XVII ISPRS Congress, Washington DC, August 2-14, 1992
published in: The International Archives of Photogrammetry and Remote Sensing, Vol. XXIX

High-Speed Solid State Camera Systems for Digital Photogrammetry

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Abstract:

For many applications in machine vision, digital photogrammetry and scientific research image sequences of rapidly moving objects have to be acquired with high temporal resolution. If the standard video rate (30 frames/sec NTSC resp. 25 frames/sec CCIR) is not sufficient, high-speed solid state cameras may be considered offering frame rates of up to 15,000 frames per second. As the processing or data reduction of their images will usually not be possible in real time, appropriate analog or digital image sequence storage devices have to be discussed.

One of the most important features of a high-speed solid state camera system is the data rate. While the systems with the highest data rates still come with analog storage on video tape, systems with digital storage on RAM or realtime disks are preferable from the aspects of accuracy and data handling. This overview will present some high-speed solid state camera systems with data rates ranging from 8 MB/sec up to 175 MB/sec, frame rates of 100 to 15,000 images per second, sensor sizes of 64 x 64 to 756 x 287 pixels, digital and analogue data storage including an own scheme with cascaded standard cameras, compare their technical data and discuss their applicability and restrictions.

Introduction

Using the term “high-speed” in combination with solid state sensor technology one first has to define what is meant by high-speed. A misunderstanding often to be found in the literature as well as in manufacturer brochures is the use of the word high-speed camera for CCD cameras with ultra-short shutter times. Such cameras - often equipped with image intensifiers - offer exposure times down to a few nanoseconds and are suitable for freezing extremely fast motions, but they usually work with the standard video signal (which means that they deliver 50 video fields per second in the European CCIR norm or 60 video fields per second in the US NTSC norm, as in all electronically shuttered cameras with interlaced output the integration times of the two video fields do not overlap) and are not suited for events which require high imaging rates. In this publication the term high-speed camera is used for solid state cameras which offer imaging rates of more than 100 images per second.

If image sequences with high imaging rates cannot be processed in realtime (where realtime is defined by the imaging rate) or have to be played back in a slow motion mode, suitable image sequence storage devices have to be designed. In general one can distinguish systems with analog image transmission and storage (usually on videotape) and digital systems (usually with RAM or realtime disk storage). While analog systems (Miquel, 1987) offer the highest data rates and storage capacities, digital systems offer some important advantages like direct random computer access to data and better data quality especially to users who are interested in any kind of digital image processing.

Film based systems do still offer the highest imaging rates (one million images per second and more - Johnson, 1990) or higher resolution at imaging rates comparable to those of solid state sensor systems, but they are not considered in this publication due to the time consuming off-line process of developing and digitizing film (Godding, 1990).

To achieve high imaging rates with solid state sensors some rather different ways can be chosen:

- Faster sensor readout (which is generally limited by the manageable data transmission frequencies).
- Higher temporal resolution at cost of spatial resolution (i.e. higher imaging rate but less pixels at constant data rates).
- Selective readout (often by skipping of a certain number of lines).
- More than one readout port per sensor.
- Multi-sensor systems.

There is no standard around in the high-speed world, so that a user has to solve some compatibility problems between camera and storage device. Some manufacturers offer complete systems, which are often tailored for special requirements. Basically those systems can be subdivided into systems for use on the factory floor and systems mainly designed for digital image processing purposes. Factory floor systems are often being employed for the examination of assembly line problems which occur too shortly in time for human perception. Their main purpose is the recording of events with imaging rates of typically 500 - 1000 images per second and a play back in a slow motion or image by image mode for visual interpretation by a human observer. These systems are usually delivered as simple-to-use turnkey systems, but they are somewhat restricted for the use in machine vision or scientific applications due to their lack of flexibility and bottlenecks in the transfer of digital image data to computer systems. For such applications computer based systems with direct access to digital images will often be the better solution.

In the following some typical high-speed systems and a (not realized) own scheme will be presented showing the potential and limitations of high-speed solid state sensor systems. The classification of systems into different categories is sometimes floating. The study does not claim to be complete, and technical details and performance data may change quite rapidly. Due to the politics of manufacturers and distributers in different countries and due to the fact that many systems are specially compiled for customers needs prices will not be given.

1. “Factory floor” systems

Factory floor systems are usually complete systems consisting of a camera, storage device, monitor and control panel mounted on a rack which easily can be moved to sections of assembly lines where disturbances occur in fast production processes. The basic task of the systems is the recording of fast events and a slow motion playback at the location of use immediately after recording in order to find causes of trouble and to be able to remove them interactively. The extremely high costs of production line stops will often justify the high investment for such systems.

The probably best known factory floor system is the Kodak Ektapro 1000 (Figure 1). It consists of a camera with a black and white solid state sensor (NMOS) with a resolution of 192 x 240 pixels. The imaging rate is 1000 images per second at full resolution and can be increased up to 6000 images per second by skipping lines and reading only every sixth sensor line, which reduces the spatial resolution to 32 x 240 pixels. The camera can be shuttered with a 10 µs shutter to freeze fast motions or synchronized with a strobelight. An intensified version is also available, and the processor is able to mix data from two cameras at reduced spatial resolution. Kodak offers two options for image storage: The analog version is a videorecorder with two videoheads and 19 read and write tracks each and special videotapes with a storage capacity of 40 seconds; for the pause mode a digital memory for 8 images is available, which can be read out via a GPIB interface. For cheap data archiving there is the possibility of a download to standard video cassettes.

8 x 8 cm

Figure 1: Kodak Ektapro 1000

As an alternative Kodak offers the Ektapro 1000 with a dynamic RAM memory Ektapro EM (Hyzer, 1990), which has got a storage capacity of up to 4800 images. Extensive trigger possibilities allow the capture of intermittently occuring random problems detected by various kinds of sensors. The dynamic RAM can be formatted arbitrarily, images can be stored at any depth (e.g. 9600 images of 4 bit depth instead of 4800 images of 8 bit depth); download on standard video cassettes and computer interfacing via GPIB are also possible.

A system with very high (analog) data rate is the NAC HSV 1000. The system is based on a 2/3” MOS colour sensor and delivers 500 images per second at full vertical resolution of 262 lines with a horizontal resolution of 350 line pairs at centre (black and white, S-VHS) or 240 line pairs at centre (colour, VHS) or 1000 images per second at a reduced vertical resolution of 131 lines. The analog data is stored on standard S-VHS video cassettes in a special format which allows the storage of 10 minutes of image data on one video cassette. Like it’s predecessor NAC HSV 400 (three-tube colour camera with 400 images per second) the HSV 1000 offers colour images, but at a relatively poor quality because it is equipped with only one sensor. A computer interface does not exist so that images can only be digitized from a playback on a videorecorder. Thus the NAC system seems not very suited for any task requiring digital image processing.

2. Computer-based systems

Some manufacturers offer complete systems consisting of a high-speed camera and a computer board with camera control and RAM chips for image sequence storage, which are better suited for users in machine vision or scientists who need direct access to digital images.

The Fraunhofer CAMSYS consists of a DALSA Turbosensor camera and PC interfaces for camera control and data transfer from a 64 MB RAM frame storage to the PC harddisk. Optionally a camera with 256 x 256 pixels and 200 images per second or a camera with 128 x 128 pixels and 1000 images per second can be used. By skipping lines the temporal resolution can be increased to 3200 images per second (256 pixel version) or 6400 images per second (128 pixel version) at constant data rate. Like with the Ektapro EM the maximum sequence length is limited to about 5 seconds by the RAM capacity.

Besides linear array sensors with data rates of up to 120 MHz DALSA does also offer some more area cameras with 32 x 32 pixels, 64 x 64 pixels (3000 frames per second) or 512 x 512 pixels (60 frames per second), all with camera data rates of 16 MHz. DALSA does not offer any storage devices, so that the compilation of a complete system has to be solved by the user.

EG&G Reticon offers some interesting cameras and systems with imaging rates ranging from 100 images per second up to 15,000 images per second. The Reticon sensors are photodiode array types with a non-interlaced output. The MC9000 series area cameras are available with a 128 x 128 pixels sensor (380 images per second) or a 256 x 256 pixels sensor (105 images per second) and have been used by scientists extensively (e.g. Dahm et al., 1990). With data rates of 8 MHz they do not belong to the fastest cameras today. The MC4256 (Figure 2) is a new fast framing camera which integrates directly into a PC. It comes with the same 256 x 256 pixels photodiode array as the MC9000, but by parallel read-out with 8 read-out ports an imaging rate of 480 images per second is achieved. The companion AT-bus interface provides complete camera control and a 64, 256 or 1024 frame memory, which corresponds to a maximum sequence length of 1/8, 1/2 or 2 seconds.

6.7 x 9 cm

Figure 2: MC4256 camera with PC interface board

Highest frame rates can be achieved with the MC6464 camera (Figure 2), that can produce analog video at 15,000 frames per second from a 64 x 64 pixels sensor with 32 parallel read-out ports. The companion control unit produces 12 bit digital video at 7500 frames per second.

6.5 x 9 cm

Figure 3: MC6464 camera

All these PC based systems with RAM storage are limited in their storage capacity as the RAM on board can not be arbitrarily extended and the write rates to standard harddisks are generally too small. An alternative to RAM storage is the storage of image sequences on realtime disks (RTD, sometimes also called videodisk). RTD systems come as parallel transfer disks (one disk with multiple write and read heads) or - mostly - as parallel disk arrays (Figure 4) and a controller distributing the data over many single disks. The most powerful systems available today offer data rates of up to 292 MB/sec and 672 GB of total capacity. Disregarded the cost such a system can be an ideal storage device for longer image sequences, if it can be interfaced to a high-speed camera.

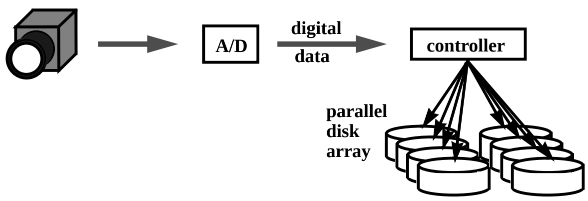

Figure 4: Parallel disk array - principle

3. Multiple sensor systems

A relatively simple method to reach high imaging rates is the sequential read-out of more than one sensor. To the authors knowledge there is no such multisensor system commercially available on the market, but if the task allows to accept some handling problems one can relatively easily design a powerful scalable high-speed system by simply cascading standard CCD cameras. If one uses for example 16 CCD cameras with 50 fields per second each (CCIR) and a shutter time of 1/1000 sec or less and synchronizes them phase-shifted in a way that the integration times do not overlap (Figure 5), one can achieve an imaging rate of 800 images per second at a resolution of e.g. 756 x 287 pixels (Sony XC77 or relatives). This corresponds to a data rate of 175 MHz, which is far beyond the data rate of any of the systems mentioned above. Working with full frames is not possible here as electronically shuttered cameras do principally integrate charges at the end of each field.

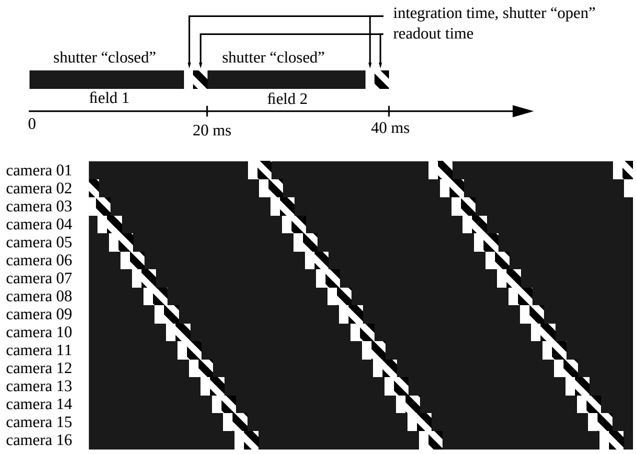

Figure 5: Phase shifted synchronization of 16 CCD cameras

The image data can again be stored on an analog or a digital device. An analog storage on videorecorders (one per camera!) allows for extremely long image sequences of up to 240 minutes, but the data handling and the digitization of images from the videotapes (Maas, 1990) becomes cumbersome, so that such a system cannot really be called an on-line system any more. If sequence lengths of about 1.5 seconds are sufficient, image sequences can be digitized directly by framegrabbers equipped with 16 MB frame storage avoiding losses in image quality due to the analog intermediate image storage (Maas, 1992). For such a digital cascaded high-speed camera system 16 framegrabbers with 16 MB of memory each would be necessary. But although consisting of 16 cameras, lenses, framegrabbers, a synchronization device and probably four host computers, such a system (Figure 6) will still be significantly cheaper than the factory floor systems mentioned above.

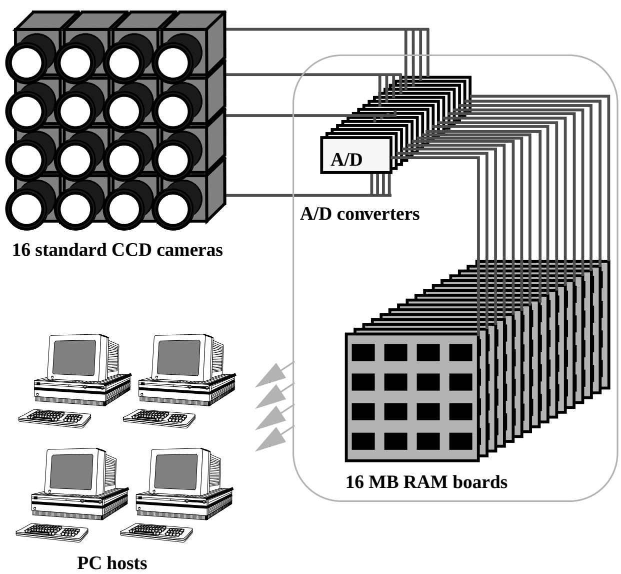

Figure 6: Cascaded 16 CCD camera system (scheme)

It offers the advantage of high flexibility and scalibility, however at cost of a relatively expensive data handling due to the distribution of data over multiple devices. The main disadvantage, however, is the fact that, if not a very complex optical system connecting all sensors to one optical path is being designed, depending on the task computationally expensive image transformations may become necessary. If these problems are considered tolerable for the designated task, cascaded CCD cameras can be a very powerful high-speed system.

Conclusion

The use of high-speed solid state sensor systems allows for the design of very efficient, flexible measurement systems. Although more expensive, systems which come with digital data storage offer some important advantages to users who are interested in more than just a visual slow motion interpretation of recorded data. But even in factory floor systems which are mainly designed for slow motion playback there is a clear tendency towards completely digital systems. Most interesting from the point of view of a user from machine vision or digital photogrammetry are PC-based systems with data rates of up to 32 MHz and RAM sequence storage, which can be purchased at a relatively moderate price (relatively as compared with other systems, not absolutely), or realtime disks, which offer much larger storage capacities. The technique in this sector is developing quite rapidly, so that very soon systems with higher data rates and larger storage capacity will be available.

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