NEW VISTAS FOR INDUSTRIAL PHOTOGRAMMETRY

Henrik Haggrén
Technical Research Centre of Finland
Finland
Commission V

ABSTRACT

The main hindrance to a wider use of photogrammetry in industrial applications, especially in manufacturing processes, has been the costly delay in feedback between the results and the process. By using digital imagery, operation in real time becomes more possible. The lateral-array image chips have a very high geometric accuracy and thus may be exploited to improve the originally limited resolution greatly. The implantation of human expertise into hardware processors enables the traditional photogrammetric system configurations to be economically used in 3-D control systems. The fundamental problems to be solved are how to handle the enormous amount of input data, how to extract the control data essential to the industrial processes, and how to manage the data flow during the whole CADMAT-processes without any loss in automation.

INDUSTRIAL PHOTOGRAMMETRY

Industrial photogrammetry is one of the main areas in the application field of close-range photogrammetry. It includes a wide variety of the surveying tasks engaged with the building, engineering and manufacturing activities.

Photogrammetric aspects

The role of photogrammetry is to provide sufficient geometric information at the different phases of industrial processes. The versatility of photogrammetry becomes evident in its analytical mode. It is predominantly accurate, three-dimensionally superior, physically place-independent and digitally most competent to further process analysis. There still remains a remarkable failing. Its cost-efficiency in the industrial process depends on the amount of the necessary and expensive equipment and expertise, and on the delay in feedback between the results and the process. These often negate its wider use, especially in manufacturing phase. Thus the developing activity of the industrial close-range photogrammetry will be further concentrated to the minimizing of these cost factors.

Examples

As to give an introductionary view of the present extensive trends of the operational use of photogrammetry close to the manufacturing process some examples are described in the following paragraphs. A common feature for all these examples is the efficient use of analytical photogrammetry in a closed loop interfacing the object itself and the construction data.

- At the Fort Worth Division of General Dynamics, Texas photogrammetry is a part of the quality assurance phase of the production line of the F-16 fighter (Danko, 1979). In the case of the wing fixture stereo pairs and theodolite sets are used to quick check of the fit geometry. According to the users the time for the accuracy check has been cut to about one-third of the previously required 120 to 160 man hours and there is no down-time for the inspection anymore. The feasibility study of the system has been based on the Keuffel & Esser A.I.M.S. Analytical Industrial Measuring Systems, which is described by Vyner et al. (1982).

- At the Régie Nationale des Usines Renault, France a system is developed for the mathematical definition of complex surfaces known as the Unisurf method. In this connection close-range photogrammetry is used to provide the essential digital data required for the analysis of surfaces (Wahl, 1983). The technique is used at the Renaults in various fields of applications, including the styling of new models of cars, design modifications to existing models, car accident investigations and statistical studies on human bodies.

- At the Division of Marine System Design, Norwegian Institute of Technology, Norway a project has been carried out to improve photogrammetric procedures as fully integrated parts of the yard's quality control program (Holm et al., 1982). The planned system consists of multistation photography supported by a permanent ground control network and occasionally auxiliary control data, such as distances, plumblines, planes etc. The data acquisition and analysis phase is organized in a way which enables a most quick response to the nominal construction data. The building of system is still under way.

A peripherical approach to the real-time photogrammetry in industrial use has been activated by a number of facilities which investigate the sensor systems for industrial robots (Allan, 1983). There particular attention is paid to the so-called proximity sensors. The proximity sensing is the mean for the robots to interact with objects within their environments and it also allows the robot to cope with unexpected events. The sensing is being investigated primarily through optical means. The most simple and compact systems today include self-scanned arrays and laser lighting. The trend still seems to be towards minimizing the external lighting and thus towards using general-purpose

VLSI-circuits suitable for parallel implementation of computer vision algorithms. A photogrammetrically well-known real-time application is the Remote Manipulator System described by Kratky (1980). A newer proposed real-time photogrammetric measuring technique acting as the robot vision system is outlined in El-Hakim (1983). Some principles and experiences in the use of matrix scan cameras with digital image processing techniques suitable for real-time photogrammetric applications are described by Real (1983).

Primary requirement

Cost-efficiency means productivity. The main factors of cost-efficiency are the system's accuracy and the response time. In Figure 1 the response time is graphed approximately as a function of the accuracy in cases of different types of input images. The traditional use of analog metric photographs, analytically handled, normally allows accuracy rates of some 1:30000 to 1:50000 of the object size within a few days or even weeks of work (graph Analog I). With extensive system modifications the response time may be slightly reduced (graph Analog II). Still the photographic process finally limits the response time down to some hours. The use of video images enables the response time to be cut down to be a couple of seconds (graph Video). The limit with the video would be the geometric accuracy at the images which is hardly better than some 1:500 or 1:1000. By using digital area image sensors the real limits are unknown. One would likely expect

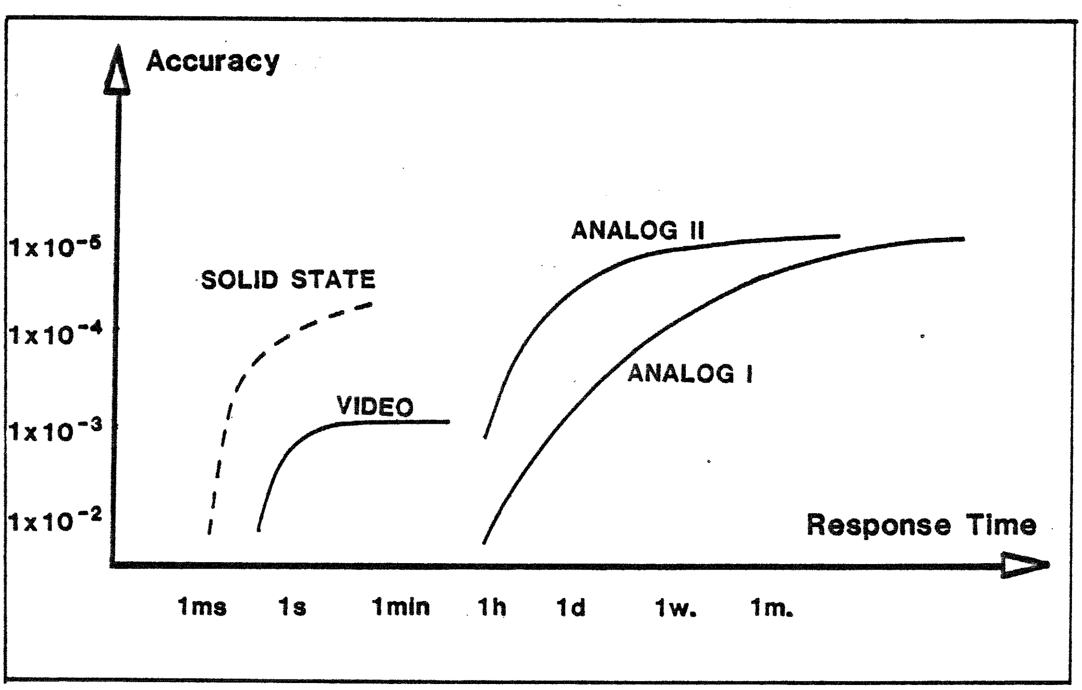

Figure 1. Response time versus accuracy in different kinds of three-dimensional photogrammetric systems according to the input-images used for the system.

the graph to be drawn as in Figure 1 (graph Solid State). Essentially, the geometric stability of these image sensors is far better than in any analog metric images. The basic problems with digital imagery and its geometry arises first in obtaining the sub-pixel accuracy. The present low pixel resolution has to be cracked in some way. In geodesy, for instance, a similar problem is solved by micrometer interpolating at the original circle graduation intervals.

Both the real-time aspects and the accuracy improvement require a very sophisticated optical and digital processing of survey data. Thus the photogrammetric system should be carefully investigated and analyzed as to get a sufficient base for further development of the real-time or near real-time three-dimensional survey systems.

THE 3-D PHOTOGRAMMETRIC CONTROL SYSTEM

The purpose of the optimal 3-D control system is to fulfil the various requirements which are dominant to the control activities in different phases of the industrial production processes. The task of the system is to extract the geometric object features three-dimensionally and to compare this information with the nominal construction data. In a real-time use it also allows the immediate back-directed instruction flows (Figure 2).

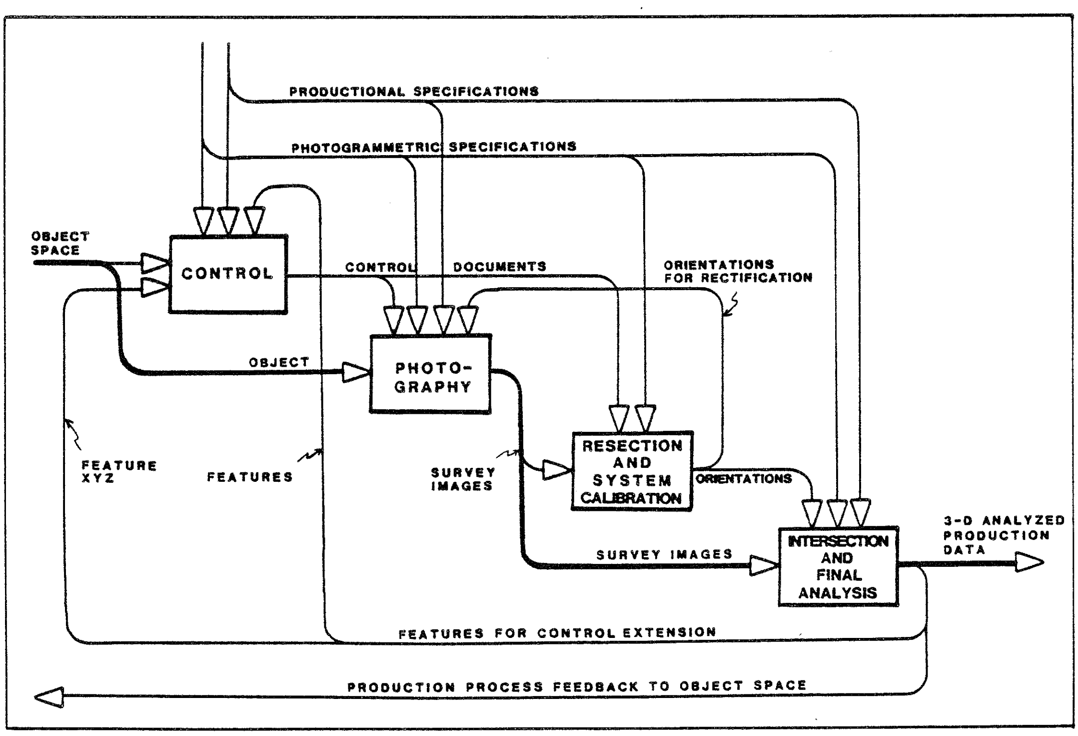

Figure 2. The proposed 3-D photogrammetric control system.

The primary requirements to be set for the system configurations will be the modularity of the system construction and the efficient hierarchial organisation between and within the various system modules. This only enables extensive utilization of the developed software and hardware components to further system modifications in all potential successive applications. The modularity also allows the gradual implantation of the human expertise into the so-called hardwired expert systems, wherever it is needed for a quick data analysis. Thus the data flow during the industrial CADMAT-processes may be optimized, and the rate of the process automation remains high.

On the following pages the system principles are outlined in more detail but still approximately. Principally, of course, the system structure is similar to the traditional photogrammetric processes. Thus the attention within explanations is pointed only to those details which seem to be unconventional in these connections. The system is divided into four subsections, which are:

1. The control.
2. The photography.
3. The resection and system calibration.
4. The intersection and final analysis.

The respective system graphs are presented (Figures 3 to 6). The system is still visionary and even somehow illusory. Thus modifications may occur when it is further developed and experienced in practice. Finally, a simple prototype system made at the Technical Research Centre of Finland is briefly presented.

The control

The task of the control subsection is to provide the data required for the coordination of the survey system to the actual object space and for the maintenance of the system stability.

There are two things worth closer attention in this section. First, in addition to the original control the new object feature data, when once extracted photogrammetrically, may also be used as further control of the system geometry. The feature data may include clearly identified details in the images like sections of lines and surfaces. Second, because of the feedback utilization the control data may be continuously updated, expanded and sequentially organized. Thus the system enables the progressive processing of the 3-D data to be performed always by the most primitive and lowest modules of the survey system. In other words, the point coordination in the object is derived not only and primarily through the original control, but also through the adjacent and already extracted object details.

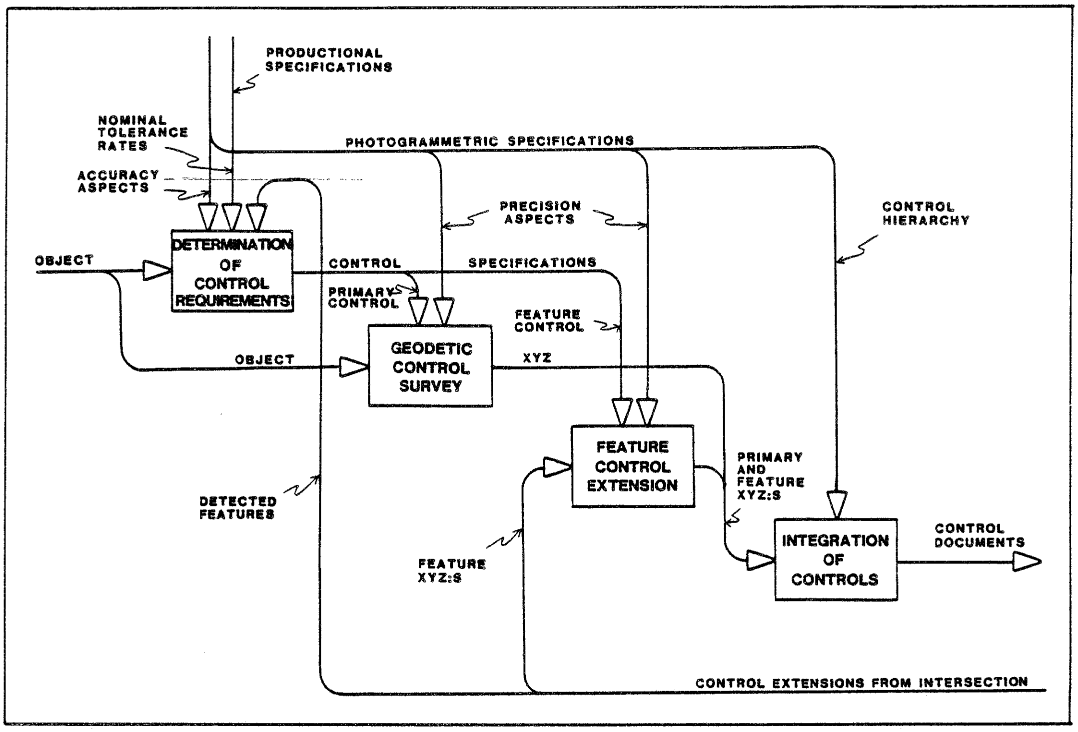

Figure 3. The control.

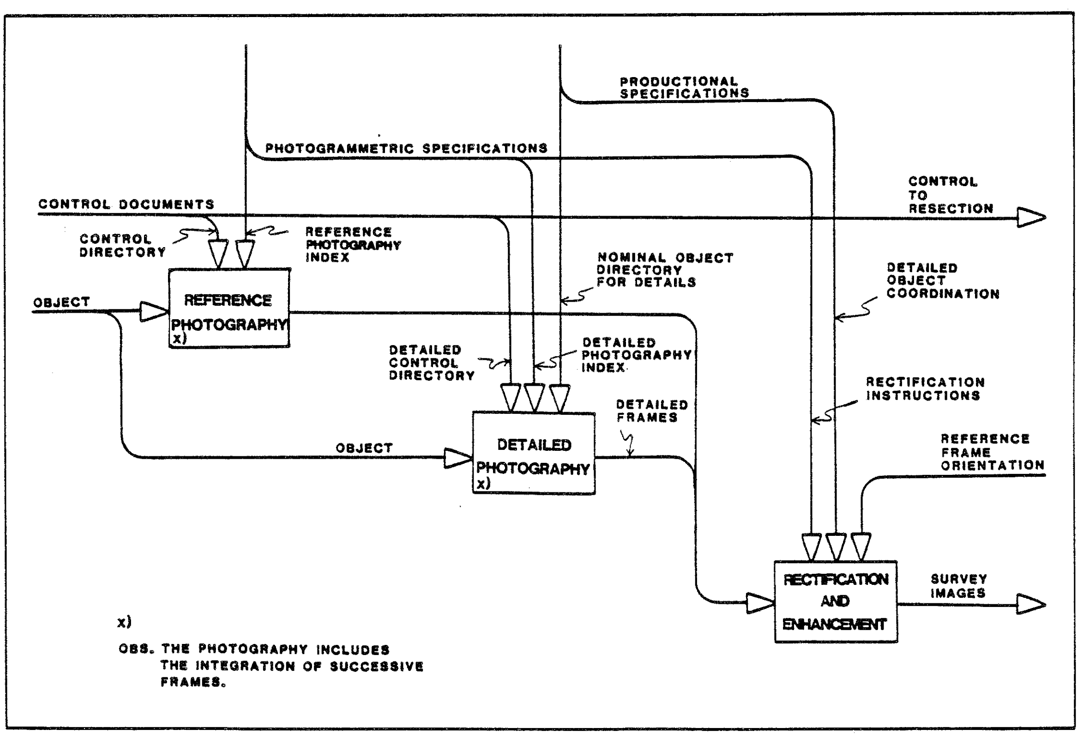

Figure 4. The photography.

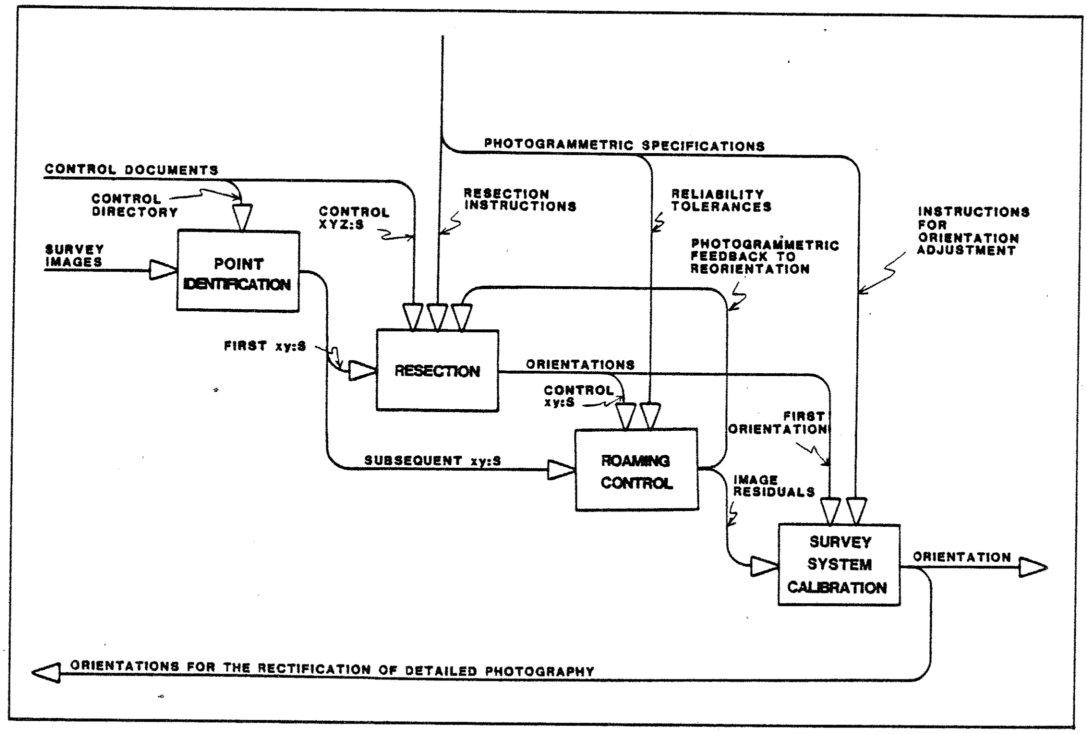

Figure 5. The resection and system calibration.

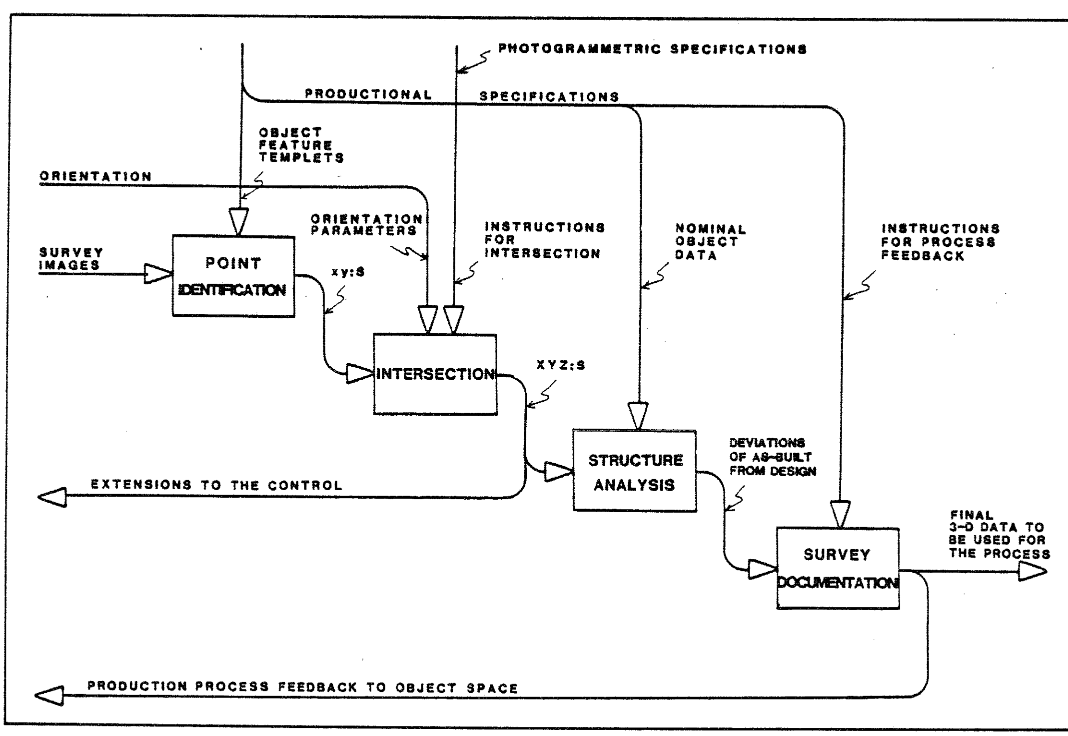

Figure 6. The intersection and final analysis.

The photography

The photography subsection includes both the digitizing and the upbuilding of the survey imagery.

The system is organized as to allow the use of two different types of survey images, the reference frames and the detailed frames. The reference frames are images containing the object space with the original control. Upon the image resolution auxiliary detailed frames are used for the closer identification of the details and for the potential sub-pixel interpolation of reference frames. The detailed imaging is directed using the preliminary object space coordinates of the details, and each image is rectified to the reference frame system according to the preliminary pointing coordinates and image magnifications. In order to get the system's noise reduced successive frames may be digitally integrated. This may be understood as repeated observations. Finally, all images are processed and those features extracted which are most competent to the photogrammetric survey.

The resection and system calibration

The task of this subsection is to provide reliable orientation data for the photogrammetric intersection phase. The section is the origin for photogrammetric process feed-back.

After a rough set-up orientation made by the operator the system is adjusting itself automatically. Each control is first located according to the preliminary image coordinates. The amount of the digital image data is then reduced by detailed windowing. For the final identification and pointing the feature extracted and compressed data will be used. The potential sub-pixel interpolating may be solved by matching the identified and rectified detailed frames into the reference frames. The geometric roaming of the system is controlled. According to it the orientation data is updated and the system is adjusted and calibrated. For the roaming control, only some of the original control points have to be continuously remeasured in the reference frames.

The intersection and final analysis

The last subsection is the interface between the present object features and their nominal construction data. Thus it is also the origin for industrial process feed-back.

Each detail, which is of interest for the production process, is first identified and intersected. The identification of the details is either made automatically by the system or supported by the system operator. Here the directory data derived from the nominal construction data may be used. The correlation between homolog image details is made digitally using the already processed survey imagery. Also here the design data of the derived construction details may be used. Finally, the 3-D geometric data of the object is immediatelly analyzed and the derived data is used for the production line.

All this of course, as to be fully utilized, needs a most comprehensive integration of the surveying and production processes.

The prototype system

The description of the proposed real-time photogrammetric system here is a part of a feasibility study made at the Technical Research Centre of Finland. The system will be further developed and therefore a simple prototype has been constructed. The prototype system includes video cameras as input devices and some special hardware processing modules for video digitizing, image storing and processing, photogrammetric manipulations and data analysis. The images are digitized with 4 bits in 128 x 128 pixels. The processing modules are self made and they primarily intend to be the outline for further system modifications and extensions. The system is still building, and any practical photogrammetric experience may not be reported so far.

THE POTENTIALS OF THE TECHNOLOGY EVOLUTION

The evolution of the basic technology, which further supports the development of the real-time photogrammetric systems primarily concerns the modern micro-electronics like intelligent sensors and VLSI-circuits. Still the components of predominant interest for the photogrammetric applications are the imager chips.

The rush extension of the number of pixels per area image sensors during the last decade seems to be laid down to a spatial resolution rate of roughly 500 by 400 pixels. The rate is primarily specified by the broadcast and communication activities. Even if there were some special sensors with a higher spatial resolution like for facsimile, the most of the commercially conceivable chips for the close-range photogrammetric systems are to be compatible with the low resolution rate.

Among the many trends which potentially support the wider use of imagers their reduced prices and extended spectral responsibility may be pointed out. According to a former market survey (Murray, 1980) the selling prices of the packaged imagers are projected to drop from $ 1000 down to the $ 20 - 40 rate in 1995. At the same time the price of moderate resolution cameras will decline to the $ 100 - 200 range. A very fresh novelty is the use of dynamic RAMs as imagers. Although being one-bit coded images, the RAMs give an exceedingly cheap and direct media to cope the computer with its environment. The price rate expected first in 1995 for imagers is already achieved by these RAMs. The extension of the spectral responsibility will respectively open up new possibilities to widen the whole application field of close-range photogrammetry.

CONCLUSIONS

Although the technology of today allows attractive visions for the real-time close-range photogrammetric applications, the operational systems as a part of the production lines in industry are still potential. The break-through is possible only if the expertises of each side, the basic technology, the industrial processes and the photogrammetric survey, are in synergy. From a photogrammetric point of view the real-time systems will hardly ever displace the metric photogrammetry, but in fact their development will combine and support each other.

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