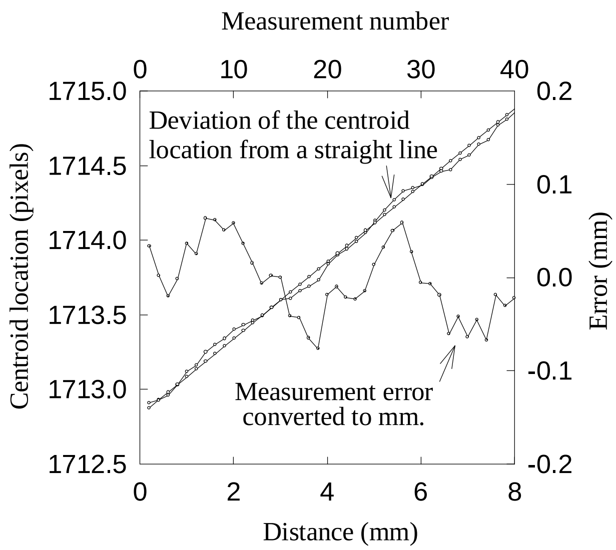

Fig. 1. Graph of calibration data versus best fit straight line.

Errors in the subpixel location of images of a straight line

The second time a correlation between camera pixel locations and target location errors was clearly seen was during camera calibration experiments using straight lines (Fryer et al., 1994). In this case the subpixel locations of the line appeared to sinusoidally oscillate (Fig. 2). By excluding all other possible causes of this oscillation such as: string vibration; string weave; lighting variations; or timing effects, no plausible explanation was immediately obvious as the effect appeared independent of the orientation of the camera with respect to the straight lines. The only clear correlation that was noticed was that the number of oscillations was always equal to the number of pixels that the line traversed from edge to edge of the image. A least squares algorithm was being used to calculate camera calibration parameters and a large number of observations were available so, although worrying, the errors were averaged in the least squares calibration procedure which produced reasonable results.

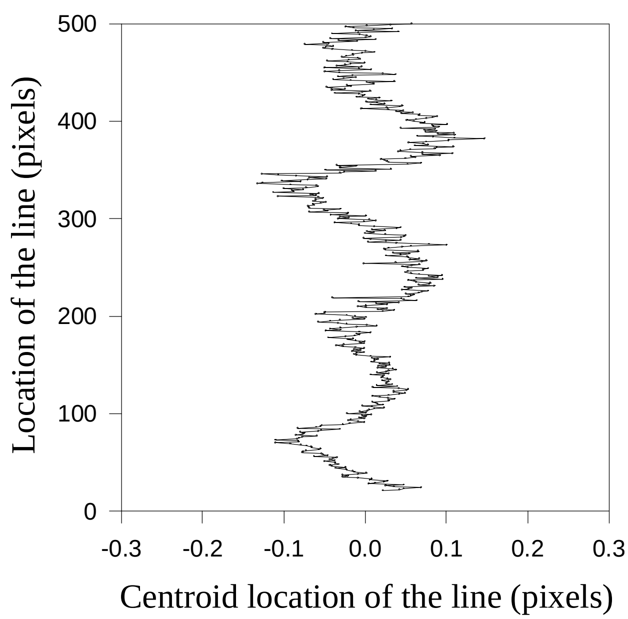

Fig. 2. Sinusoidal oscillations of the location of the line when using the centroid method

Errors in the location of retro-reflective targets

In a series of experiments to analyse the performance of retro-reflective targets, an investigation was conducted into the subpixel accuracy of target location. During the course of these experiments some larger than expected variations in the location of the targets were observed. These errors initially suggested that such targets would not give an unbiased location under rotation (Fig. 3).

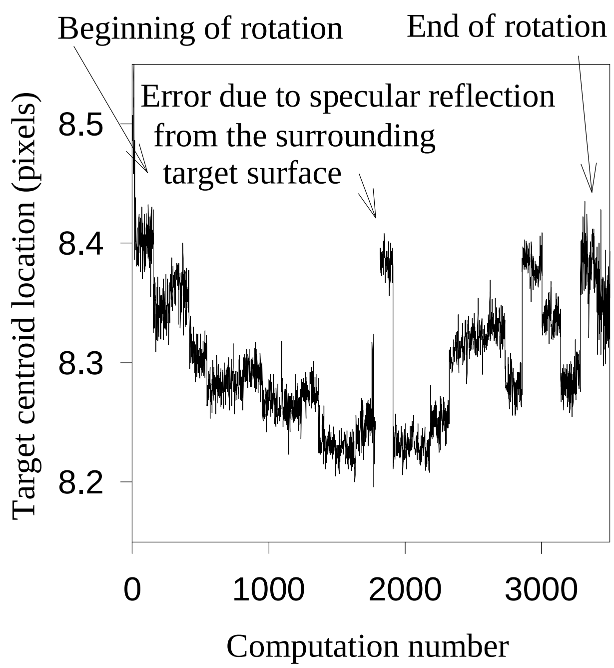

Fig. 3. Variations in the subpixel location of a rotating target

However, because a number of other influences were also present in these observations, it was necessary to isolate them from the experiments before any conclusion could be reached. One such effect was the change in the intensity of the target as the angle presented to the light source and camera was changed. To investigate this the camera and light source were left in a static position and the exposure time of the camera changed. Fig. 4 illustrates the results of these tests where an unexpected movement in the computed position of the target was observed.

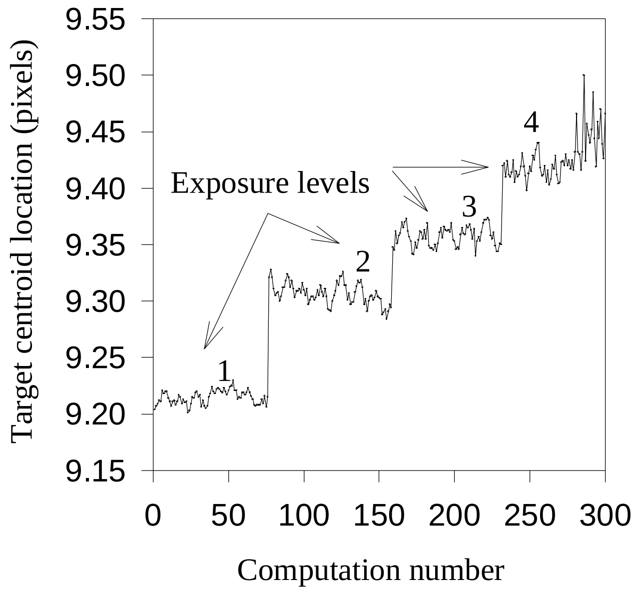

Fig. 4. Variations in the subpixel location of a static target due to exposure time changes

Postulation of the source of the subpixel errors

In all of these experiments there is evidence of a systematic effect which alters the result of a computation of the centroid of a target. Such an perturbation is highly undesirable in a photogrammetric measurement system. The source of this effect was established when a related problem was discussed in an article concerning laser power measurement errors using CCD cameras (Roundy et al., 1993). In this article the problem of an incorrect zero signal level was discussed in the context of an associated error in laser power or laser beam width measurement. This signal level is sampled during a period known as the “back porch” and is produced by a number of CCD sensor pixels that are shielded from incident light. The level of this signal is related to electronic noise which changes in quantity depending on the temperature of the sensor. This voltage output is used to adjust the level of the voltage supplied to the analogoue to digital converter. However, the relationship between this black-level-clamped signal and the analogue to digital converter is usually adjusted by a potentiometer on the frame-grabber. Hence, the level may be adjusted so that the zero light level signal is below the zero threshold of the analogoue to digital converter. A simulation of this effect confirmed that an artificial threshold in the frame grabber would result in an error in location. Once this was understood the characteristics presented in the three cases were logically explained. When the intensity values for a target or line are symmetric there will be no error in location but, as the target intensities become asymmetric the target location using the centroid method will oscillate from one side of the true location to the other. To test whether this effect was significant with realistic intensity images a simulation was performed for a line with a Gaussian shape intensity profile using a sigma of 1.5 The effect, with and without a subtraction of six grey levels from the true target values, is illustrated in Fig. 5, and Fig. 6 respectively.

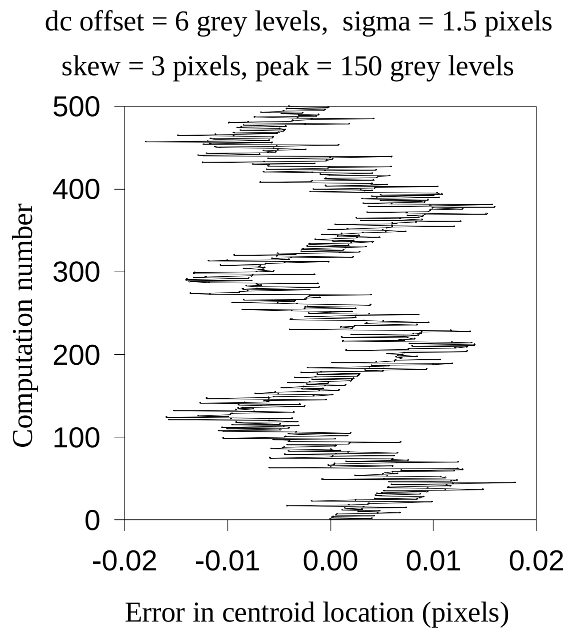

Fig. 5. A simulation of the effect of threshold on the location of a line with a subtraction of six grey levels

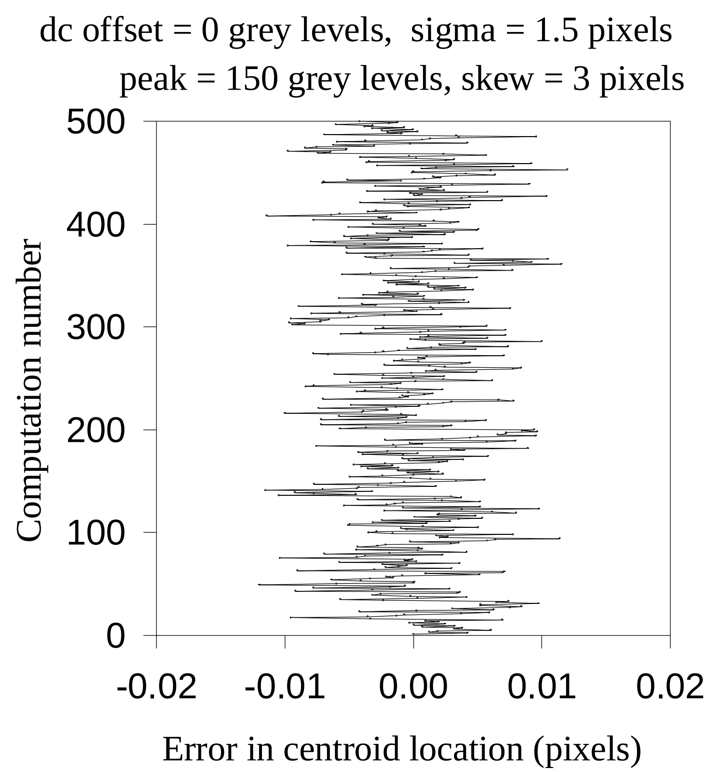

Fig. 6. A simulation of the location of a line without grey level subtraction

The problem with this type of error is that it is systematic. Further simulation experiments revealed a similar effect for circular targets. To experiment with this effect on practical images the frame grabber black-level-clamp level was adjusted and the residual of a least squares straight line plotted using the computed centroid of a line. As the clamping level was adjusted it was found that it was possible to remove the oscillating centroid error (Fig. 7).

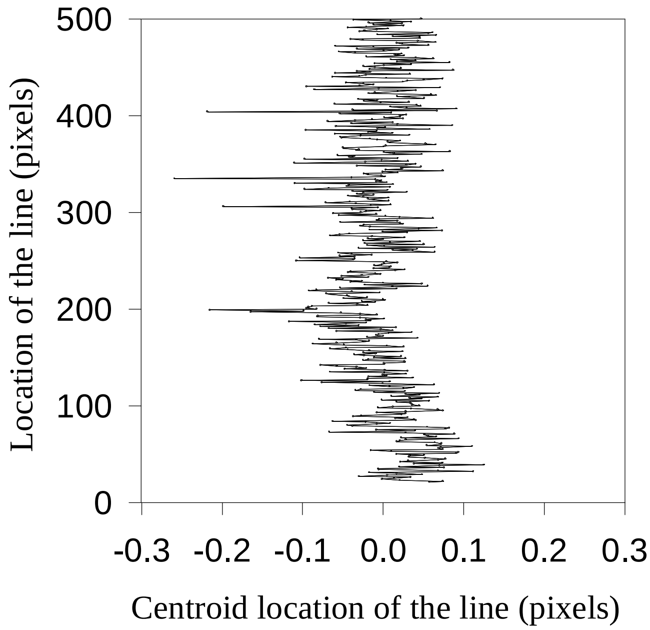

Fig. 7. Elimination of sinusoidal oscillations with correct frame grabber set up.

The outliers on the left hand side of Fig. 6 are the result of an intensity of value one appearing to one side of the centroid computation window. The slight deviation from a straight line is probably caused by tangential lens distortion (the camera was set up to minimize radial lens distortion). Tests were also carried out using this frame-grabber setting to measure the centroid location of the retro-reflective targets. The results of one of these tests is illustrated in Fig. 8.

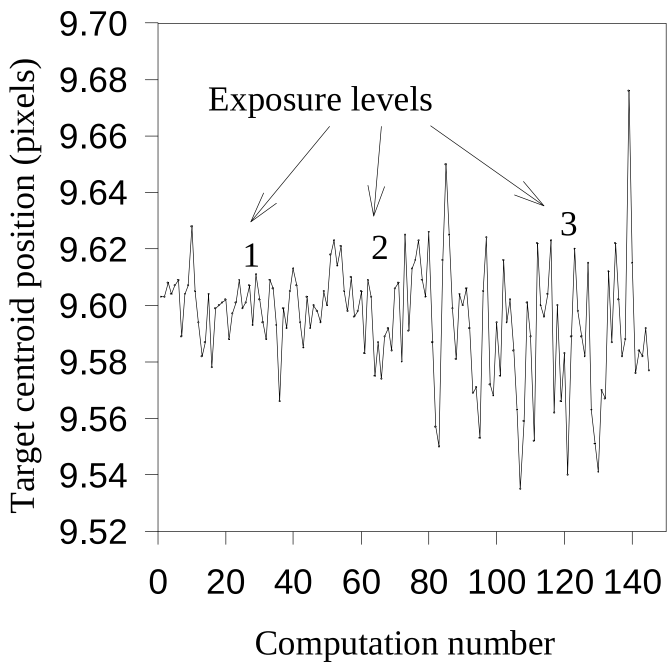

Fig. 8. The stationary target location error with three changes in exposure level

Tests carried out using this set up for three-dimensional measurement have given improved results (Clarke et al., 1994). Further simulation tests have revealed that the squared intensity centroid method is less affected by the DC offset than the centroid method. Whether least squares patch matching methods are affected has yet to be established. It is not clear that subpixel errors associated with pixel positions which are evident in the work of other authors cited earlier have the same source as those in this paper, as similar effects can also be produced by other means. However, there appears to be no doubt that, in the case of this frame grabber and camera combination, the postulated cause is valid.

Conclusion

The problem of an incorrect level of the black-level-clamped signal being applied to the A-D converter would not usually be noticed in the apparent quality of the images. Many frame-grabbers may be set up correctly, but it appears that the adjustment of the frame-grabber needs to be analysed carefully for high precision photogrammetric measurement. A general solution to this problem may be to use a method suggested by Lenz (1994). In this case the output of a twelve bit A-D converter at the point of optical blanking (at the end of each line) is compared to a desired digital output of value eight and the input offset adjusted accordingly. Hence, a stable translation of light intensity to A-D converter output code is achieved. Such a method would appear to be well suited to solve the problem of an incorrect reference level. In this situation, and in the case of the laser power level measurement, the objective is good radiometric measurement as opposed to the objective of good geometric measurement in photogrammetric applications. In this paper the connection between the two, at least for the centroid method, has been established.

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References

Beyer, H.A., 1987. Some aspects of the geometric calibration of CCD cameras. Proceedings of ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland. 437 pages: 68-81.

Beyer, H.A., 1993. Determination of radiometric and geometric characteristics of frame grabbers. Videometrics II SPIE Vol. 2067: 93-103.

Beyer, H.A., 1989. Calibration of CCD cameras for machine vision and robotics. Automated inspection and high speed vision architectures III. SPIE Vol. 1197: 88-98.

Clarke, T.A., 1991. Application of optical techniques to surveying. PhD Thesis. City University. 310 pages.

Clarke, T.A., Cooper, M.A.R. and Fryer, J.G., 1993. An estimator for the random error in subpixel target location and its use in the bundle adjustment. Optical three-dimensional Measurement Techniques II. Wichmann, Karlsruhe. 624 pages: 161-168

Clarke, T.A., Cooper, M.A.R., Chen, J. & Robson. S., 1994. Automated three-dimensional measurement using multiple CCD camera views. Photogrammetric Record. In press.

Clarke, T.A., 1994. An analysis of the properties of targets used in digital close range photogrammetric measurement. SPIE Vol. 2350. In press.

Dahler, J., 1987. Problems in digital image acquisition with CCD cameras, Proceedings of ISPRS Intercommission Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland, 437 pages: 48-59.

Fryer, J.G., Clarke, T.A. & Chen, J., 1994. Lens distortion for simple C mount lenses. International Archives of Photogrammetry and Remote Sensing. XXX(5):97-111.

Ge, R., 1993. Linejitter detection of CCD cameras. Optical three-dimensional Measurement Techniques II. Wichmann, Karlsruhe. 624 pages: 239-246.

Lenz, R., Beuthauser, R. and Lenz, U. 1994., A microscan/macro scan 3x12 bit digital colour CCD camera with programmable resolution up to 20,992x20,480 picture elements. International Archives of Photogrammetry and Remote Sensing. XXX. (5): 225-230.

Maalen-Johansen, I. 1993. On the precision of subpixel measurements in videometry. Optical three-dimensional Measurement Techniques II. Wichmann, Karlsruhe. 624 pages:169-178.

Roundy, C.B., Slobodzian, G.E. and Dan, K.J., 1993. Digital signal processing of CCD camera signals for laser beam diagnostic applications. Electro Optics, 23(109):11.

PAPER REFERENCE

Clarke, T.A. 1995., A frame-grabber related error in subpixel target location. Photogrammetric Record. Vol XV. No 86. pp. 315-322.