P17 Design of a 148,680-pixel Ultrahigh-speed, High-Sensitivity CCD

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ABSTRACT

We are currently promoting development of an ultrahigh-speed, high-sensitivity broadcast camera that is capable of capturing clear, smooth slow-motion videos even in cases where lighting is limited, such as at professional baseball games played at night. Last year, we developed an ultrahigh-speed broadcast color camera[1)] using triple 81,129-pixel ultrahigh-speed, high-sensitivity CCDs[2)]. This camera had about ten times the sensitivity of standard high-speed cameras, and enabled an entirely new style of presentation for sports broadcasts and science programs. In order to develop an ultrahigh-speed broadcast camera with higher resolution, we designed a new 148,680-pixel ultrahigh-speed, high sensitivity CCD.

INTRODUCTION

High-speed cameras can capture images of objects that are moving too fast to be seen clearly by the human eye. Because such images can be played back as slow-motion video, these cameras have many applications in broadcast programming.

Most conventional high-speed cameras use CMOS imaging devices[3)] that read signal charges at high speed with an X-Y matrix switching method. However, CMOS imaging devices have inferior noise characteristics compared with CCD devices, and so a good signal-to-noise ratio cannot be attained in high-speed imaging with a short exposure time, particularly under less than bright lighting. Accordingly, high-speed imaging of sufficient resolution and quality is very difficult to attain in night-time sports events.

Last year, we developed a high-speed camera suitable for broadcasting programming. The camera that we developed employs three special CCDs that provide both high-speed operation and excellent sensitivity. When used for actual live coverage of professional baseball or golf events, this camera is capable of broadcasting slow-motion video that has unprecedented image quality and motion resolution, to the extent of clearly capturing the moment of impact of a ball with a bat or club.

In order to develop an ultrahigh-speed camera with higher image quality for broadcasting, we designed a new 148,680-pixel ultrahigh-speed, high sensitivity CCD.

ARCHITECTURE OF THE ULTRAHIGH-SPEED, HIGH-SENSITIVITY CCD

In ordinary CCDs, the signal charge generated in photodiodes by light must be read from outside the device over a long transmission path (1,000 or more transfer steps), making it difficult to attain higher frame rates. Our camera employs a special CCD sensor called an In-situ Storage Image Sensor (ISIS). Each pixel of the ISIS sensor has its own in-situ storage area for image signals.

This reduces the steps involved in transferring the signal charge to one per frame, opening up the possibility of ultrahigh-speed imaging at up to 1,000,000 frames/sec. Furthermore, sensitivity ten times higher than that of conventional CMOS imaging devices is obtained by designing the CCD for a large photodiode area as well as low noise.

The structure of ISIS is described above (Fig. 1). Image signals generated in the photodiodes are transferred to the linear in-situ CCD storage, whose placement is slightly slanted to the grid axes of the photodiodes. The one-directional transfer significantly simplifies the structure of the gates and metal-wiring within the in-situ storage. The simplicity of the structure also contributes to increase the yield rate and decrease noise. The frame rate depends on the transfer rate of the storage CCD. The linear in-situ CCD storage has a slightly slanted alignment, of which the angle is adjusted so as to place the lower linear CCD storage under the upper one without wasting space.

In the readout VCCD, a vertical drain for the overwriting operation is installed. During the image-capturing phase, old image signals are continuously drained to the substrate by means of the vertical anti-blooming drain, and the latest ones are successively stored in the linear in-situ storage. The operation continues in parallel at all the pixels until a trigger signal is released to stop the image capturing operation right after the occurrence of a target event.

In the readout phase, one vertical VCCD channel at the right end of each storage area works as a readout CCD.

The readout operation is as follows:

(1) The charge transfer operation stops in the linear CCD storage areas. The operation transfers only image signals stored in the readout VCCD to the HCCD below the photo-receptive area. The readout VCCD becomes empty.

(2) Image signals in the storage are transferred to the readout VCCD until it is filled with signals. The cyclic operation of (1) and (2) continues until the storage and the readout VCCD become empty. For the cyclic readout operation, the storage CCD and neighboring readout VCCD are designed to be operated independently. The CCD element at the end of the linear in-situ storage, which is the top of the readout VCCD of each pixel, works as a switch to control the transfer of charge packets from either the linear CCD storage or from the upper part of the readout VCCD, or from both of them together.

SPECIAL DESIGN OF THE NEW ULTRAHIGH-SPEED, HIGH-SENSITIVITY CCD

We have designed a new ultrahigh-speed, high sensitivity CCD with the following unique features:

1) Optimized layout design achieves 148,680 pixels, about twice the number of pixels compared to the previous design, without any increase in the chip area or loss of sensitivity.
2) In order to increase the capture time during ultrahigh-speed capturing, the CCD memory cell has been reduced in size and the number of frames increased, enabling an image recording capacity of 144 images, an increase of about 1.4 times.
3) We split up the horizontal CCD to achieve eight parallel outputs, so that in the case of speed up to 1,000 frames/sec, an external memory can be used for extended continuous capturing.

Table 1 shows a comparison of previous ultrahigh-speed CCD and the recently designed new ultrahigh-speed CCD and a block diagram of the sensor is shown in Fig.2.

CONCLUSIONS

We designed a new 148,680-pixel ultrahigh-speed, high sensitivity CCD for broadcast camera with higher resolution . In the future, we plant to continues develop prototype devices, and cameras using there devices.

REFERENCES

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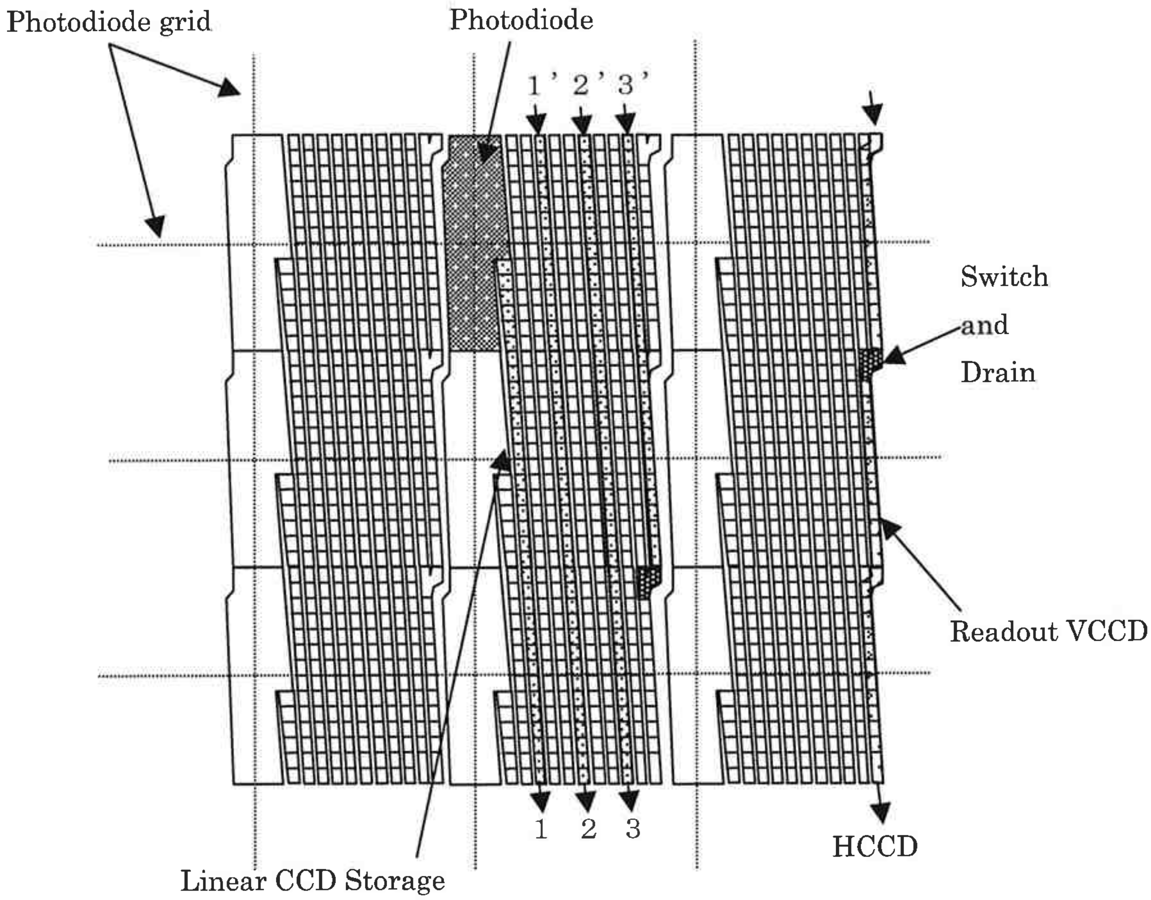

Fig. 1. Overview of the ultrahigh-speed, high-sensitivity CCD

	Previous CCD	New CCD
Frame rate	1,000,000 fps (max)	< 1,000,000 fps (max)
Pixel count	312×260(81,120)pixels	360×413(148,680)pixels
Pixel size	66.3×66.3microns^2	50.4×50.4 microns^2
Size of CCD element	5.1×5.1microns^2	3.0×3.6microns^2
Fill factor	13%	16%
Number of stored images	103 frames	144 frames
Charge handling capacity	25,000 electrons	17,000 electrons
Overwriting drain	Installed	
Transfer scheme	4-phase transfer (Quasi 2-phase transfer for HCCD)	
Parallel readout	none	> 1,000fps(8 readout taps)

Table 1. Comparison of ultrahigh-speed CCDs

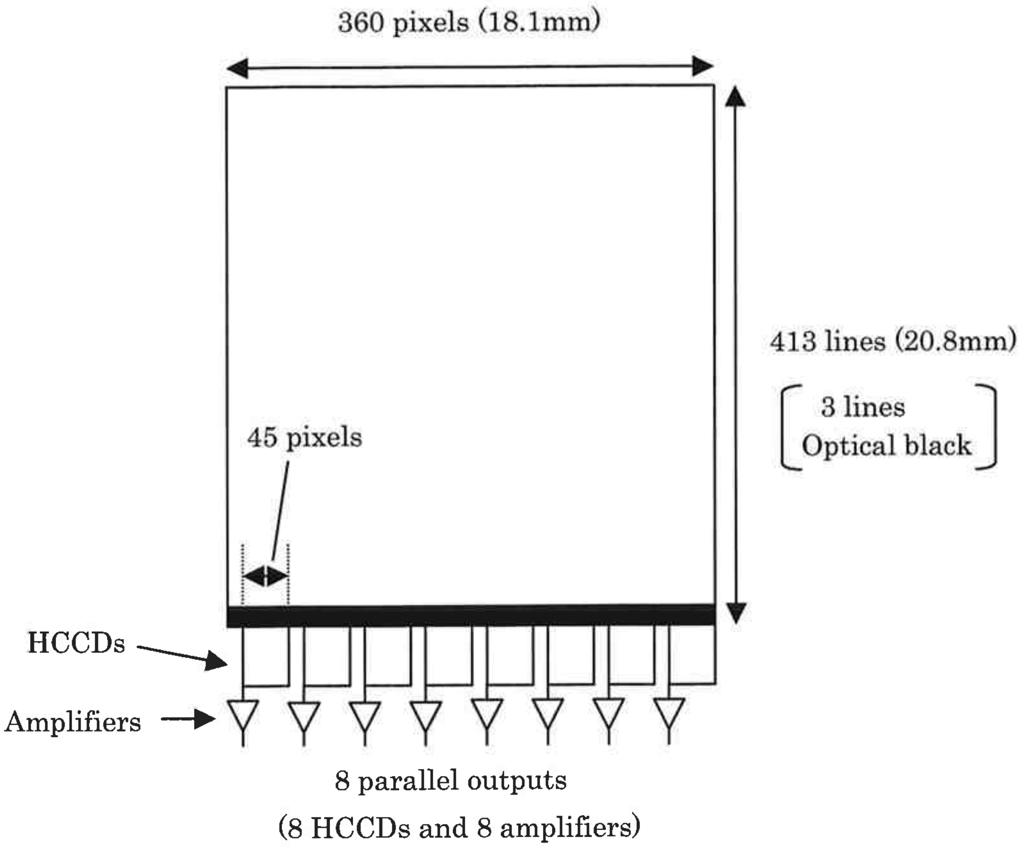

Fig. 2. A block diagram of the 148,680-pixel ultrahigh-speed CCD