DIGITAL MULTISENSORAL VIDEO-THERMAL SYSTEM FOR CLOSE RANGE METROLOGY APPLICATIONS

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ABSTRACT

The presented digital multisensoral, hybride system VISION PLUS along with software POPOS combines the video and thermal images acquisition and advanced processing on one system-measurement platform. The system enables images recording in real-time in on-line mode with four video cameras CCD and one thermal camera. The capturing and digitization of successive images sequences is made in an original developed frame grabber PCI plug-in card. The images processing is carried out interactive in the off-line mode.
The system consists of the main tool VISION PLUS for controlling and management of digital data acquisition. Simultaneously this package is created for archiving, processing, measuring and analyzing the data from thermal and visual images. The system architecture is supported by the additional photogrammetric software package POPOS. This program is designed for 3D object coordinates estimation, using the DLT and/or the method of bundle adjustment. The selfcalibration of the CCD cameras can optionally be performed.
The software has a modular object structure and open architecture and it was written in Delphi and/or C++ language. The presented system is characterized by functionality, multi purpose universality and user friendly interface working in the Windows 95/98/NT environment.
VISION PLUS is mainly designed for common determination of geometrical and thermal object information in close range metrology applications, especially for high speed and dynamic processes. The close range metrology elaboration in this digital system could be realized in the following schedule: images acquisition, cameras calibration, photogrammetric objects reconstruction, thermograms evaluation, directional emissivity correction.
In this paper typical close range imaging and elaboration are discussed.

1 INTRODUCTION

In the field of metrology there is a large demand for nondestructive optical measurement methods (Grün, Kahmen,1997; ISPRS, 1998). This need is directly related to the necessity of quality control, diagnosing and object monitoring in close range in the new areas of applications, e.g. in technology, industry, medicine, research, development, etc. In order to broaden the spectrum of obtained geometrical and physical information about objects examined, particular attention is paid to joining many sensors, particularly digital ones, into one system measurement platform. In the vision metrological systems advanced processing methods of obtained digital images and application of operators allowing automation of preparation process are becoming standard. The initial results of elaboration can be then submitted to computer object modelling in the virtual reality.

Currently available commercial digital measuring systems differ as to their architecture and performances because of different tasks and requirements these constructions must meet. Due to the variety of solutions suggested it is difficult to evaluate and compare them against uniform criteria and standards. Construction and preparation of vision metrological measurement system must include many factors and design assumptions influencing the final technical parameters of the system. The basic construction criteria should include:

- application of the system
- type and speed of recorded kinematics processes
- dimensions and object texture
- spectral range of recording
- type and technical parameters of used sensors

- mode, measurement type
- range and accuracy of elaboration
- type and form of presenting the results
- user friendly
- price and system parameters ratio

The modern digital photogrammetric measurement system should, depending on the application, be characterized by a high speed of obtaining and processing mutlisensoral digital data, high degree of automation, functionality and universality.

2 SYSTEM ARCHITECTURE

The presented video-thermal system VISION PLUS for close range applications resulted from conception of low cost multisensoral photogrammetric digital system based on PC computer. The system was created in Poland in cooperation between the Department of Photogrammetry and Remote Sensing of the Olsztyn University and the Institute of Electronics of the Technical University of Łódź. The system is a continuation of previous done works (Sawicki, Więcek, 1996; Więcek et al., 1998c).

2.1 Hardware overview

The elaborated video-thermal system VISION PLUS, in which modern hardware and software standards are used, enables parallel, simultaneous and synchronous digital images acquisition in real time in on-line mode with maximum 4 low cost video monochrome cameras CCTV CCD Panasonic WV- BP312/322 and one thermal camera AGEMA 880 or Inframetrics 760.

The frame grabber cards-advanced PCI plug-in cards (mode „Plug and Play") was originally developed in the Institute of Electronics of the Technical University of Łódź under dr. B. Więcek. The frame grabber construction and resulting technical parameters specify the method of acquisition and analog to digital signal conversion as well as the speed of the digital images storing in the board buffer.

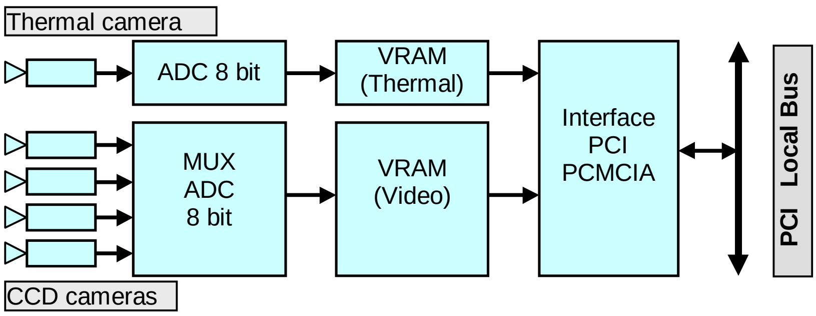

Figure1. Block diagram of the system architecture

The presented system has two hardware options: stationary and portable which result from the construction of the frame grabber cards. These solutions differ in respect to operation platform and the speed of data transmission. Due to this fact, the system has become more universal in application since, depending on metrological features of the object, conditions and parameters of recording, it is possible to have two independent configurations of the system. The stationary version is based on the PC-Pentium host computer with PCI (*Peripheral Computer Interconnect*) bus. The interface is the PC plug-in card offering the high performance 32 bit data transfer and burst mode that provides accelerated throughput of data across the bus of 132 MB/s with the frequency 33 MHz clock rate. Frame grabber card acts as the internal, put-in card installed in one of the PCI computer slots. The portable version is also adjusted to PCI standard and is based on portable, notebook Pentium computer, which is equipped with PCMCIA slot. Due to its external parameters the FG card could not have been installed inside the portable computer. Connection to the computer is done with a wire and PCMCIA card (DAQCard- DIO-24 by National Instruments). In result, for this solution digital data transmission is much slower, at the speed of a few MB/s.

The frame grabber cards have 4 independent inputs for composite analog video signal (CCIR) from CCD cameras and one analog input for the thermal camera. The analog multiplexer is in the video channel transferring the subsequent frames with the delay of 20 ms, a high speed 8 bit A/D converters and a synchronization circuit. The memory buffer implemented using fast VRAM memory for multimedial applications is designed as a FIFO (*First-In-First Out*) memory. Reading and recording of the image is done sequentially and allows fast, every 160 ms, recording of thermal images (100kB/ image) and video sequences (300kB/ image) in 8 bit resolution (256 gray levels). These provide also high speed of digital images transfer to host computer. Programmable device FPGA by XILINX was used to service VRAM memory and for direct data transfer. Considering the initial resolution of solid state sensors CCD and of the thermal sensor the video images have the VGA computer graphics standard display resolution of 640x 480, however, thermal images are 272x 286 and in both cases with square pixel.

The geometric quality of the video image generated in digitalization with FG cards is significant for the accuracy of the photogammetric digital processing. Sampling clock restoration is a very important element of the interface. The video capturing channels work with clock restoration using DPLL (*Digital Phase Locked Loop*) circuit with the frequency of 80MHz. The sampling rate of video signal (CCIR standard) at 14.545 MHz ensures the square pixel and the proper image size on the screen. Taking into consideration the real size of the CCD sensor, its nominal resolution and active image resolution after digitalization process, the approximately square pixel of $p'_{x,y}$=6.25 μm in size was obtained. DPLL used provides satisfactory synchronization quality and in result eliminates the linear deformation of the digital image. Due to this the line jitter was minimized to 18.2% of the pixel size which is equal to 1.0 μm. DPLL based restoration circuit is recommended in high resolution video systems where even slight changes in phase clock can disturb the smoothness of the images captured.

In order to utilize fully the parameters of frame grabber cards and to optimize their work in computer system environment, special drivers have been made. Drivers automatically find frame grabber cards, initiate them properly in the system and facilitate communication with application environment.

2.2 Tools software

The presented system consists of two compatible software packages. Both program packages, VISION PLUS and POOPS, are written in Delphi and/or C++ language with the native 32 bit code. The software has a modular object structure, open architecture and is Windows 95/98/NT compatible. The software user interface is the same as for all Windows applications, contains the tools menu, submenu, dialog boxes, toolbars, etc. It allows the user to choose specific functions and options in the interactive mode. The visual and thermal image processing and advanced elaboration are carried out interactive in the off-line mode.

The main tool is called VISION PLUS, that is the program for controlling and managing the frame grabber, video and thermal images capturing and digital data acquisition in different modes. Simultaneously the package is created for archiving, preprocessing, processing, measuring and analyzing data from thermal and visual images. VISION PLUS program includes the following basic task blocks:

- continuous acquisition of digital images in sensor configuration for chosen parameters, that is: mode, appropriate resolution, number of sequences, exposure interval, etc.
- visualisation on screen of recorded images and sequences
- digital images processing
- digital processing of video and thermal images
- pixel coordinates measurement
- quantitative and qualitative temperature measurement
- 2D projective transformation of vision and thermal images
- geometric items (points, close polygons, polyline)
- disk surgery

Digital operators for video and thermal images processing are implemented in the software – low pass and high pass filtering, histogram stretching and equalization, contrast enhancement, contours extraction, interpolation, etc. The advanced images processing include: color and shade changing, zooming, scale changing, overlapping and mixing of thermal and video images as well as digital projective transformation. The measurement options make it possible to measure pixel coordinates, carry out analytical projective 2D transformation, to read points/section/area temperature distribution, to determine emission, and to correct temperature. It is also possible to include thermal camera parameters – focal length, aperture, camera calibration as well as object environment parameters – temperature, emission, and setting reference points.

VISION PLUS software uses a special image file format – TVV, which supports fast recording of images together with important photogrammetric and thermal information and facilitates the access to arbitrary image window. In order to use, they are exported into BMP format. VISION PLUS allows also importing in BMP format which facilitates digital images elaboration with different resolutions that are recorded by other sensors.

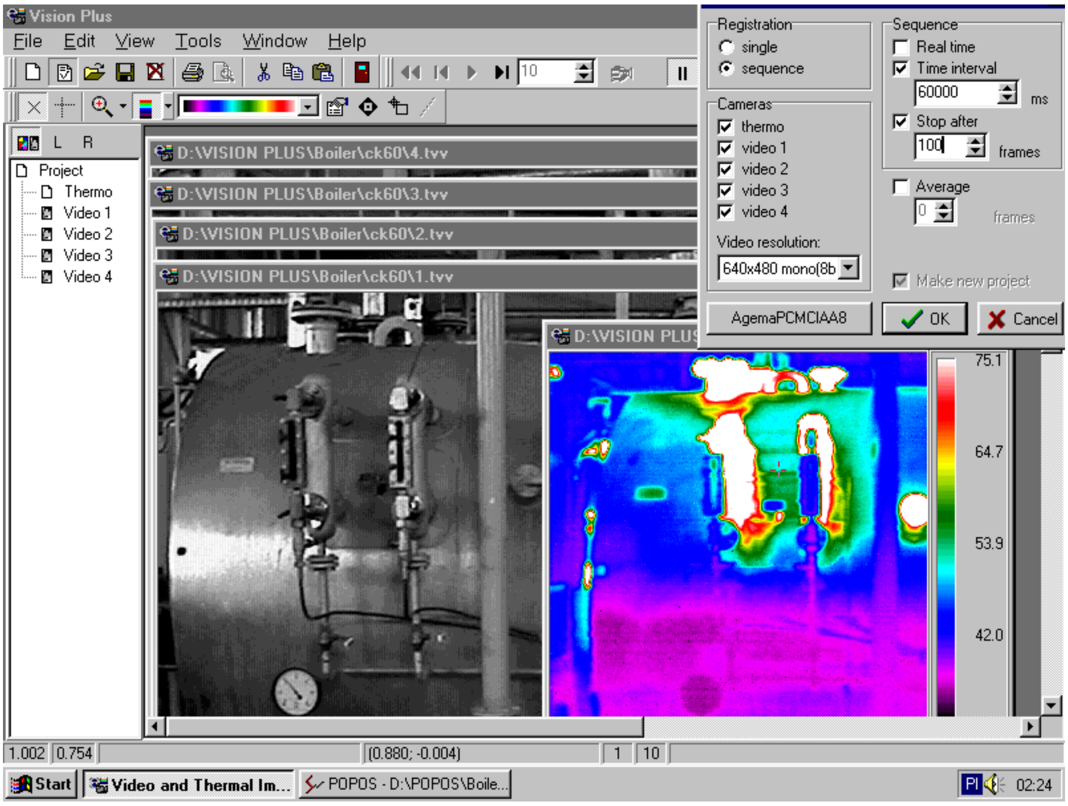

Figure 2. The VISION PLUS program window – screen tool bars are visible, project status, active dialog box and images sequence (4 video and 1 thermal image)

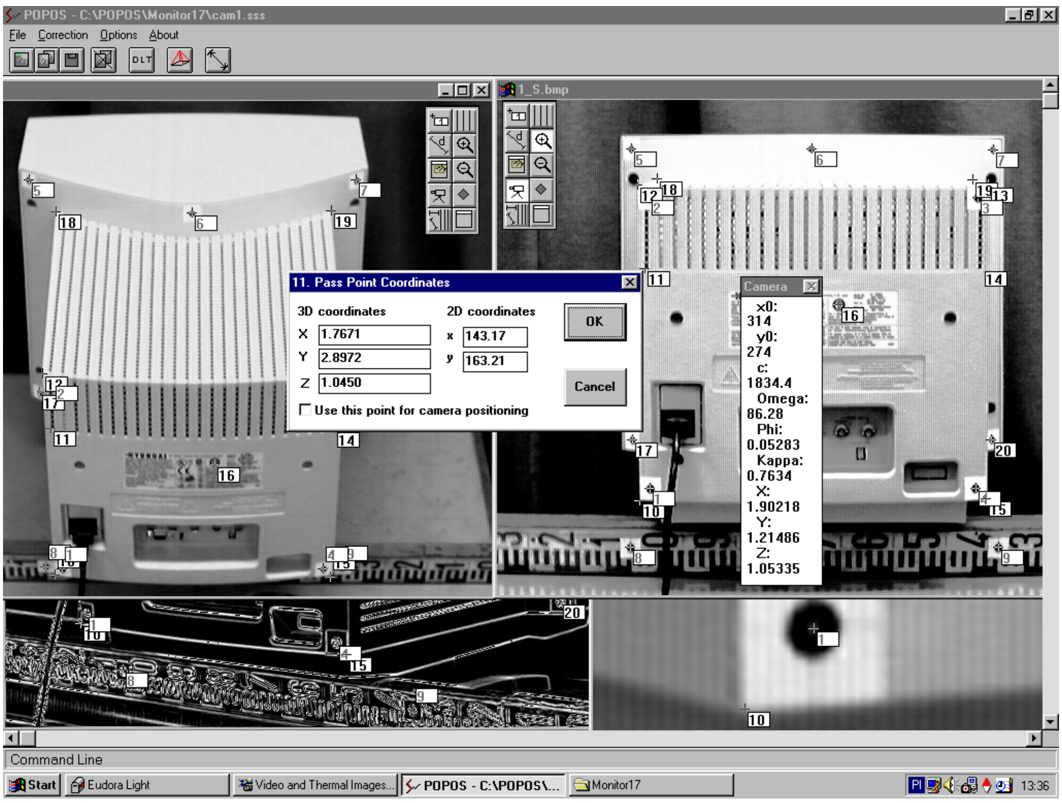

Figure 3. POPOS program window with 4 video images – screen toolbars and dialogue boxes are visible. The top left window – primary image, the top left – after histogram equalization, bottom left – after contouring, bottom right – zoomed image after interpolation

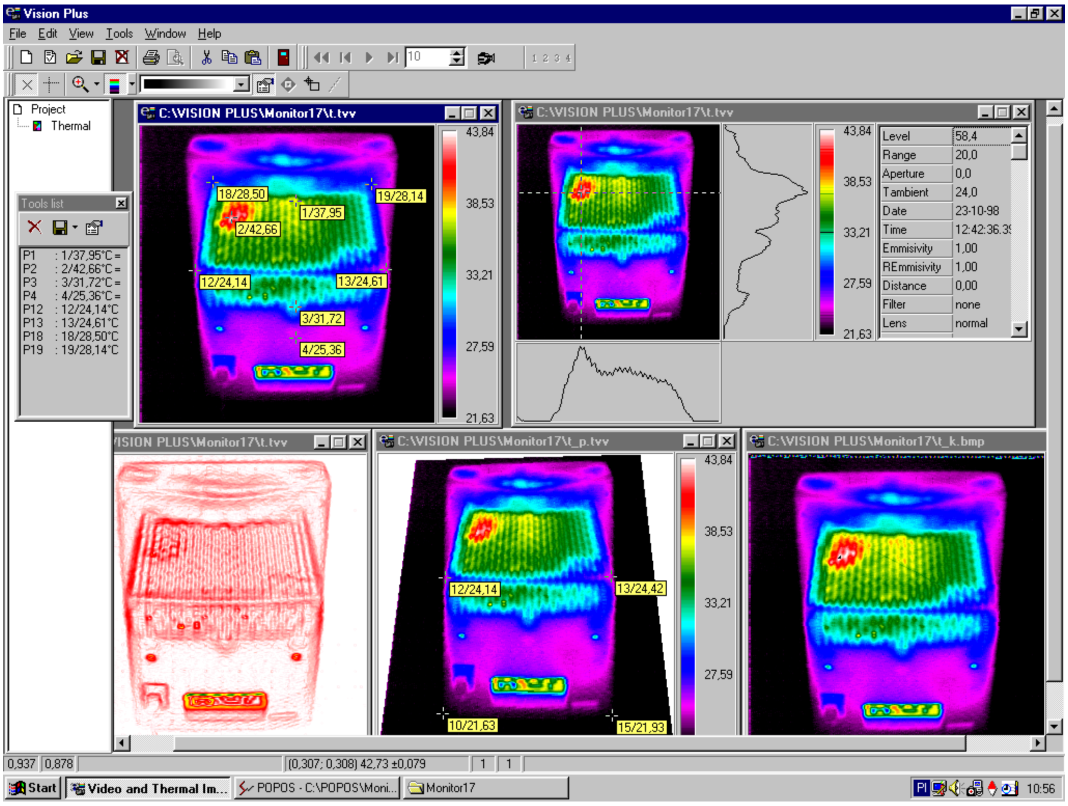

Figure 4. VISION PLUS program window – thermal images in thermovision elaboration phases

The system architecture is supported by additional software package – POPOS (*Point's Positioning*) for digital close range photogrammery. The POPOS program uses principally digital images from the VISION PLUS system, but it can work independently of the main VISION PLUS tools using images obtained with other digital cameras or images digitized by scanners. As Windows environment application it is written in C++ language, and can communicate without any problems with VISION PLUS module what allows for direct files importing. The POPOS uses BMP image file format.

POPOS program is designed for 3D object coordinates positioning. The coordinates of the object points can also be estimated using the DLT method (*Direct Linear Transformation*) or the method of bundle adjustment. The self calibration of CCD cameras can be performed optionally. The choice of the method depends on image registration conditions and photogrammetric measurements and solution conditions. The adjustment can include additional geodetic and photogrammetric observations in the object space. POPOS program allows to realize in an interactive way the following procedures in 3D photogrammetric positioning:

- project handling
- digital images processing
- image points, control points, additional geodetic and photogrammetric observations management
- image coordinates measurement (manual or semi automatic mode)
- digital camera calibration (optional)
- 3D positioning + camera self calibration „on the job" (optional)

This program provides subpixel accuracy of the image points measurements in the manual mode. Zooming procedure as well as active crosshair cursor and mouse button are used for measurements. Coordinates of homologous image points are multiple measured and the results are automatically given as mean value. Semiautomatic measurement of signalized points provides a implemented in the POPOS program the least squares template matching LSM.

The standard functional model of bundle method or DTL transformation modelling of the interior orientation for the calibration (selfcalibration) can be expanded by additional parameters, describing the radial symmertic and tangenial lens distortion. In this program we used sets modelled by Brown (1971) and Tolegard (1989). The correction of geometric systematic errors generated in low cost solid state cameras are enclosed in additional parameters modelling the scale on x axis and in regard to shear.

The presented digital system is characterized by functionality, multi purpose universality and has user friendly interface in the Windows 95/98/NT environment.

3 CLOSE RANGE METROLOGY ELABORATION

The vision metrology in various applications require a wide spectrum of geometrical and physical object information. On the basis received from VISION PLUS video-thermal system it is possible to measure and determine the geometrical and physical information in object space. The 2D rectification and 3D restitution and distribution of object temperature can be applied in various engineering applications. This system is mainly designed and recommended for determination of common geometrical and thermal object information in close range metrology applications, particularly for high speed and dynamic processes.

The close range metrology elaboration which uses total functions of VISION PLUS digital systems and supporting POPOS program can be realized in various conditions according to the following research schedule:

- video and thermal images acquisition
- CCD cameras self calibration (optional)
- photogrammetric 2D or 3D object reconstruction
- thermograms measurement and analysis
- directional emission correction

During system testing carry out experiments by typical close range applications. Two cases are discussed and presented on enclosed illustrations – digital elaboration of industrial steam boiler (case 1) and computer display (case 2).

3.1 Photogrammetric 3D points determination

In the applications discussed the measurement session was carried out in the following configuration: 4 video cameras CCD Panasonic WV-BP312/322 and thermal camera AGEMA 880. CCD camera stations created a configuration of convergent photographs. The average distance of picture registration was about 5 m (1) and 2 m (2). Low cost lens ERNITEC was used for experiments; cameras and lenses were earlier calibrated in the laboratory in conditions resembling the described applications. In otherwise case the parameters of interior orientation of each camera must be calibrated established anew. It is necessary to specify a large number of control points and to do self calibration „on the job" together with terrestrial photographs network solution. In the two cases discussed the control calibration of CCD cameras in another registration procedure. Single photos were taken from four camera stations with the same camera. Control points (14 and 9 respectively) were placed evenly and spatially on the object. Targets were marked with circles and their size, depending on local image scale, was no smaller than 5-7 pixels. Control point coordinates were determined using geodetic survey with accuracy of $\sigma_{X,Z} = \pm 0.2$ mm, $\sigma_Y = \pm 0.3$ mm.

During the first stage of photogrammetric elaboration, and using POPOS program, the measurement of control points and discreet points in pixel image coordinates was done in automatic mode and using the implemented LSM method. Only on convergent photos for the most distant points the algorithm of automatic pattern search was ineffective. For this group of points manual measurement of pixel coordinates was done and then the results were brought to mean value using automatic function of creating mean value. Zoom function, equalization operator and contouring as well as bilinear interpolation were used additionally. These functions are illustrated in figure 3.

In the research discussed only the interior orientation x_0, y_0 i c_K each CCD camera was calibrated for control. The increase of the number of parameters modelling radial and tangential distortion led to singular solution in the DLT. In comparison with laboratory calibration results the difference of on mean 3 pixels was determined for coordinates of the principal point x_0, y_0 and 3.5 pixel for focal length c_K. These differences were deemed insignificant. The elements of interior orientation of cameras specified during laboratory calibration were used in the adjustment. The estimation of 3D points coordinates was done by bundle adjustment of convergent photographs network. Table 1 shows the mean accuracy of adjusted object points coordinates.

Object	σ_X [mm]	σ_Y [mm]	σ_Z [mm]
1	±1.55	±1.95	±1.75
2	±0.35	±0.50	±0.40

Table 1. Standard deviations of object space coordinates

This compares to an image subpixel accuracy below 0.5 of the pixel size. The obtained estimation results can be accepted as sufficient.

3.2 Thermal evaluation

The qualitative and quantitative analysis of recorded thermograms was done with the tool function of VISION PLUS program. The surface temperature, the temperature in chosen points were read, temperatures of cross sections were measured. The registration parameters were read from information panel. 2D projective transformation of the thermogram was done on the basis of 4 reference points, which coordinates had been determined earlier in 3D photogrammetric positioning process. During thermographic elaboration contouring function, zooming, interpolation and color changing were used.

Directional correction by photogrammetric 3D object recording was presented in detail in works (Sawicki et al., 1998; Więcek et al., 1998a; Więcek et al., 1998b). The calculation algorithm and first results of thermovisual evaluation of electronic circuits were presented in these works. This method enables the temperature correction on digital thermographic images. On the basis of the normal vector to a given object plane and normal vector to the plane of thermal sensor the coefficient of directional emissivity is calculated. The normal vectors to both planes is done by photogammetric method.

In the second discussed case the surface temperature correction obtained was max. $\Delta T = 6.5^{O}$ C and the mean $\Delta T = 4^{O}$ C in the area of the highest heat emission of 30^{O} C and the real environment temperature of about 21^{O} C. See figure 4 – top left and bottom right respectively. This method can be unreliable for many materials and surfaces – particularly rough and with high emission factor.

4 CONCLUSIONS

The vision metrology in various close range engineering and industrial applications require a wide spectrum of geometrical and physical object information. The presented multisensoral, hybride video-thermal system VISION PLUS along with additional photogrammetric software package POPOS combines the digital video and thermal images recording in the real-time and advanced image processing on one system-measurement platform. The system allows acquisition and immediate archiving, measuring, analyzing and information extraction from thermal and visual images. The digital images elaboration is carried out interactive in the off-line mode. The presented digital system is characterized by functionality, multi purpose universality and has user friendly interface.

The elaborated multichannel video-thermal system VISION PLUS presents the author's original solution, in which modern hardware and software standards are used. This system is a new generation solution. It is characterized by the following technical parameters:

- integrating maximum 4 CCD cameras and one thermal on the basis of shared frame grabber
- construction of new quality frame grabbers and use of modern computer technology standards (PCI-Bus, Slot-PCMCIA)
- modular structure of the software
- open architecture of the system resulting from its work in the multi tasks Windows 95/98/NT environment
- registration of high speed, dynamic processes
- parallel video and thermal images digital processing
- 2D and 3D object reconstruction together with thermographic elaboration

A typical scheme for monitoring, metrological measurements and information extraction in close range with the video thermal digital system was established. The potential possibilities of the system's use include a wide range of metrological measurements, diagnosis and research in micro and close range. The practical application of the multichannel digital video-thermal system in the close range metrology and the accuracy of the results are limited and conditioned by low resolution of CCD sensors and infrared thermographic camera. In view of the photogrammetric solution conditions, a relative accuracy of 3D coordinates estimation ranged from 1:3 000 to 1:5 000 in the object space. The obtained results of processing in the video-thermal system are integrated with standard formats of the CAD/GIS environment. A direct link to the CAD/GIS system and further object visualisation and modelling are possible.

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