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Shorter Contributions

BUILDING A DIGITAL CLOSE RANGE THREE DIMENSIONAL MEASURING SYSTEM FOR LESS THAN £5000

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Abstract

The use of CCD cameras for digital photogrammetry has only slowly been taken up by the photogrammetric community. However, the pace of change is quickening with better understanding and cheaper equipment. Recently a decision was made to start some research into close range three dimensional digital measurement. The overall objective was to develop a low cost system for the automated measurement of small industrial objects. This shorter contribution describes the initial stages of this work.

INTRODUCTION

A THREE DIMENSIONAL measuring system has been constructed by purchasing several CCD cameras with a frame grabber and by writing software to (i) grab an image; (ii) recognise, locate and label targets; (iii) match targets; and (iv) perform a bundle adjustment to produce three dimensional co-ordinates. The objective was to build an automated three dimensional measuring system. There is seldom enough money available to buy equipment without regard for price and performance considerations. This short, topical, contribution analyses some of the decisions that were made in order to construct a measuring system with the following specification:

(i) a measurement space of approximately $0{\cdot}5 \times 0{\cdot}5 \times 0{\cdot}5$m;
(ii) more than two CCD cameras;
(iii) controlled illumination of the work area;
(iv) flexible camera positioning;
(v) targeted subjects; and
(vi) a budget of less than £5000.

In order to keep within the budget, it was necessary to improvise. This is a common occurrence and should not prevent lessons from being learnt from our experience. The subjects considered in this paper are the construction of a measuring frame, lighting, cameras, frame-store, system control and computing system.

CAMERAS

The desired camera qualities were the highest resolution consistent with geometric stability at a price whereby three cameras were affordable. A further requirement was a signal output to ensure a pixel clocked analogue to digital (A–D) conversion, as opposed to using the common, but inaccurate, phase locked loop (PLL) timing method. The importance of a pixel clock is assessed in Beyer (1992), but its use ensures that theoretical resolution is increased by a factor of ten or more. PLL line jitter is quoted by Analogic (1991) as 1/4 pixel to 1/8 pixel, whereas the potential subpixel accuracy of target location with pixel clocking is 1/20 pixel and 1/100 pixel (Beyer, 1992). Early tests using a plumb line have shown errors of between 1/5 pixel and 1/10 pixel without the pixel clock. Three Pulnix TM6CN cameras (Pulnix, 1991) were selected at a total cost of £1344·79; this price included a single cable and power supply. These cameras offer the following features: good stability, high sensitivity, small size (45mm wide × 39mm high × 60mm long), 752 × 582 pixel format, CCIR standard video, pixel clock and variable electronic shutter speed (1/60s to 1/10 000s). The authors were fortunate to possess three identical Fujinon (25mm, f/1·8, C-mount) lenses and therefore did not need to purchase these. Some old optical mount rods and retort stand clamps were used to position the cameras with respect to the frame. A thorough analysis of the characteristics of each camera and their interaction with the frame-store is currently being performed.

FRAME-STORE

The choice of frame store required the greatest amount of investigation, but in the end was self-selecting because of the criteria of (i) multiplexed inputs; (ii) pixel clock; and (iii) enough memory to hold all frames without processing (> 1Mb). It is possible to buy many frame-stores for less than £1000, but few of these have multiplexed inputs and none were encountered that allowed pixel clock inputs. Most had enough memory for one or two images. Of the remaining frame-stores, only those which allowed a flexible set up were suitable for use with a pixel clock input. Many of these frame-stores have impressive, highly advertised features, such as graphic processors or transputers. When analysed, these functions were not appropriate to image measurement and in many cases could not be directly assessed by the programmer as they were used only for board specific data handling processes. A simple frame grabber made by EPIX, the SVMGRB4MB (EPIX, 1991) was selected that had six inputs, a single pixel clock input, 4Mb of memory and a flexible architecture. This frame-store has been successfully used by a colleague and by NASA, is made in the USA and is marketed world-wide. Some boards that offered many features were not yet in production and were likely to be produced in relatively low numbers. These were rejected because reliability and manufacturer support were considered important. The cost of the frame-store, including a cable, was £2367·63. Our experience with this frame-store has been mixed. The documentation to allow hardware programming of the board was found to be very poor and caused time wastage in understanding the basic operations, such as programming the look up tables and the hardware cursor. However, the software libraries are certainly adequate for the user not to need to program the board directly. The price of libraries ($995) was not within the budget, so this should be taken into account when considering this board.

COMPUTER

Processing images and performing bundle adjustments with reasonable speed requires a lot of processing power. A 80486 based processor was identified as being the minimum that would be sufficient. It was not possible to afford a complete PC, so a 33MHz motherboard with 4Mb of memory was purchased and installed in the casing of an old 80286 PC. The hard disk was also targeted as a possible bottleneck; a cached controller card and 110Mb hard disk were installed which gave a × 2 saving in compilation time compared with a system without the cache controller because of the intense disk activity required using a 'C' compiler. The cost of this upgrade was £952.

The connexions made between cameras, frame-store and computer are shown in Fig. 1.

CAMERA SUPPORT FRAME

A selection of 25mm square cross-section tube called "speedframe" was left over from another job. This was used to construct a frame on which the cameras were mounted and which supported a controlled lighting arrangement. The layout is shown in Fig. 2.

The design of the frame allowed three cameras to form an equilateral triangle perpendicular to the usual Z axis (vertical) for the object. Ultimately, the frame will be

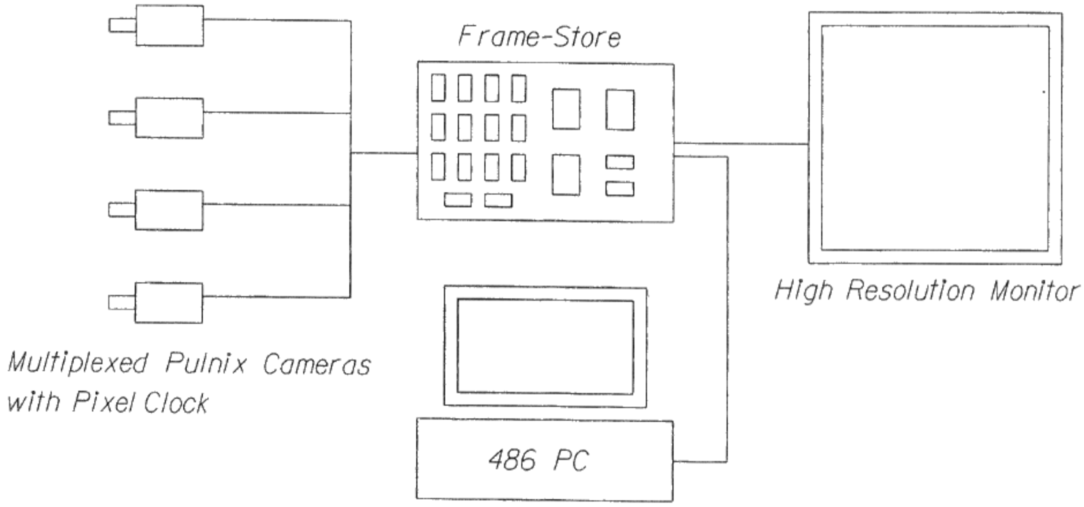

FIG. 1. Schematic diagram of the connexions between cameras, frame-store and computer.

covered with white cloth and illuminated from outside in order to produce diffuse light internally. Currently, retro-reflective target spots are illuminated by projecting a light source as near to coaxial with the camera optical axis as the physical size and location of the camera will allow.

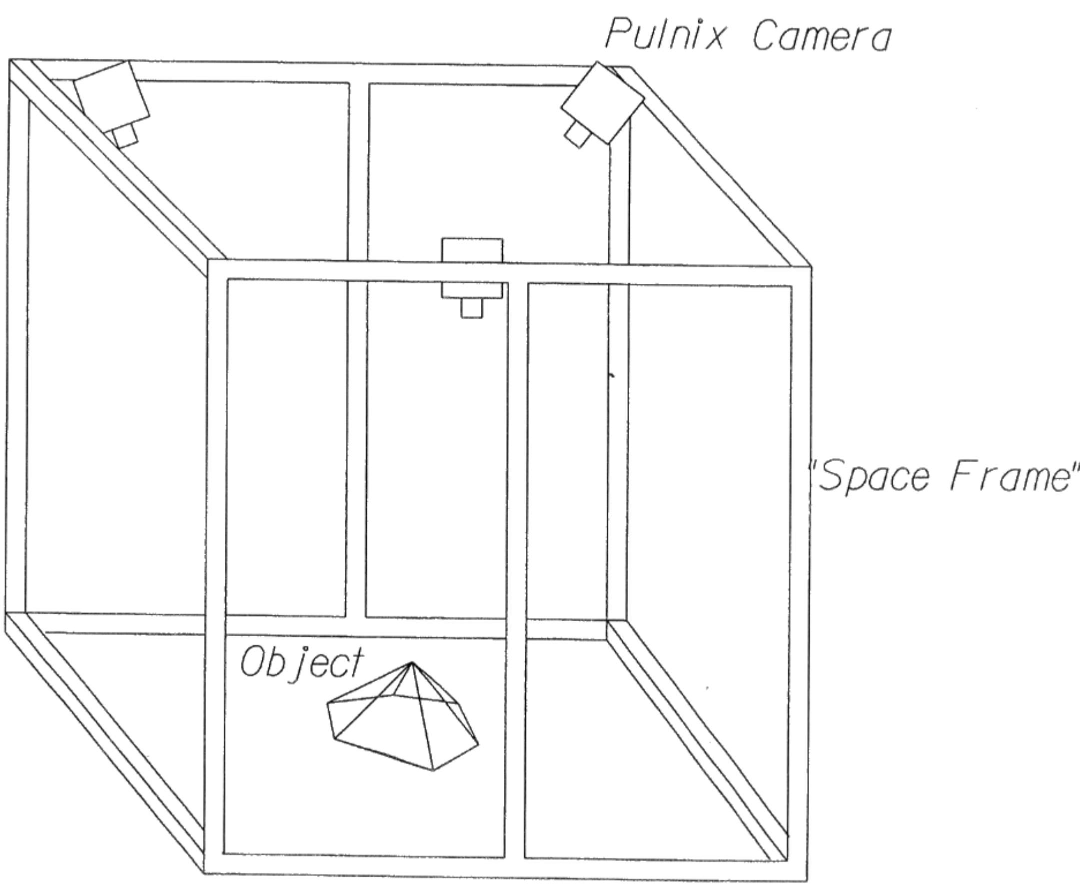

FIG. 2. The layout of cameras within the frame.

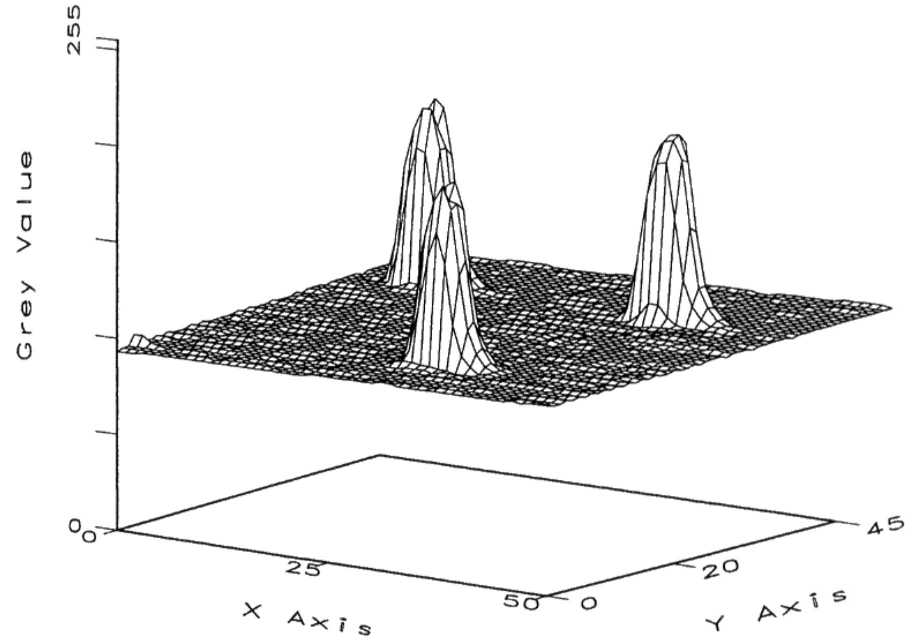

FIG. 3(a). Original three dimensional intensity profile.

CONTROL

In order to provide control of the measuring system for automated measurement, an input/output (I/O) board with 96 individually programmed logic lines was purchased (Computer Boards Inc., 1990). These lines are planned to be used as follows:

Pulnix camera exposure time control	30 lines
driving *xy* motion tables	16 lines
lighting	8 lines
control of pixel clock multiplexer	8 lines
light projection system	8 lines
spare	26 lines.

The card is placed within the computer and connected to the devices via a ribbon cable and a junction box. The box directs each of the lines through appropriate drivers to each device. For instance, the lines can be used directly to control the exposure time of the Pulnix cameras, but the use of a relay would be needed to switch a mains light on and off. The method of controlling each individual line is a simple matter of outputting a control byte to the desired port within the computer. The cost of this board was £181.

INITIAL PROJECTS

A number of initial conclusions can be drawn from preliminary work with the system.

Image Intensity Profile

The Pulnix camera/EPIX frame-store combination is superior to the authors' previous equipment, a PCVision frame-store and a borrowed Mintron camera. Fig. 3(a) shows an intensity plot from the original combination. The full image intensity range of 0 to 255 was not achievable because neither the camera nor the frame-store were adjustable to comply with the CCIR standard. Instead, the image values lie between 30 (no light) and 180 (full illumination). The reduced range was caused by a mismatch in the output signal range of the camera compared with the input signal requirement of the A–D converter. Fig. 3(b) shows the improvement in signal to noise level using the new camera. Pulnix was found to be very good at supplying technical information for its cameras.

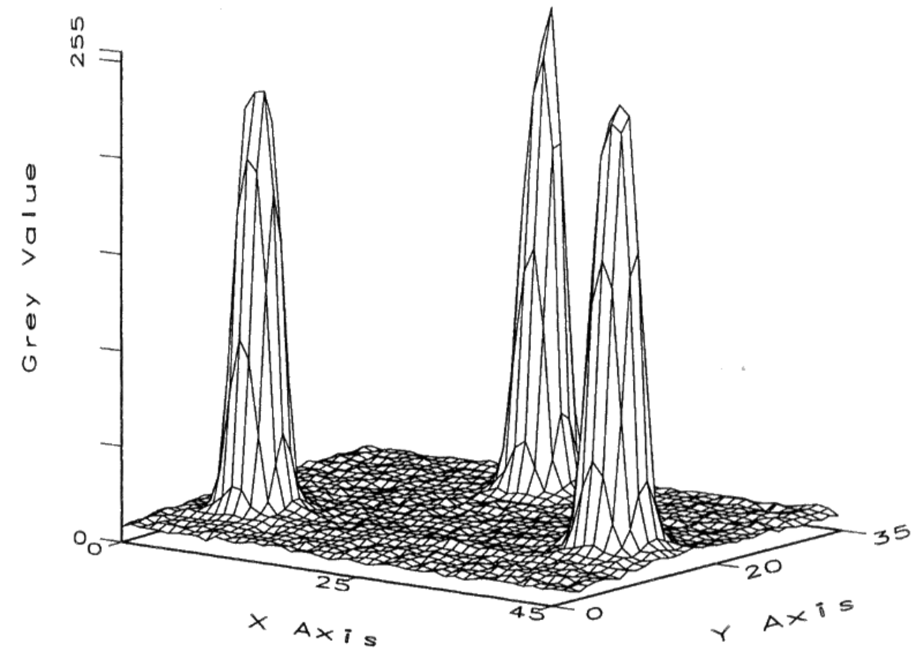

FIG. 3(b). Pulnix three dimensional intensity profile.

Frame-store Performance

The frame-store has performed well, but has caused frustration because of the lack of technical information that requests to the manufacturer have not solved. Use of the pixel clock input will require the building of a pixel clock multiplexer if more than one camera is used. Some changes to the board are also needed if the composite synchronisation pulses are used for the timing of lines and fields from the camera.

Image Size

The use of larger, 752 × 582, pixel images has caused strategic consideration of the software that is written. The code has been made portable so that the basic functions can be used on any computing platform with minimal changes. In order to allow the evolution of software using the images collected by the system, the software has been written so that a variety of high resolution colour display standards may be used. By these means development of the software is not confined to a computer equipped with the frame-store.

Target Field Experiment

Some initial work was conducted by imaging a retro-reflective target field with a square-based pyramid image geometry. The targets consisted of 3M fine grain retro-reflective sheeting which was punched into circular shapes, approximately 2mm in diameter; the images formed by these targets were approximately ten pixels in diameter. Unfortunately the pixel clock could not be used because modifications to the frame-store had not yet been completed. All targets were identified using a binary segmented image to measure the diameter, area and perimeter of a potential target. The centroid method was used to locate the targets to sub-pixel level. The targets from a master image were arbitrarily labelled. The targets from the other images were then labelled to correspond with this image. These image measurements could next be processed using self calibrating bundle adjustment techniques. Calibration parameters included radial and tangential lens distortion, focal length variation and principal point offset. In order to gain an initial understanding of the photogrammetric capabilities of the system, a free bundle adjustment was computed to give an indication of the performance achievable. Co-ordinates estimated from the free adjustment were checked by making tape measurements between selected targets. These check measurements were found to be in agreement to the level of precision of the tape. Some results pertinent to this discussion are shown in Table I.

TABLE I. Some preliminary results from a four photograph free adjustment with a single camera.

Degrees of freedom	σ_0^2	R.m.s. image co-ordinate standard deviation *x*	*y*	R.m.s. object space standard deviation and object space precision *X*	*Y*	*Z*
108	0·463	0·46μm 1/18·3 pixel	0·52μm 1/15·8 pixel	0·0274mm 1:14 963	0·0281mm 1:14 950	0·0581mm 1:7056

It can be seen from these results, without the use of a pixel clock, that sub-pixel accuracy of the order of a sixteenth of a pixel was achieved. With a pixel clock, refinements in target imaging and the development of matching algorithms, it is expected that this value can be significantly improved.

CONCLUSIONS

So far only the basis of the measuring system has been developed and further costs will be incurred. It is acknowledged that there are many hidden costs involved. However, even with only a small budget available, a useful start has been made to our research programme.

The future programme of work will use all the components described in order to automatically collect images, reliably recognise, locate and label targets, perform a bundle adjustment and output three dimensional co-ordinates in an interactive graphical display. A thorough analysis of the performance of the cameras and their interaction with the frame-store is in the process of being completed.

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Résumé

L'utilisation de caméras à DTC (dispositifs à transfert de charge, en anglais à CCD) pour la photogrammétrie numérique n'a été prise que lentement en considération par la communauté photogrammétrique. Toutefois les changements s'accélèrent maintenant que les équipements deviennent moins chers et que l'on se fait une meilleure vue d'ensemble. On vient de prendre récemment la décision d'initialiser des recherches dans le domaine des mesures rapprochées à trois dimensions.

Il s'agissait globalement de développer un système bon marché pour des mesures automatiques sur de petits objets industriels. On décrit dans cette brève contribution les phases initiales de ce travail.

Zusammenfassung

Die Nutzung von CCD-Kameras für die Digitalphotogrammetrie setzte sich bei den Photogrammetern nur zögernd durch. Aber mit dem besseren Verständnis und den preiswerter verfügbaren Ausrüstungen geht jetzt der Wechsel schneller vonstatten. Vor kurzem wurde entschieden, einige Forschungen auf dem Gebiet der dreidimensionalen Messungen in der Nahbereichsphotogrammetrie zu beginnen. Der allgemeine Gegenstand war die Entwicklung eines preiswerten Systems zur automatischen Vermessung kleiner industrieller Objekte. Dieser Kurzbeitrag beschreibt das Anfangsstadium dieser Arbeit.