REAL-TIME PHOTOGRAMMETRY AS USED FOR MACHINE VISION APPLICATIONS

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ABSTRACT

A photogrammetric machine vision system, called Mapvision, has been developed at the Technical Research Centre of Finland. The paper deals with the principles of real-time photogrammetry as applied to machine vision. The present machine vision markets and the commercial systems are shortly overviewed. The practical examples presented concern the tentative experiences of applying the Mapvision and its preceding prototype system for industrial inspection and assembly control.

REAL-TIME PHOTOGRAMMETRY AND MACHINE VISION

Machine vision needs real-timeness. The definition of machine vision is /Machine Vision..., 1985/:

> "The use of devices for optical non-contact sensing to automatically receive and interpret an image of real scene, in order to obtain information and/or control machines or processes."

The definition has been adopted first in 1985 by two recent and related organizations, namely the Machine Vision Association of the Society of Manufacturing Engineers (MVA/SME) and the Automated Vision Association (AVA). According to this definition the machine vision applications should cover also the major part of the real-time photogrammetric applications.

Generally, the machine vision has its origin and inheres in today's factory automation. In a restricted sense it is also referred to as computer vision or even as robot vision. Thus the geometrically most stable metric images ever at hand are put first to work on factory floors to identify and sort pieces. The photogrammetric operations have been limited to image scaling or at most to two-dimensional coordinate transformations of single images.

The more thorough role of the photogrammetry in the vision systems should be to three-dimensionally quantify and locate the interpreted object data. In, for example, dynamic robot vision systems this would lead to a confusing amount of image processing operations on each image and within nearly incredible time constraints. Therefore the first successful steps towards the real photogrammetric machine vision systems have to be taken rather on the pointwise measuring and control applications. The more sophisticated vision applications will surely get their turn later on.

Today there seems to be an ever expanding need for any kind of digitally controlled three-dimensional measuring systems. Products are designed on computers, they can be manufactured by aid of computers and even machined on numerically controlled equipment. Anyway, there does not exist any proper and cost efficient system, neither photogrammetric nor other optical or mechanical system, to be used for automatic inspection of large three-dimensional products /Cleaveland, 1985/.

Within these applications the requirements are challenging and high enough both for the accuracy and for the performing time. Photogrammetry as a measuring technique is familiar with and well suited to high accuracy demands. The best and recent examples are to be found on industrial and engineering sectors, where potentially as high as even 1:250.000 accuracy rates for photogrammetric mensuration have been reported /Fraser et al., 1985/.

Of course there is a long way from the 1:500 resolution rate, which coincides with the standard CCD-cameras today, to those high-accurate applications. Anyway, for example a tenfold subpixel interpolation leads to a potential accuracy rate of 1:5.000. And this has already proved to be sufficient for a variety of real-time photogrammetric machine vision tasks in industrial manufacturing practice. But the technical accuracy limits do not remain stable. The newest detectors count even for more than 2.000 by 2.000 elements on a single imager chip /Holt, 1985/.

On the other hand, the real-timeness for example in photogrammetric assembly control or gauging tasks may count for seconds. During these seconds there is enough time to make measurements on several multi-stational photogrammetric images, to repeat several settings on each measuring point, to intersect the object space coordinates and to compare, still in real time, this as-built data with the as-designed process data.

COMMERCIAL MACHINE VISION SYSTEMS AND APPLICATIONS

Machine vision has become one of the fastest growing fields in the industrial automation markets. The projected trends for the annual growth rate of units of machine vision systems vary conciderably the highest estimates being about 50% yearly. This translates to a real revenual growth of 15%, or even to 35% per annum if the component and other spin-off sales are added. The lower growth rate when compared to unit sales has its base on decreasing unit costs. Annual sales of machine vision systems are expected to pass $1 billion by the end of the decade. The sales have been and are prospected to be mainly to the automotive and electronics industries, accounting collectively for about over one half of the total markets /Tech Tran Corp., 1985 and Feder, 1986/.

Today there are between 100 and 200 of companies offering industrial machine vision systems for use in assembly, inspection and other manufacturing operations. They have their scientific base and future, more or less, on the vision topics currently pursued by numerous research organizations, which are generally involved in advanced image processing. In addition to the research organizations and machine vision manufacturers, a number of companies are developing vision systems for their own in-house use /Tech Tran Corp., 1985 and Feder, 1986/.

Most machine vision systems act as rudimentary eyes that see objects in two dimensions and in black-and-white under curiously controlled illumination conditions (Figure 1) /Weber, 1985/. The slight course onto the use of gray-scale

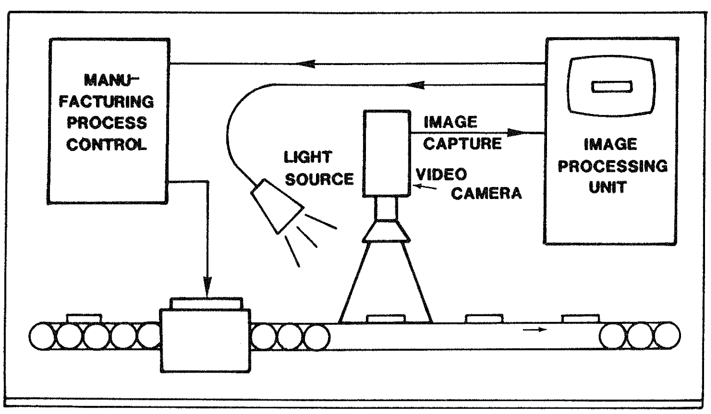

Figure 1. The most usual way of photogrammetric measurements in machine vision is limited to image scaling or at most to two-dimensional coordinate transformations of single images /Weber, 1985/

or color images in commercial systems is mainly due to the increasing processing capacity available on the component markets. None of these systems can fully handle the third dimension /Allan, 1985 and Rosenfeld, 1985/.

The ideal way to obtain reliable three-dimensional information about a scene is to measure it directly. Presently it is solved by using stereopairs consisting of parallel or slightly convergent images. In several cases one of these two stereo images is replaced by structured light projectors with known perspective geometry (Figure 2). The projectors then produce on the objects sharp and clearly defined patterns of stripes or dots, which are then identified on the images and immediately located in three dimensions.

There are purely practical reasons to refrain from utilizing the sophisticated photogrammetric models within the recent commercial systems. First of all, the effective real-time image processors do not allow any large geometric transformations before the matching of the corresponding image elements or object features. Secondly, the use of convergent imaging systems would lead to remarkable

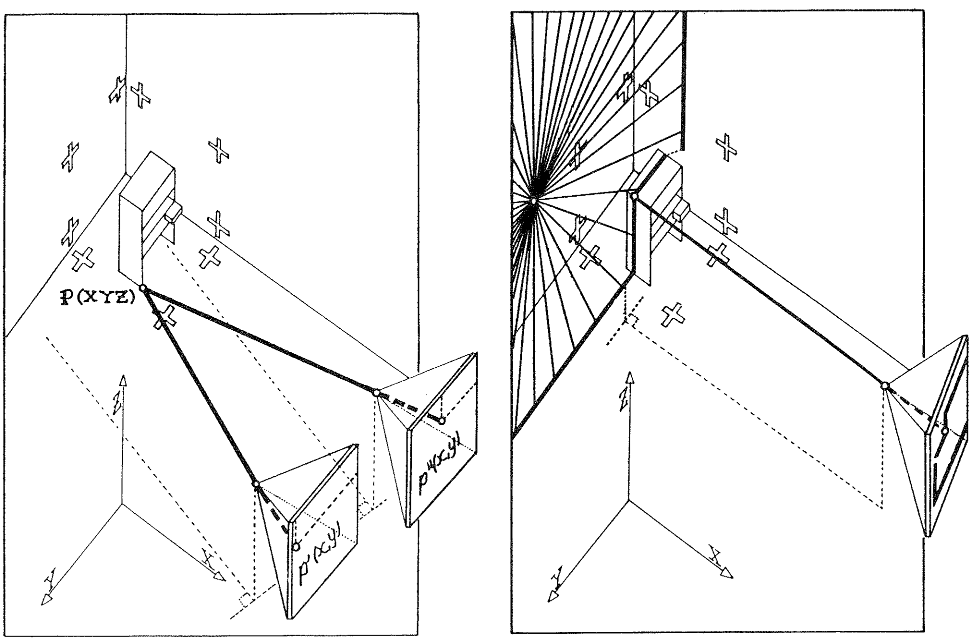

Figure 2. The third dimension in commercial machine vision systems is achieved by stereometric photogrammetry using parallel or slightly convergent images. The one of the stereo images may be replaced either by a plane of light or a set of gridded light spots projected by an absolutely oriented laser.

geometric problems due to the lens distortion effects. Lastly, when dealing with robot vision applications there are no actual needs for accurate three-dimensional measurements in real-time beyond the reach of the robot itself.

MAPVISION

Since early 1985 a photogrammetric prototype system for real-time engineering applications has been used at the Technical Research Centre of Finland /Haggrén, 1986/. The system consists of simultaneously operating CCD-cameras and an especially developed photogrammetric microprocessor. The original and simple purpose for building this kind of stand-alone prototype system has been to make the real-time photogrammetric principles practically operational and thus demonstrative also for the non-photogrammetric machine vision appliers.

Now we have got completed the succeeding version in our line of real-time photogrammetric machine vision systems. The performing capacity of the recent system conceptually meets the general needs of the industrial inspection and automated manufacturing control applications. We have considered the minimum reguirement for the spatial resolution for the measuring system to be as 1:5.000. It means a better measuring accuracy than 1mm in 5 meters in each of the three coordinate directions. The time delay for these measurements is about one second for each point.

The other of the system's new specifications is the ability to measure also moving points. This characteristic is of importance when applying real-time photogrammetry in tracking and quiding of automotive vehicles or remote manipulators. The grabbing time for the moving points to be measured is in relation to the imaging system and is now 1/25 of a second. The measuring frequency is respectively about once a second.

The new system is called Mapvision (Figures 3 and 4). It refers both to the technique of making maps and to the ability to map within the system's range of vision. It is also an acronym of Machine Automated Photogrammetric Vision System. On the other hand a recent MAP is the local network practice developed by General Motors Company for manufacturing automation (Manufacturing Automation Protocol), which is also nearly becoming an international standard.

The Mapvision's system concepts are versatile in regard to the measuring requirements and applications: first, there are four cameras which may be freely oriented in relation to the object space, secondly, the use of video allows the utilization of differend kind of imagery and, thirdly, the spatial accuracy may be adjusted according to the purpose.

The accuracy rate of the Mapvision system relates to the image resolution. In a basic mode the images are digitized with 8 bits in 512 by 512 pixels. The image processing part then extracts the targets or light spots on the images with a tenfold interpolation. The repeatability of the system remains geometrically stable and counts for less than 0.05 pixels during longer periods of continuous operation and even within days.

The preceeding practical experiments with the prototype system already confirmed the assumption that the tenfold pixel interpolation also improves the total accuracy of the Mapvision system. By using two convergent images and the same interpolation algorithms which are now inside the Mapvision the relative accuracy rate of 1:5.000 was achieved. This was proved by comparing, after the set up calibration of the system, the coordinates of a set of check points with the corresponding "true" coordinates, which were measured by intersecting with theodolites. The accuracy research with the Mapvision itself is now going on and for the present unfinished.

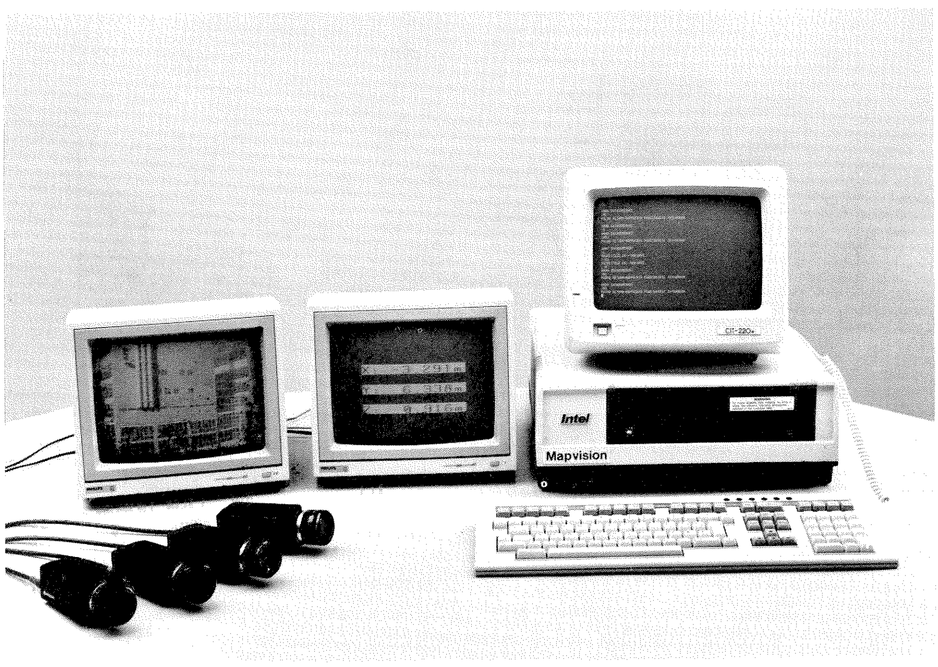

Figure 3. The Mapvision is a stand-alone photogrammetric machine vision system especially developed for industrial inspection and assembly control applications.

The first practical experiments with the Mapvision will be on the applications within industrial inspection and assembly control. In developing both the Mapvision and the prototype system we have taken into account that the systems are able to be developed further to new applications with new requirements. Because of the use of video cameras the potential applications are more due to the camera system than to the Mapvision itself. Principally, the applications like high-speed photogrammetry or underwater photogrammetry for example are within a relatively close reach.

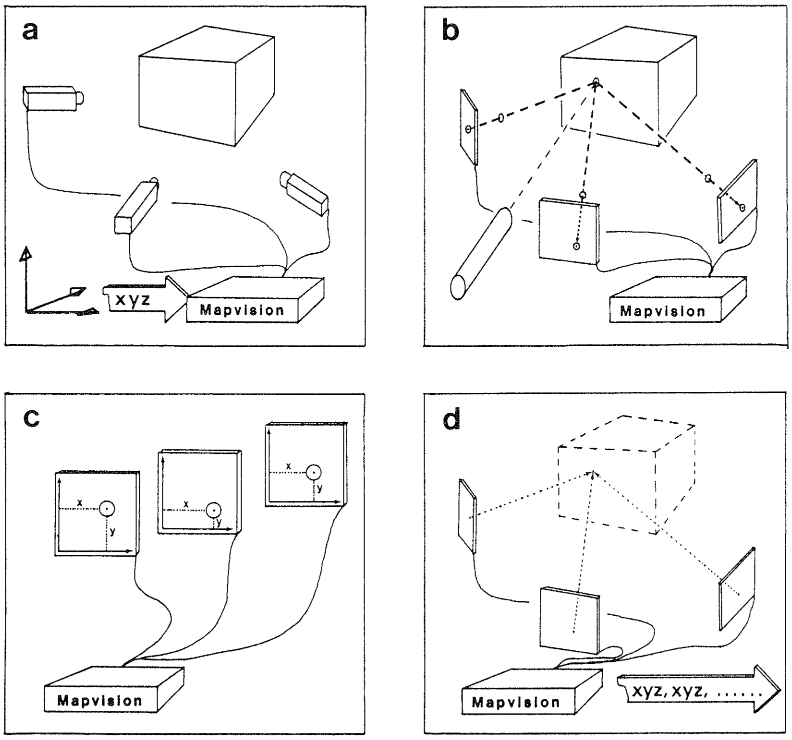

Figure 4. The functions of the Mapvision system. First, the system is set-up calibrated and the transformation parameters from two- to three-dimensional coordinates are solved using XYZ-control points (a). Under the surveying phase the points to be measured on the object space are first projected onto the image planes (b). The points are either targeted or pointed by a laser beam on the object surface. Then the points are identified and located on the images (c) and finally all the three coordinates of the points are calculated using the calibrated transformation parameters (d). The accuracy of the Mapvision measuring system is 1:5.000, for example 1mm in 5 metres, the grabbing time for moving object points 1/25 of a second and the frequency of the measurments about once a second.

The Mapvision consists mainly of standard and off-the-shelf camera and processor technology (Figure 5). There are no special optical or mechanical moving components included in the measuring system. Therefore the producing of the tailored Mapvision systems for specific and experienced applications will be ecomomic even in minor series. The real problem to be solved in the nearest future is rather on the business side itself i.e. how to move the systems out of the research laboratory and onto the factory shop floor.

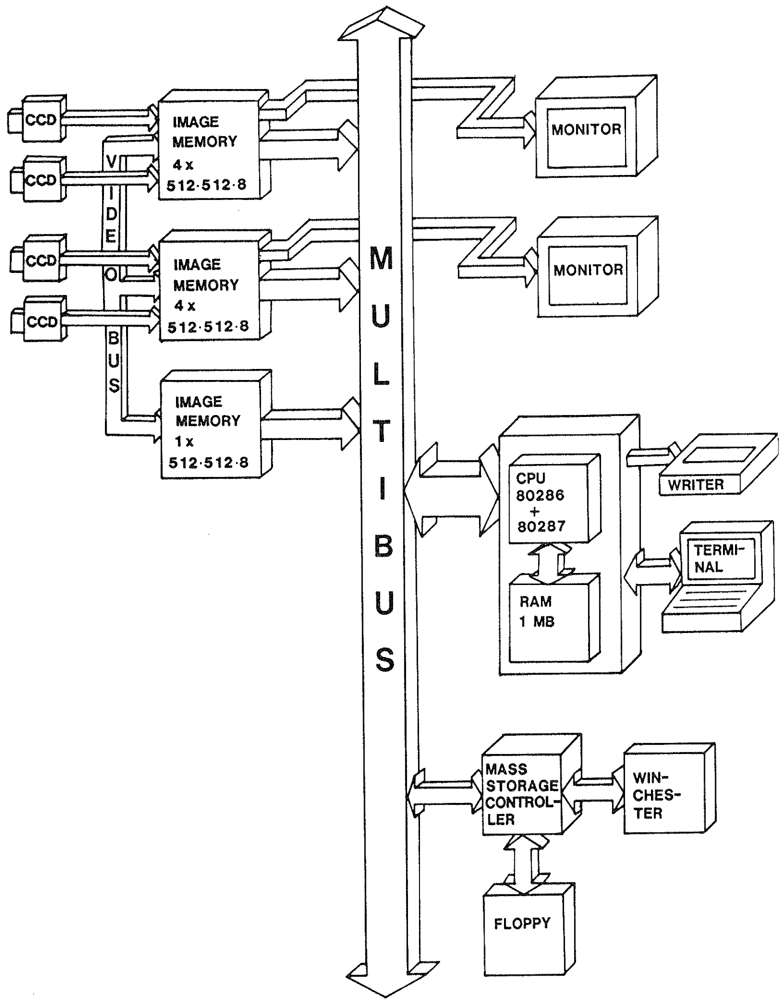

Figure 5. The Mapvision system diagram. The system consists of standard and off-the-shelf camera and processor technology. The system graphed above is used for development research of photogrammetric machine vision applications. The tailored Mapvision systems may be applicationally reduced.

CONCLUDING REMARKS

There are no technical obstacles today to apply photogrammetry in a really fascinating amount to machine vision. It is up to usselves how to get rid of the traditional thinking of photogrammetric systems and how to come in to this new era. The accuracy limit of 1:5.000, the real-timeness of about one second and the applications for factory automation handled in this paper are to be considered only as practical mileposts on this way. The real challenges lie far beyond them and are steadily effected by the rapid development of electronic, or better to say electro-optical component and processing technology.

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