REAL-TIME PHOTOGRAMMETRY: THE FAST ROAD TO VIRTUAL WORLDS ?

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ABSTRACT

The relations between photogrammetry and virtual reality (VR) are manifold. Not only can VR data be generated by photogrammetry, but photogrammetric techniques can also be used to control the interaction between the human and the virtual world. This paper gives a brief account of the status of development of digital close-range systems. In particular we will focus on the recent development of CCD-cameras and framegrabbers. We will distinguish the functionality of "point trackers" from commercial motion capture systems, general "low end" systems, and systems for reconstruction of surfaces. Also, we will comment on systems for the recording of larger structures, like in mobile mapping, architectural photogrammetry and laser scanning. Finally, some remarks will be made about more separate, specific new developments.

1. INTRODUCTION

Virtuality translates into "possibility", "opportunity", but also "force", "power". Therefore, a virtual reality (VR) is a possible reality, resting in a computer until it is brought to life and action by an operator. In a more technical definition a virtual environment (VE) is a computer-generated, simulated world, which must allow the user to view it from any point or direction and to interact with its objects. While the use of virtual environments finds an ever increasing audience and publicity in science, technology, education, entertainment and other areas, the creation of the data for realistic (sic!) virtual worlds remains a bottleneck. Here photogrammetry represents a viable technology to generate both vector data and natural texture data. Actually, the photogrammetric stereomodel has represented, for almost a century already, a rudimentary form of virtual environment (VE). Traveling with the 3-D measuring mark through the stereomodel provided for the operator an excitement which is paralleled today by roaming through virtual 3-D space using gloves and helmet-mounted displays.

The key restrictions of the traditional approach were the source data images being in analogue form, the lack of a modeled object, and limited control mechanisms. The superimpositioning capability of analytical plotters constituted already an additional step towards VR-functionality.

The relations between photogrammetry and VR are manifold. Not only can VR data be generated by photogrammetry, but photogrammetric techniques can also be used to control the interaction between the human and the virtual world. Therefore it should be of interest to investigate into the current status of the interdependence between photogrammetry and VR. For that, this paper gives a brief account of the state of development of digital close-range photogrammetry (or "videogrammetry"). We will follow here a strict defi-nition of "real-time". For a videogrammetric system real-time performance means that the response time of a process must be within one video cycle (25 or 30 Hz).

As it turned out in recent years, the advances in videogrammetry were mainly technology-driven. The emergence of new application areas was then a result of extended system functionality. In this context CCD-cameras as the prime sensor devices do play an important role. This is why we will start with a report on the latest developments in CCD-camera technology and also make some remarks about frame grabbers. In chapter 3 we will present information on point cloud generators and point target trackers with real-time or near real-time capabilities. Chapter 4 deals briefly with commercial surface reconstruction systems, while chapter 5 offers a more detailled view on approaches for the recording of larger structures. In this respect we will distinguish mobile mapping systems, systems for architectural photogrammetry and long distance laser scanners.

Finally, some other notable videogrammetric developments are adressed in chapter 6.

While aerial photogrammetric techniques may of course also contribute to the generation of VEs, we will, according to the topic of this Symposium, focus on close-range issues.

2. STATUS OF SOME SYSTEM COMPONENTS

Photogrammetric systems are applied to a great variety of different problems. Although one might conclude from this

that a number of different system concepts have emerged accordingly, but this is not true. One actually can distinguish two basic user requests (compare also Fraser, 1998). The first is high-accuracy dimensional measurement, as it is required in industrial manufacturing. While on-line and fast processing is an issue here, real-time performance is hardly required. The second comprises a broad spectrum of low-to medium-accuracy applications, including architecture, robotics, navigation, motion capture, and the like. For some of these applications real-time or near real-time processing is a key demand.
In general, a videogrammetric system consists of the components shown in Figure 1.

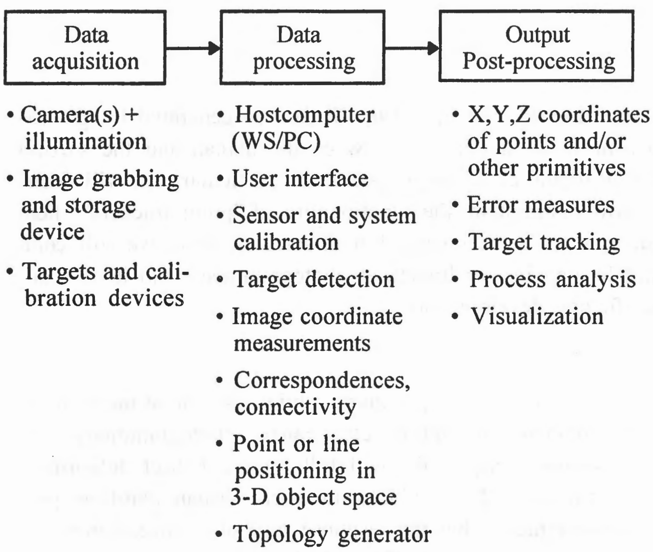

Figure 1: Components of a videogrammetric system

In the following we will look at some of the components for data acquisition, CCD-cameras and frame grabbers, as they have developed over the past few years.

2.1 Cameras

CCD- and other semiconductor cameras have emerged in a great number of types. We distinguish

- Standard CCD
- Large format CCD, HDTV
- Studio cameras, camera backs
- Sequential hybrid imagers (video theodolite, turning/tilting cameras, micro/macro cameras, line scan cameras)
- Still video
- Camcorders, digital video

These cameras vary according to parameters like chip type (matrix or linear array) and size, number of pixels, pixel pitch (resolution), output norm, type of synchronization, internal/external storage devices, and camera control elements.
Standard CCD-cameras are nowadays available to the hundreds and highly affordable. The main new features are pixel-synchronous readout or digital output, which avoids synchronization problems like line-jitter, and thus provides for geometrically rather clean images and progressive scan, which allows to image a full frame at once, thus getting rid of the image shift effects of a moving object, caused by interlacing. Large format CCD-cameras and chip backs are available with up to 4096x4096 pixels (e.g. ALT Systems, with KODAK KAF 16 800 sensor, 9 µm pixel, 12 bit, programmable sub-array, hosts SGI, PC).
While turning and tilting cameras, micro and macro cameras can only be considered expensive temporary solutions for our problems at hand, the potential of line scan cameras has never been fully investigated and exploited in photogrammetry. Test examples can be found in Murai et al., 1986, Godber et al., 1994, Zographos et al., 1997, Wu, 1997, Reulke et al., 1997, but in all cases linear array cameras with fixed sensor positions are used, while the camera or the object are either translated or rotated. Linear array scanning cameras are available producing up to 7000x7000 pixels (Power Phase of Phase One) and they constitute, because of their relatively low price, a viable alternative to the expensive very large format CCD area array cameras in static applications.
A great boost to digital camera technology has been given by the so-called "still video" cameras. These are handheld, portable digital cameras with all the features and controls of a photographic camera. The great majority of them does not really make use of a video signal, but the images are internally A/D-converted and digitally stored before they are transferred to a computer. Therefore, the term "still video" is misleading, but nevertheless firmly introduced. Working horses on the highend side are the Kodak DCS 200 (1524x1025 pixels) and DCS 460 (3060x2036 pixels). While the DCS 200 can record 5 images in 2 seconds, the DCS 460 produces only 2 images in the same time. Therefore real-time processing cannot be an issue here. Still video cameras are either produced for the mass market of the common photo amateur or the professional photoreporter market. Information concerning new products is readily available in daily newspapers and computer magazines (compare the Digital Camera Guide, March 1997, Plug-In Systems). Digital cameras with medium resolution (1024x768 pixels) are already available well under US$ 1200.-. This area of consumer electronics is developing so fast that keeping contact is not easy.
A similar development can be observed with digital camcorders. A new camera is offered almost every month. Major players in this field are Hitachi, JCV, Panasonic, Sony. For less than US$ 2500.- one gets for instance with the JCV Cybercam GR-DVM1 a one-chip camera with 670 000 pixels, 10x zoom (100x digital), 60 minute cassette, 6 cm LCD-monitor with 180 000 pixels, digital output for PC and video-printer, including multimedia interface, docking station, and PC-software. With the HITACHI MP-EG1A the first camcorder with integrated 260 MB PCMCIA harddisk has been launched, which allows for 3000 still images at 704x480 pixels JPEG or 20 minutes MPEG-1 videofilm.
For photogrammetrists these consumer electronics products have many features which make them interesting alternatives to the good old standard ("industrial") CCD-cameras. How-

ever, real-time capabilities are missing with both still video and digital camcorder technology.
Besides those mainstream developments we also note the evolvement of some specific features, as

- High speed recording; e.g. EG&G MB 4256 (256x256 pixels, 8bit, 1000 frames/sec, digital recording) or Phantom V3.0/Arrow/Rider (512x512 pixels, 500 frames/sec, digital PC interface), or Kodak EktaPro Series of Motion Analyser
- High speed/high resolution linear array colour; e.g. Dalsa (tri-linear architecture 3x2098 pixels, 30 MHz data rate)
- Microminiature CCD-camera; e.g. Toshiba IK-M41A (410 000 pixels, 1/2" chip, microlens, 38.9 mm length, 17 mm width, 16 g)
- Medium resolution progressive scanning; e.g. Pulnix TM-1001 (1024x1024 pixels, 9 µm, 15 Hz, digital output, 1/60-1/60 000 shutter)
- High resolution chip backs; e.g. KODAK DCS 465 (Hasselblad, Mamiya, colour, B/W, 3060x2036 pixels, 12 bit, 12 sec imaging time) or Dicomed Big Shot (Hasselblad 500 EL, EL/M, 553 ELX, instant colour, 3-shot sequential color, B/W, 4096x4096 pixels Loral Fairchild CCD, 15 µm, SCSI → Power Mac)
- Positioning sensor integration (GPS + bearing sensor); e.g. Konica Land Master GPS camera
- Smart sensors (IVP); sensor level processing camera-integrated microprocessor ("Smart Camera"; "Ranger Camera", 250 000 points/sec)
- Improvement of resolution by "half pitch shifting" of the green chip in 3-chip colour cameras
- Very large chips; e.g. Philips 9216x7168 pixels (laboratory status)

Especially the smart sensor concepts ("seeing chips") and the camera-integrated processing are concepts which strongly support real-time processing. On-chip functionality may include lower noise, better S/N ratio, programmable sensitivity, non-uniformity and shading corrections, variable exposure and timing control, region-of-interest capability, dynamic pixel size and shape, parallel image processing. On-chip processing is already commercially available, e.g. the 5402 range of monochrome medium resolution CMOS sensors from VLSI Vision Ltd., Saratoga, CA (http://www.vvl.co.uk). Camera-integrated processing has been reported by photogrammetric system manufacturers (http://www.geodetic.com). For machine vision inspection tasks a camera that integrates framegrabber, computer and software is available in form of the SmartImage Sensor, DVT Corp., Norcross, GA (http://www.dvtsensors.com).

2.2 Frame grabbers

Progress in framegrabbers has not been as startling as with cameras. Actually, the need for separate framegrabbers is constantly diminishing due to the developments in camera functionality, as mentioned under chapter 2.1. Nevertheless, the user has nowadays a wide choice of framegrabbers. Kodak alone lists for their cameras 18 manufacturers for PC platforms, with an average of more than 2 products each. For Mac, SUN, DEC and HP platforms only 1 to 2 manufacturers provide for products. This is a clear indication of the manufacturers´ emphasis.
In Image Processing Europe, 1998 a framegrabber board survey including 70 products is presented.
A typical current good performance framegrabber is the Matrox Genesis-LC. It can deal with virtually any video device: colour/monochrome, analogue/digital, frame scan/line scan, offers a single slot PCI bus solution with a transfer rate of over 100 MB/sec, can simultaneously capture up to 4 video streams with a total of 140 MHz, and offers on-board memory and real-time processing functions like cropping, tagging, zooming and subsampling. For further information contact for instance http://www.matrox.com/imaging (Matrox), or http://www.datx.com (Data Translation).

3. REAL-TIME OR NOT ?

If we accept the definition of "real-time" for a videogrammetric system such that "the response time of a process must be within one video cycle" (25 or 30 Hz) we will quickly realize that there are only very few reports on truly real-time 3-D videogrammetric performance available.

3.1 Point trackers

In early successful applications, like the control of Space Shuttle´s Manipulator arm (Kratky, 1979) or the control of a table tennis robot (Beyer et al., 1989) high performance was achieved through hardware-based grabbing of blob-like targets in the analogue video signal. Other applications in biomechanics used lateral effect photodiodes (PSDs) to achieve video speed or even more (Woltring, 1974, Krzystek, 1990, Maurice et al., 1990). It is also well-kown for long that systems based on three or more linear array CCD-cameras equipped with cylinder lenses can track a single LED target with a frequency way beyond video rate (e.g. OptoTrak, 1997). But then, the tracking of just one point in 3-D space constitutes a very specific solution. This restriction has been overcome by the system PRIMAS (Sabel et al., 1993), which is capable of tracking about 20 LED targets at 100 Hz with two CCD-cameras. Aiming at measurement rates of 500 targets per 1/25 sec is the proposed system of Clarke et al., 1997. Maas, 1997 has reported in a dynamic robot calibration project that with a three CCD-camera arrangement 8-10 points can be tracked with 25 Hz on a SUNSparcStation 20, without any special DSP-hardware. Algorithmically, the data processing includes coarse target location, centroid operator and spatial intersection from the camera triplet.
A particular solution has been presented by Chikatsu et al., 1997b. They are developing a 60 Hz progressive scan camera which reads the digital images directly into 512 MB computer memory. Image processing functions like binarization and labeling are performed by hardware. Thus about 100 markes can be tracked in real-time. Human body silhouettes can also be extracted. The system is still under development. In another application Chikatsu et al., 1997a have used a video

theodolite in order to track a model (toy) ski jumper. This was achieved at a rate of 3.2 images per second for an image window of 150x150 pixels.

In conclusion, there are currently just a few 3-D systems that provide for video real-time responses in a strict sense, and these systems can only cope with a handful of blob-targeted points at most and operate with standard video image formats.

An interesting application is proposed in El-Hakim et al., 1996, where two CCD-cameras are supposed to track the movements of a person´s head and hands, which are marked with retrotargets, in front of a display screen at NRC´s VE facility. If the 3-D aspect is not strictly enforced, or/and if a substantial loss of accuracy can be accepted, then systems like the one reported by Paradiso, Sparacino, 1997 on tracking for music and dance performance may also count. However, if the term "real-time" is a bit stretched to "quasi or near real-time", meaning just time-constrained solutions, many more systems are coming into the picture. Among those are for instance the GSI V-STARS INCA 4.2 and 6.3 cameras, which come with embedded 486 PC. The flood of pixel data caused by the large formats of 2024x2024 and 3072x2048 pixels respectively is compensated by on-board processing capabilities. Images may be compressed down to 10% and on-board functions include coded target recognition, blob measurement and problem detection, like no flash, missing targets, missing pictures, bad camera aiming, weak points, etc. The overall performance may be characterized best by the fact that one object point marked by a probe can be determined in a two to three images configuration in about 1 sec (this includes recognizing and measuring 6-12 coded targets and 5-6 points on a probe). This concept clearly offloads the system bus and the host memory substantially.

3.2 Special application: Motion capture systems

Tasks of increasing impact are the recording of objects under motion. Besides the traditional applications in medicine, biomechanics and sports the movie- /TV-animation and the video games industries represent quickly expanding markets. No wonder that many system manufacturers and service providers try to get a strong foothold in the market. Here the optical systems seem to be gaining momentum compared to earlier tethered magnetic solutions (e.g. Motion Star Wireless, Flock of Birds, both Ascension Technology Corp.; Ultra Track Pro, Star Trak, both Polhemus). Current systems for optical motion capture include

- Cybersight (records moving surfaces), Lawrence Livermore National Laboratories
- Expert Vision HiRes, Motion Analysis Corp., Santa Rosa, CA
- Multi Trax Pro, Adaptive Optics, Cambridge, MA
- OptoTrak, Northern Digital, Waterloo, Ontario, Ca
- Photo 4D-Pro, CompInt, Nepeau, Ontario, Ca
- Vicon 370E, Oxford Metrics, Oxford, UK
- ProReflex and MacReflex, Qualisys AB, Sävedalen, Sweden

Among all these systems the author is aware of only one which makes use of strictly photogrammetric principles.

Typically the systems allow to apply up to 6-7 cameras and are capable of tracking 100 and more markers. Normally they are used in full body recordings of humans and animals. Opposed to that, single cameras are used for face tracking. Face tracking system vendors include

- Adaptive Optics, Cambridge, MA
- Digits´n Art, Montreal, Ca
- Motion Analysis, Santa Rosa, CA
- SimGraphics, South Pasadena, CA
- Vierte Art GmbH, Munich, Germany
- X-IST Realtime Technologies GmbH, Huerth, Germany

Face tracking is usually also performed with markers, but products are underway which are based on muscle motion tracking (e.g. Deface from TechImage).

Because of the simplicity of the marker-based facetrackers (one camera, few key points only) video real-time performance is realistic. The much more complex multi-station motion capture systems deliver their results (trajectories) within a few minutes, once the system is calibrated. Sampling frequences extend well beyond video, up to 240 Hz, or even 1000 Hz with smaller image formats and less markers.

3.3 Commercial low end systems

Besides automatic, accurate high end systems there is another branch growing quickly: low cost, low priced systems which usually run under the slogan "turning photographs into 3D models".

Among those are

- 3D Builder Pro, 3D Construction Company, TN
- 3D Expres, 3rd Dimension Technologies, Inc., CA
- PhotoModeler, Eos Systems Inc., Vancouver, Ca
- Wireframe Express, Synthonics, CA

Especially PhotoModeler has become fairly advanced and popular. For a few hundred US$ it includes a multi-station bundle adjustment with a rudimentary form of self-calibration, curves and cylinders, plane and line fitting, texture mapping, and 3DS, OBJ, VRML, DirectX, and DXF exports.

The emphasis of these systems is on the production of CAD-compatible data. This can be in form of sparse point clouds or dense mass point data sets representing surface descriptions. We use PhotoModeler quite extensively in teaching. It offers a simple user interface, is fairly robust, and gives students quick access to the multi-station processing problem.

4. RECONSTRUCTION OF SURFACES

Systems for surface reconstruction, especially for medical and industrial applications (e.g. reverse engineering) have recently emerged in great numbers. Most of them use either coded light, sometimes combined with a phase shift approach or laserscanning/lasertriangulation principles. Vendors of the former are ABW (Wolf), Breukmann, DCS Corp., Massen

Machine Vision Systems, Newport Opto CAM, RSI Oberursel, Steinbichler. The latter system principle is offered by BCT GmbH, Hymarc Ltd., IBEO GmbH, Odetics, Medar Inc., Vision 3D, 3D Scanners Ltd., CGI, Cyberware, Digibotics Inc., Kreon Industries, Laser Design, Minolta, Perceptron, Sharnoa, SMX, L.O.T.-Oriel Suisse, Erwin Sick AG, RIEGL Laser Measurement System GmbH, Vitana Corp. These lists are not meant to be complete, but should simply indicate the active commercial scenery in this field. Of course, in addition to that, there are also many University-based systems around.

Most systems generate a single view dataset at very high speed, typically over 10 000 points/sec. A new trend is to connect the individual surface patches of a large or complex object (like a full car) by bundle triangulation using targetted points and still video cameras (e.g. Newport's Atos XL or compare Malz, 1996, Michaelis, 1996). This is when photogrammetric expertise enters the picture. Another method of combining unregistered data sets is to utilize either identical surface intrinsic parameters of overlapping patches, or texture information (tie points) when images have been created (e.g. Sculptor, Fraunhofer IGD).

5. RECORDING OF LARGE STRUCTURES

Large structures of indoor and outdoor scenes are of particular importance to VR-applications. These structures are usually so complex that fully automated processing fails. In such cases either manual or semi-automated processing techniques are applied.

Mobil mapping systems: A number of such systems has emerged over the past years. They all can be characterized by a hybrid sensor design. Typically the outdoor systems come with sensors like GPS, INS, odometer, barometer, 2 B/W video cameras for object positioning, 1 colour video camera for object recognition (Klemm et al., 1997). Some allow for additional voice entry and are interfaced to a GIS database.

Photogrammetric functions, although available on all systems, do not seem to be highly advanced in terms of automation. First results of line matching have been shown in Benning, Braess, 1997.

In contrast to that, there seems to be an increasing interest from a practical point of view, and new applications are added like the one described in Volz et al., 1997 and Streilein, 1998, which refers to the recording, documentation and analysis of building damage occuring during earthquakes.

For indoor 3-D mapping applications an interesting system has been presented by El-Hakim et al., 1997. Since GPS cannot be used indoors, the absolute positioning is being done by videogrammetric triangulation. Local 3-D surface information is collected via laser point triangulation fully automatically, while other functions, like feature extraction for bundle triangulation, have to be supported manually. For building up the 3-D environment real-time performance is not an issue and nothing is said about timing in the navigation phase.

Architectural photogrammetry: The previously mentioned application for earthquake damage assessment is in essence already a digital system for architectural photogrammetry. Progress in this area has been achieved in recent years in particular through the development of methods for object-oriented, semi-automated measurements and the integration of CAD. In Streilein, 1996 very coarse CAD models of the object are used to initialize an automated measurement process, whose results improve the CAD models both in terms of level of detail and metric accuracy. The operator monitors and guides the iteration procedure interactively. As a matter of principle, the reconstruction is achieved via several iteration layers, and thus real-time performance is not even intended.

While the issue of model-based reconstruction is gaining in importance (compare also Förstner, Gülch, 1997 and Haggren, Mattila, 1997), experts in architecture and archaeology have, understandably, not a great interest in real-time performance. User and scientists of this area are more focusing on visualization and information system (Monument Information System) issues.

Key innovations in this field do come partly from external groups. Debevec et al., 1996 for instance have described an interesting system which includes model-based feature measurement, model-based stereopsis, and view-dependent texture mapping.

Laser scanning systems: Laser scanning systems, based on the time-of-flight principle, and providing also greyvalue image data, are occasionally used to record larger objects. Examples can be found in Hug, Wehr, 1997 (reconstruction of the skeleton of a complete dinosaur) and Wehr, 1997 (reconstruction of a cave and a statue).

6. SOME OTHER NOTABLE DEVELOPMENTS

In a review paper for the Symposium of ISPRS Commission V in Melbourne, Australia the author presented an account of the development of digital close-range photogrammetry from earliest attempts in 1984 and before, up to the year 1994 (Gruen, 1994). Since then the technology has constantly advanced, pretty much along the predicted lines. However, a few interesting recent landmark developments, which are not covered by the previous chapters, are worth mentioning.

- The full automation of exterior orientation of images of structured environments has made progress through the use of coded targets, target grouping or special EO devices (Niederoest, Maas, 1996, Schneider, 1996, Fraser, 1997).
- The accuracy of videogrammetric 3-D deformation measurement has been pushed to better than 1:250 000 (Maas, Niederoest, 1997).
- Oda et al., 1996 report about the CMU video rate stereo machine, a system which produces dense 200x200 elements depth maps from multi-camera arrangements with up to 6 cameras at 30 frames per second. Combined with an image overlay procedure called "z keying" the system is able to

have a real person walking around in a synthetic room with mapped texture at the rate of 15 frames per second.

- Face reconstruction and modeling, combining stereo and silhouette data, has led to remarkable results (Fua, Miccio, 1997). However, the potential of videogrammetric techniques has not yet been fully exploited in this context.
- Volume element tracking with 3-D least squares matching has now been implemented as a multi-cuboid matching procedure, considering neighbourhood conditions between adjacent cuboids (Deusch et al., 1997). The results of a continuum motion analysis system for 3-D flow measurement by Laser Induced Fluorescence (LIF) imaging show a remarkable improvement.
- The concept of energy minimizing functions (Snakes) and global least squares matching has been combined into a new type of Snakes, the LSB-Snakes (**L**east **S**quares **B**-spline Snakes). LSB-Snakes can measure linear features in multi-image configurations and deliver directly a 3-D object space representation (Li, Gruen, 1997). This can be of great value whenever 3-D linear features have to be reconstructed from a multitude of images.
- In a recent effort (Fua et al., 1998) a videogrammetric system is being used and a concept for data processing is presented which integrates motion analysis, surface reconstruction by image matching and silhouette extraction within a unified approach. The application refers to full body modeling under motion, where moving humans are recorded and later animated in different environments.

7. CONCLUSIONS

Among the many applications of videogrammetric systems video real-time or near real-time performance is only required in special cases, where dynamic events have to be monitored and controlled, like in robotics, navigation and userinterface technology. Real-time performance is to a great deal dependent on the project specifications, on the hardware used and on the algorithmic complexity.

On the hardware side we observe some mainstream developments in the sense that CCD-cameras are becoming available in a great variety of different types, with ever increasing number of pixels, at more affordable prices. Unfortunately, the number of pixels is inversely proportional to the computing time performance. This disadvantage is balanced to a certain extent by the fact that within the "smart camera" concept some elementary processing functions are performed "onboard", before the pixel signal leaves the camera. Furthermore, the increasing possibility of having digital read-out and very broad system busses like the IEEE 1394 "Firewire" supports also a very fast processing concept. These developments will render the current framegrabber boards obsolete in a foreseeable future. Cameras and processing devices will further converge into integrated units.

With current standard technology (3 CCD-cameras, SUN SparcStation 20, no special DSP hardware) we can track about ten signalized points at 25 Hz with an accuracy of 1:10 000 and better. This is sufficient for a number of tasks which allow for the use of passive markers. However, in some applications like motion analysis, many more markers (100 and more) or non-marked, natural features have to be tracked. If this needs to be done in 3-D with fairly high accuracy than video real-time can only be achieved with extraordinary hardware integration efforts.

For the generation of virtual environments we have to distinguish two different approaches, which also lead to different computing time requirements. Firstly, there is the case of essentially off-line generation of VEs. There are typical applications in architecture and archeology, in virtual museums, mobile mapping, and in all kinds of design and simulation tasks. While it is desirable here to generate the data very quickly, video real-time performance is not a hard constraint. Secondly, we have the cases of interaction of living subjects, mostly humans, with synthetic, virtual environments. These are the true challenges for videogrammetric systems performance. In many cases, high accuracy requirements are coupled with severe computing time performance expectations. There is ample room for valid research topics and system development work. Digital photogrammetric technology will remain an attractive and relevant discipline for the years to come.

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