CCD MULTICAMERAS INTERACTIVE DIGITAL SYSTEM FOR CLOSE RANGE PHOTOGRAMMETRIC APPLICATIONS

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ABSTRACT

In the paper a concept of a digital photogrammetric system based on the low cost CCD cameras and computer of PC type is presented. The system is mainly designed for photogrammetric 3D data acquisition of points in object space on the basis of digital images. In the proposed solution, low cost CCTV (Closed Circuit Television) - type CCD cameras were used. Orginal solution of the problem of digitization of video sequences was applied in the system. It was performed by construction of special framme grabber card. The maximum four cameras are linked with the computer through a frame grabber which is based on the modern video processor in order to provide enough power to compute images in real time. Entire hardware is managed by the software working as application in MS WINDOWS enviroment. The integrated management and photogrammetric software is briefly discussed to present the current potentialities of the whole system. Additionally , the most suitable image processing methods for contour extraction and quality improvement of visualization of digital images are implemented in the system. First experimental results, obtained from the test field studies, determine current and eventual possbilities of application of the system in close range photogrammetry - in solving of problems in the field of industrial metrology. Possible diretions of further development of the system are also given.

1. INTRODUCTION

Among the systems that record, process and perform analysis of digital images, a group of photogrammetric digital measuring systems may be distinguished. Architecture of these systems is based on electro-optical CCD sensors, computer hardware, digital processing techniques and on photogrammetric methods of elaboration. In comparison to other digital video systems, this group of systems is characterized by application of at least two cameras, often simultaneous recording images as well as by elaboration method based on one of photogrammetric functional models. What is more, during elaboration process, the observations are subject to a classical adjustment as well as to analysis of accuracy and reliability. Applications of the photogrammtric digital system concern close range recording and deal with, first of all, 3D positioning (optionally also 2D), reconstruction of engineering object shapes, extraction of information from 3D data in the industrial measuring techniques.

With regard to the duration time of measuring process and processing of the digital data, the photogrammetric digital measuring systems may be, in general, classified as follows :

- on line systems, working in real-time i.e. in cycle of video image recordin (1/25s or 1/30s, according to the standard of the vision signal) or near real-time,
- off-line systems, working in interactive mode (they are often hybrid systems).

Quality of the digital system depends on many factors. The most significant are the following: characteristics and largess of generated digital data sets, which result from resolution of the electro-optical sensors that were used, applied processing algorithms as well as structure, parameters and technical possibilities of electronics hardware.

The CCD cameras together with digitizing frame grabber card constitute basic elements in each video digital system (Baltasavias, 1990; Gruen, 1988). They decide about size, resolution as well as geometrical and radiometric quality of digital images, it means they influence significantly on possibilities of practical applications of the system. Power and computational speed of the host computer,efficiency of software and algorithms can improve quality of the primary digital images only in limited degree.

Photogrammetric digital measuring systems should characterize themselves with high speed of large digital data sets acquisition and processing, high accuracy, functionality and multi-purpose universality of

applications, and simultaneously, with possibly low price.

2. DESIGN CRITERIA FOR CONSTRUCTION OF THE LOW-COST SYSTEM

This concept consisted in elaboration of a recording, digital data processing and measuring system based on the so called, designed for these purposes frame grabber card- a specialized electronic system- constructed specially for a computer of PC type, coupled with electro-optical CCD sensors and through application of a proper control and photogrammetric software.
Construction of a low-cost digital system for close range applications having medium accuracy foresaw realizarion of the following assumptions concerning the hardware and software :

- the construction will be based on the IBM PC or compatible computer, instead of a workstation,
- low-cost CCTV (Closed Circuit Television) - type CCD solid-state cameras with video output (analogue signal) of low or medium resolution will be applied to this system,
- application of a frame grabber card, oriented on digital elaboration in off-line mode in close range photogrammetry,
- the system will be controlled from under user-friendly Microsoft WINDOWS environment.

When converting the above tasks to practice, the authors were fully aware of influence of these assumptions on accuracy, reliability of results, speed and degree of automatization of the process of elaboration.
Design and construction of a low cost photogrammetric digital off-line system, working in interactive mode for close range applications was performed in the frame of cooperation between the Chair of Photogrammetry and Remote Sensing, Olsztyn University of Agriculture and Technology and the Institute of Electronics, Technical University of Lodz in Poland.

3. SYSTEM OVERVIEV

In this part of the paper, they way of working of the basis hardware and software components of the proposed system as well as characteristics of its utility and functional properties.

3.1 CCD cameras

One of possible sources of digitized image acquisition are electro-optical sensors with CCD matrix used as converter. Advantages of the CCD cameras when applied as visual sensors within structure of digital system are undoubted (the most significant with regard to the project realization are given) :

- considerable stability and precision of image space geometry after digitisation,
- immutability in time of geometric deformations,
- correction of geometric and radiometric errors can be performed with numeric means,
- possibility of application of a camera with transmission of a composite video signal united with pixelclock or of a camera with integrated A/D converter together with direct transmission of digital data.

In low-cost digital systems, industrial TV cameras are in common use because of their relatively low price (Luhman, 1991). They use standard video signal for output of discrete information on grey levels of pixels.
Process of digitization of the analog video signal and of the primary digital data from CCD matrix contained in it, is unfortunately connected with creation of geometric deformations of the image: the so called effect of linejitter and change of the image scale as well as with radiometric disturbances (Baltsavias,1990; Beyer, 1987; Beyer, 1988; Beyer, 1992; Lenz, 1990).
In this elaborated system we have decided, because of financial respects, to use relatively cheap monochrome solid state sensors CCD - Panasonic WV-BL204 cameras, with the European CCIR video standard norm (Gruen, 1988). Transmission of the image is carried out using composite video signal, or optionally with external synchronisation. The CCD image sensor is of the interline transfer modus and has dimensions of 6.4(H) × 4.8 (V) mm^2 which is equivalent to scanning area of 1/2" pick-up tube. The CCD sensor's resolution is 577(H) × 581(V) pixels with a physical pixel size of 11.1 μm × 8.3 μm. The Panasonic standard C mount lens used for the project having focal length of 12 mm, with focus range adjusted by camera and field of view approximately 30 by 22 degrees, was recommended for optimum performance.

3.2 Frame grabber

An integral part of the system architecture, determining its technical advantages and quality is interface - frame grabber card, which cooperates with computer AT bus. Monochrome CCD camera interface (Figure 1) contains 16-bit graphic processor (TMS34010-40MHz) dedicated for complex video operations e.g.: rotation and mixing, etc. performed in real-time. The interface mentioned here has been designed to co-operate with modern dual-port memories what allows processor to access the image memory while capturing data from the camera. The graphic processor operates with maximum speed at 40MHz clock rate, what ensures the image processing in real-time, during its capturing. The image processor operates using pipeline and cache mechanisms. The local-bus architecture allows to access the video memory by ADC circuitry. graphic processor and host, respectively. A CRT controller included to the graphic processor is a fully programmable device, that makes possible to adjust a system resolution to the application. In the realised project 640×480 resolution is chosen to make compatible capturing with PC-VGA display standard. Higher vertical resolution of 480 lines per image is used while camera works in interlace mode.
Sampling rate of video signal at 15MHz ensures the square pixel and the proper image size on the screen.

Video capturing circuit works with clock restoration based upon the VCXO phase locking loop (PLL). This causes high stability of the restored sampling clock and, in consequence high quality of the captured image. VCXO-based restoration circuit is recommended in high-resolution video systems, where slight changes in the phase clock can disturb the captured image smoothness. The circuit is equipped by automatic black-level detection (CLAMP), what makes it possible to process images correctly for different images with contents. A/D conversion is always performed for the active part of the line, and the black level of the signal is assigned to a certain quantization value.
The possibility of reprogramming of the graphical processor during its operation is the additional feature of the presented solution. Both the image memory and GSP's registers are accessible for Host in any time. The local software running on GSP platform has been written with the use of „C" and assembly language for Texas Instruments graphic processors.

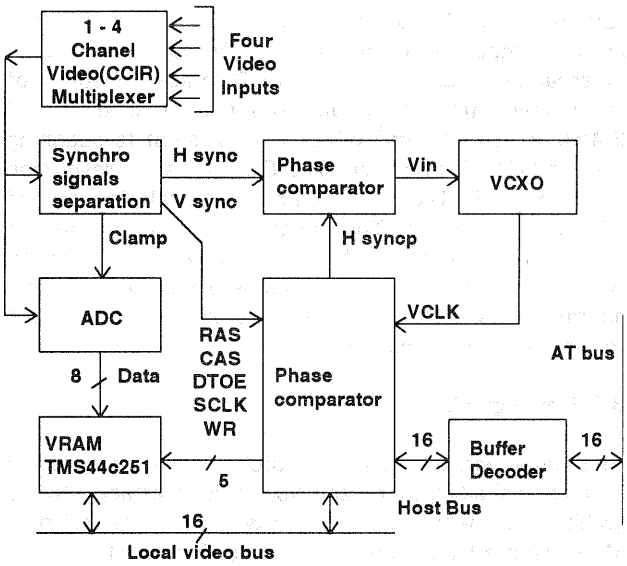

Figure 1. Frame grabber block diagram

Additionally, the presented solution is uses the clamping circuitry for proper A/D conversion being independent from the contents of the image. The entire interface has been designed with the use of programmable logic devices (PLDs) in the form of half-size IBM PC-compatible computer-card. In order to fasten the transmission and capturing rate, 8/16-bit DMA transfer is applied. This feature allows to use the presented interface in so-called "Life-video" mode, where the moving images are being displayed on the computer screen in real-time. A small size of developed interface makes it possible to use it in the portable Notebook Computer.
The presented frame grabber card for this system has been made at the Institute of Electronics, Technical University of Lodz. It has maximum 4 video analog inputs for independent, parallel connection of 4 CCD Panasonic cameras, which are compatible with monochrome television video signal in CCIR standard (25 full images/ sec.). The frame grabber uses the composite video signal for digitization.The frame grabber enables conversion of successive video sequences generated by the CCD cameras from analog to digital form, and further transmission to the operational memory of a computer. Theoretical dimensions of the image recorded by the frame grabber before digitization amounts to 7.1(H) × 4.0(V) mm^2, while dimensions of scene after frame grabbing amounts to 5.3(H) ×4.0(V) mm^2 respectively. Thanks to high frequency of pixel digitization (ca 15 MHz) pixels are approximately squares of 8.3 μm in size. Ratio of the pixel sides lengths amounted to 1.007.
Others basic technical parameters of the designed frame grabber board :

- frame size HxV 640x480
- number of digitized discrete grey levels 256
- number of grey levels (VGA) 64
- converter A/D and D/A 8 bit
- file size with single image 307 kB
- max. number of images displayed at the same time 4
- max. number of measuring points on the image 100

The frame grabber card has been installed to the PC 5P60 computer it means Pentium with PCI-60MHz board, 16 MB Ram, that was equipped with 64-bits graphic accelerator SVGA, PCI Matrox II of 2MB memory. Video is displayed on a 17" RGB monitor manufactured by MAG Technology. For assurance of correct and optimal work of the system, it is important to use the SVGA graphic card configured to have resolution of 800 x 600 and to display at least 256 colours. If the conditions are not fulfilled, the images will be displayed in pseudo-colours, instead of proper grey levels.

3.3 Control and manages software

The software that controls and manages the frame grabber has been written in the Borland C++ programming language as application under MS WINDOWS 3.1 environment and is steered by user through a system of menu and submenu. The software allows to capture the images as well as to process them. The implemented procedures enable image acquisition, processing enabling geometric transformations of digital images and interactive measurement of pixel coordinates. Processing is carried out in off-line mode, after storing the images in computer memory.
The basic menu of the programme consists of the following options : File, Edit, View, Options, Camera, Window, About. In case of choosen orders it is possible to call the option in fast mode through pressing proper buttons of the keyboard (e.g. zoom through F10). If certain option cannot be used because of false using of the program that controls the work of the frame grabber, then the respective option is displayed in grey. Some examples of windows displayed the digital images are shown in the Figure 2.

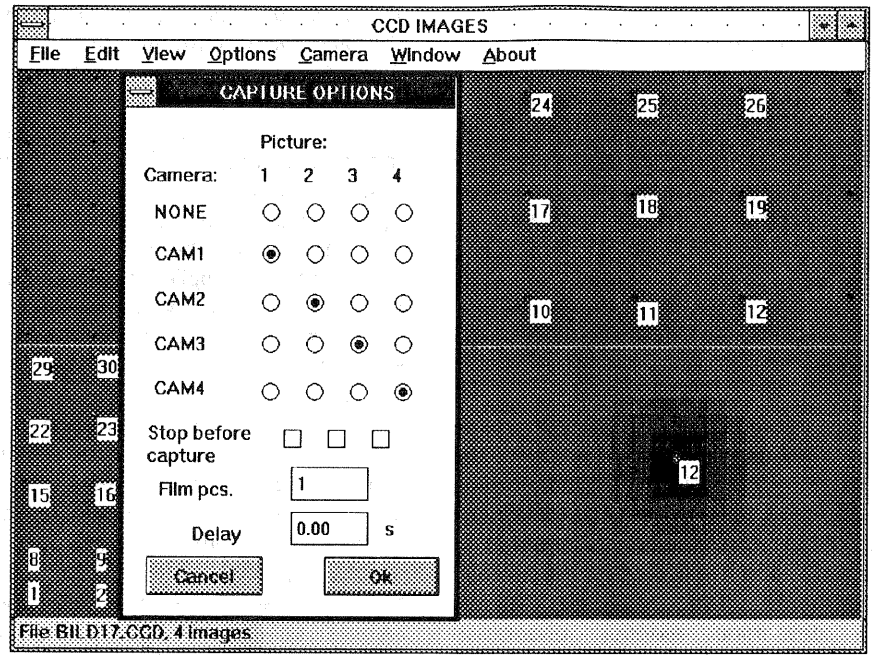

Figure 2. Window with four single images from testfield targets with dialog-box (image in normal case). The images 2 and 4 are zoomed out.

This frame grabber card makes it possible to perform many unable operations, the most essential for its work are as follows :

- continuous acquisition of generated analog images from one CCD camera, in the so called mode "Live video", without their digital storing,
- continuous acquisition of a certain number of images having defined recording interval, in the "Film" mode, from maximum 4 cameras, together with their automatic storage; for successive images created files get extension *.c01, *c02 etc.,
- automatic acquisition of 4 successive images sequence from single camera or parallel single images from max. 4 cameras,
- conversion of the recorded images to digital form,
- transmission of the images to operational memory RAM or their storage on HD or FD; the files obtain the extension *.ccd,
- display on the screen of single images or 4 successive images from single cameras or single images from not more then 4 cameras,
- zooming of image parts,
- processing of digital images, comprising :
- correction of quality image trough one of 4 contrast enhancement methods
- contouring of the image with one of 4 extraction methods,
- measurement of point coordinates on the screen in interactive mode with automatic assignment of numbers to successive points; there is a possibility of point position correction or their cancelling,
- creation of files containing numbers and coordinates of reference point in the screen pixel coordinate system; they are written down in ASCII codes, with extension *.rp,
- conversion of files *.ccd with recorded digital images to the *.bmp format.

The system produces standard bit-map format files to store the images on the hard disk. This makes it possible to export the video images to other MS WINDOWS applications. The sequence of the images are stacked in single file in order to diminish their numbers in the current directory. In real-time mode, because of storing images in the computer memory, the number of acquired images is limited. Practically, for today's computers with some megabytes of memory, this problem does not exist.

3.4 Image processing procedures

In the module of digital processing, admitted range of processing techniques comprises procedures enabling image quality improvement and contouring of edges if the objects contained in digital image. Methods of image quality improvement make it possible to correct deformations of the image caused by, among others, non-proper lighting of the object, badly set sharpness, additional noise occurring, etc. These are contrast enhancement methods :

- histogram equalization method,
- linear histogram stretching.

The second category of this range are operators :

- non-linear processing - squaring,
- non-linear processing - rooting.

Detection of object edges in the image allows to obtain the image in the form of distinguished borders of the objects being in the scene (non-continuous change of image attributes). It enables logical interpretation of the image. Applied contour extraction methods comprise :

- gradient method using 1-st order neighbourhood,
- gradient method using 2-nd order neighbourhood,

- Laplace's filter,
- the fast method - "colour in the neighbourhood".

Possibility of obtaining the image in the form of distinguished object contours (quasi binary images) is important because of its further applications to engineering projects elaboration supported by the CAD systems. Digital image containing recorded, contoured object (or possibly converted to binary form through use of the computed threshold) can be processed photogrammetricaly and exported further to CAD environment.

3.5 Bundle adjustment

Our own software for photogrammetric 3D positioning in off-line mode of operation was implemented. The software was written in FORTRAN-77 programming language. Special algorithm for general sparse matrices was used (George, 1981).This program is oriented to application in close range and it is based on the method of bundle adjustment. The program allows conventionally to determine exterior orientation parameters, object points coordinates (X,Y,Z) as well optional interior orientation parameters of the camera by selfcalibration bundle adjustment. In the program, the traditional model of bundle adjustment, ed. photogrammetric observations and directly observed coordinates (weighted control points) can be enhanced with additional geodetic observations of the following types : spatial distances, coordinate differences (height differences), horizontal and vertical directions in object coordinate system etc. For maximum precision of 3D point positioning the additional parameters in the functional model of the on the job calibration are obligatory.

3.6 Utility functions

Generalizing, it can be stated that the elaborated system fulfils the following basic user's functions :

- modular structure of the system,
- programmable frame grabber,
- open architecture of the system resulting from its work in the MS WINDOWS environment,
- generation of images using visual sensors - max. 4 CCD cameras,
- transmission of optical images and processing them to obtain digital form in on-line mode,
- modules of digital processing of images,
- interactive pointwise measure of pixel coordinates,
- common determination of geometric and radiometric errors in "on the job" mode,
- 3D positioning and reconstruction of non-topographic objects in close range.
- integration of the output data with standard formats of the CAD/GIS systems environment.

4. TESTFIELD MEASUREMENT - FIRST EXPERIMENT

In the first experimental trials devoted to estimation of accuracy of the system as well as its flexibility, a simplified procedure of calibration and determination points coordinates through triangulation was admitted. The accuraccy potential of a proposed system for photogrammetric point determination, using the selfcalibration approach in conjunction with a small close range testfield was studied. The testfield consisted of a panel 0.6 × 0.8 m^2 in size, on which 35 control points were placed regular in a network of squares and 4 more point were placed approximately 200 mm above the plane - the idea proposed by Gustafson was applied (Gustafson, 1988; Gustafson, 1992). The testfield was placed horizontally. Accuracy of points positioning was estimated to be 0.05 mm. Size of the testfield was choosen to fulfil approximately the field of sensor image. Ratio of the panel and image scene amounted to about 1.4. The retro-reflective targets are black circles with a diameter of 8 mm on white background with a small white dot in the centre (for centering and for theodolite measurements). The testfield was imaged from eight different camera positions (Wester-Ebbinghaus, 1983). 4 convergent and 4 normal case scenes taken with Panasonic CCD camera cover the plate). The image scale was approximately 1:200 for normal case and the average object depth from the perspective amounted to 2.4 m. Figure 3 shows the images configuration. The targets are thus imaged onto 3 to 8 pixel with regard to influence of the convergence angle.

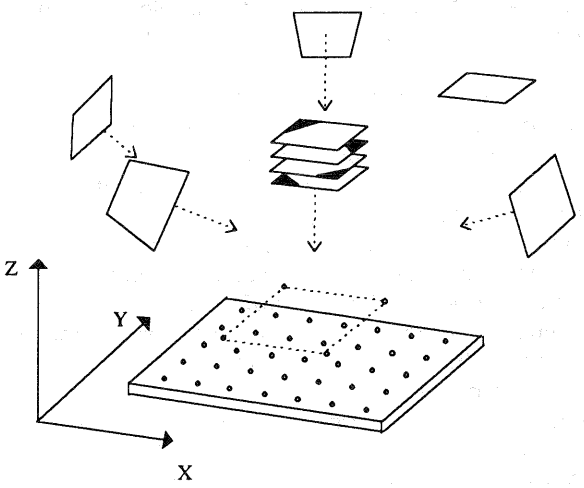

Figure 3. Test object and CCD camera images configuration.

In the first step the option of selfcalibration for single camera was studied. Using a selfcalibrating bundle adjustment , the parameters of interior and exterior orientation were calculated. The additional parameters for correction of the coordinates of the principal point, camera constant of the sensor, first two parameters for radial symmetric lens distortion and tangential distortion (Heipke, 1992) were to be determined. Next, multi images recording of test object from convergent camera positions was performed. Determination of all parameters, in this number X,Y,Z of targets coordinates of the test object was carried out through common bundle adjustment. Image coordinates of the signalized points were measured manually, repeatedly, on the screen of monitor. The measurement accuracy in image

space corresponds to 0.5 of the pixel spacing. The resulting standard deviations of the points of the testfield after bundle adjustment lied in the range of 0.2 mm which is equivalent to a relative accuracy of 1:3000 in object space. Considering the applied method of pixel coordinates measurement and the functional model enhanced in small degree for additional parameters, the obtained results can be accepted as sufficient.

5. FINAL REMARKS

The digital system for close range photogrammetric applications presented in this paper is in testing phase now. The test comprise optimisation of conditions of digital images sequences performing, studies of effects of certain filtering methods and contrast correction on measurement accuracy in the pixel coordinate system.
In current form, the system can be used for off-line 3D data acquisition in the process of monitoring of non-topographic objects in close range ,in such cases when immediate extraction of information on the studied object is not needed. The current architecture of the system, i.e. its first stage of development, limits the speed and accuracy of digital processing. The first, experimental tests gave sufficient results of three dimensional points determination, especially when the simplified procedure of elaboration is regarded.
In the nearest future, the system will be developed in the following directions :

- to apply automatic procedures of structural object recognition on images, and automatic measurement of pixel coordinates,
- to enhance the functional model of bundle method with further, additional system calibration parameters.

On the basis of gained experience, we perform construction of video-thermal system (multi-media-sensor system) within independent research project. In this system, a new generation frame grabber board will be coupled with AGEMA-880 infrared camera together with CCD multicameras photogrammetric digital system. Video-thermal system, in which all the sensors will work parallel will designated for multi-purpose industrial monitoring.

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