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8—37

1kHz Smart Camera with Image Processing Feature

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Abstract

We have advanced applied research of a high-speed image processing system, which can perform image capturing, processing and control output of an image within 1 millisecond. The compact camera module developed is able to perform real time image processing at 1kHz, and can be easily adapted for development of various applications. Moreover, when applied to 3-dimensional measurements, we have confirmed that practical measurements can be done with this system. Furthermore, by using line-feedback-AGC with the real time image processing function, accurate measurements can be performed over a large dynamic range.

1 Introduction

In today's highly informative society, high-speed visual information processing is required as an important component in various engineering fields, such as manufacturing process control, transportation system, traffic, information communication, and amusement. However, processing speed is restricted by video frame rate (30 frames/sec) in order that many present image-processing systems may acquire a picture with a CCD camera. On the other hand, actuators can be controlled in one millisecond, such as in the case of FA robot control. That is, in the robot control system combined with the conventional CCD camera, the capability of an actuator cannot fully be achieved. In order to overcome the limitation, a visual sensing system including sensing, image processing and robot control has been proposed as S^3PE architecture [1,2] and reported the effectiveness in the area of robot system.

In the S^3PE architecture, a processing element (PE) is given for every pixel of an image sensor, and SIMD type parallel operation realizes ultra high-speed, real time image processing. Since the PE is controlled by the programmable control unit, general-purpose image processing can be achieved. It is now possible to mount the S^3PE architecture in a LSI chip, or a circuit board because of semiconductor integration technology progress in recent years. A CPV (Column Parallel Vision) system of personal computer size has also been developed and applied for high-speed general purpose image processing and robot control [3-5]. With the CPV system, development and an actual proof experiment of image-processing algorithm can be easily conducted under the high-speed environment of operation of 1kHz frame rate. However, although this system can satisfy both the demands of flexibility and high resolution, it is at present large and expensive. Further miniaturization is indispensable when it is mounted onto FA apparatus. We then redesigned and built the small camera system, which unified the real-time-image-processing by limiting a function for specific applications. This system (housed in 65x65x55mm case) achieved 1kHz image capture and real time image processing.

2 System Construction

The system consists of two main units, a sensor unit and a control unit as shown in Fig. 1. The sensor unit has the sensor chip whose specification is summarized in Table 1. The sensor chip and an output image is shown in Fig. 2. The sensor unit is a CMOS image sensor with 256x256 PD array and 128 A/D converter array. By employing 2x2 pixels bining mode, the CMOS image sensor is utilized for 1kHz, 128x128 pixel sensor. The gain can be set up externally in eight stages in the range of 30 times the minimum. Further increases in frame rate are possible for this sensor via feedback control of an image-processing unit. The control unit consists of FPGA with its operation determined by hardware description language. Various functions of the camera system can be performed with selection of algorithm-IPs. This algorithm development is performed in a CPV system with high operational

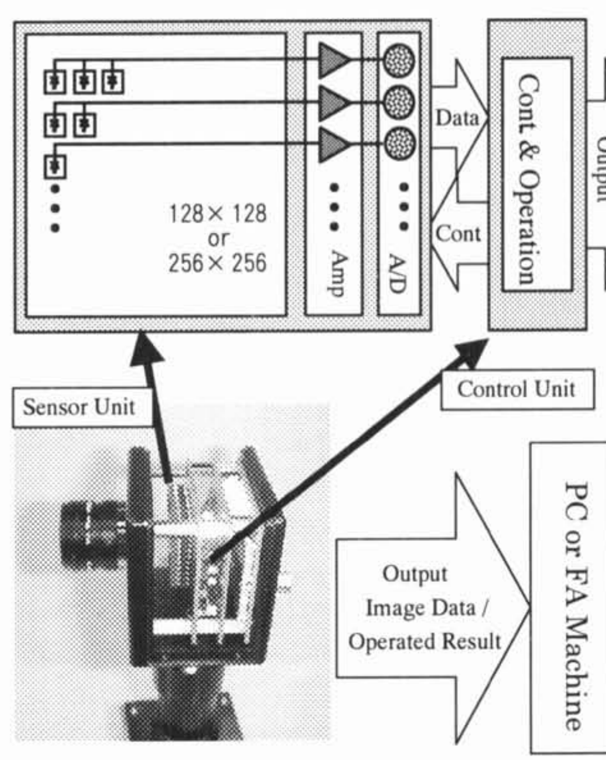

Fig.1 System structure

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capability and flexibility. Before IP development work, it could perform a proof experiment and a merit examination easily. A/D conversion is carried out one line at a time, and an image is transmitted to a controller as an 8-bit series signal. The operation processing method serves as successive parallel processing to image data. By internal memory, image processing using the information on two or more lines can also be performed. 3x3 filters or 5x5, 1-dimensional and 2-dimensional center of gravity operations, and a position detection function of multiple points have already been developed. We have confirmed that each operation was executed within 1msec (1 kHz frame rate). The output of the camera system -- a live image, an operation processing image and operation results such as 1-dimensional center of gravity of an object etc, can be set up easily. Therefore, if it is applied to FA apparatus, it will function as an image detection and position detection sensor. Moreover, it can be used as a preprocessing camera of a CPV system with the S^3PE architecture. Connection with a personal computer (PC) is made through a general-purpose interface board. The library for processing image data and operation result was developed in a C language environment. Since image transfer rates and operating speed of the PC causes bottlenecks in processing, real-time image processing in PC is difficult. Therefore, the concept of the small camera system is to have the camera perform the high-speed-processes internally, and transmit only operational results to the PC. The PC makes higher order processing, such as informative integration, statistics processing, man-machine interface, and control of actuators. An example of composition with a general-purpose interface board is shown in Fig. 2. In this paper, we have applied the 1kHz smart camera system for 3-dimensional measurement by means of the light section method. By using high speed feedback control of sensor gain, we have experimentally confirmed that high speed feedback control enables the system to have wide measurement capability.

3 Image-processing Functions

3.1 1-dimensional and 2-dimensional center-of-gravity

The 2-dimensional center of gravity of an object can be searched for by calculating the 0th and 1st-order-moments of the luminosity distribution in a frame. To determine the center of gravity, it divides from the 0th-moment, and division is required. It is important to decide what functions the camera will be made to perform during system design. By outputting the 2nd-moment, it is possible to detect the position of parts and direction, in part inspect application. Moreover, by searching for the 1-dimensional center of gravity of luminosity for every transverse direction of every line, the central line of an object can be acquired with sufficient accuracy. The form of slit light can be measured with sufficient accuracy. 3-dimensional measurement by the light section method explained in Chapter 4 uses this function.

3.2 Image filtering

The function to perform filtering operation of 3x3 or 5x5 was applied to the image acquired by the sensor. Filter processing of many stages, such as edge processing of an image, to which smoothing was applied are possible. Moreover, it is also possible to change the prepared filter externally via a control signal.

3.3 Position detect of brightness points

By choosing a local maximum detection filter as the

	specification
Pixel pitch	20μm
Pixel number	256x256 (128x128 by bining mode)
Frame rate	250Hz(256x256), 1KHz(128x128)
Signal output	128ch parallel A/D output
Output levels	8bit
Power supply	+5V
Power consumption	400mW
A/DC speed	1 Mbps
Noise	<1000 Electorons
Chip size	7x11mm

Table1 SensorSpefication

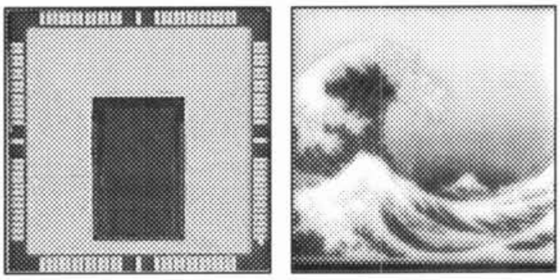


Fig.2 Sensor chip and output image

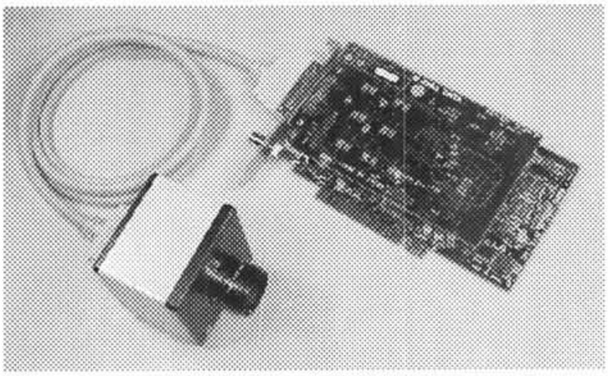


Fig.3 System setup of the smart camera

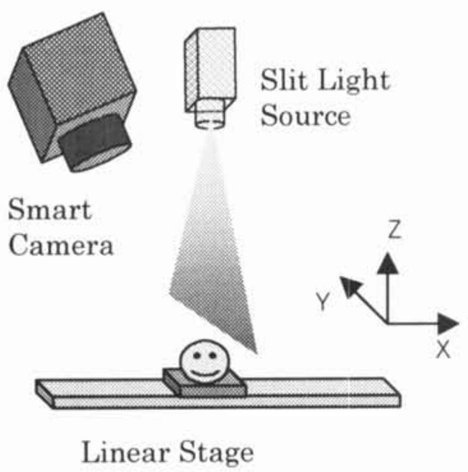


Fig.4 Experimental setup for 3D measurement

above-mentioned 5x5 filtering ability, the position of a luminosity peak is detectable. Furthermore, if center-of-gravity operation filtering is performed to the circumference domain, it is possible to acquire the brightness points position in a screen to sub pixel accuracy. By outputting to PC using the position information as binary data, many brightness points can be acquired easily using high frame rates e.g. 1KHz.

4 3-dimensional measurement

By utilizing the 1kHz smart camera, we have built an experimental setup of light section method as shown in Fig. 3. In this functional camera system, it arranges so that the transverse direction line (simultaneous read-out line) of the direction of a slit light source and a sensor may become perpendicular. By using a 1-dimensional center-of-gravity operation function for it, slit light form is easily measurable. The detection accuracy of a slit light position serves as a sub pixel order by performing center-of-gravity operation. If this is combined with the high-frame-rate that is the feature of this functional camera, it will become possible to perform real time and highly precise 3-dimensional shape measurement under high-speed scanning operation. In this case, with the scanning speed set at 1kHz (1000 mm/sec) and camera set at 30 degrees to the light source. The camera scans a 20mm x 20mm area of the object (pyramid stairs), onto which slit light is projected. The results are shown in Fig. 4. When the direction of scan is set to X, the width direction is set to Y and the height direction is set to Z, the resolution of X directions is 1mm per frame, and geometric resolution of Y and Z are 0.16mm and 0.31mm per pixel respectively.

Here, by the light section method, there is a problem that the intensity of reflected light changes with the difference in the reflectivity of the material of an object and the sharp angles of the object projections. If the angle of the field for measurement, light source and measuring instruments is small (see portion of the doll in Fig. 6), the amount of reflected light will decrease sharply and sufficient measurement accuracy will not be attained. Since the form of reflected light is searched for by center-of-gravity operation. If the rate of amplification of a sensor is gathered, generation of increased line width of reflected light, and the saturation of luminosity can cause degradation of measurement accuracy. In order to avoid such a problem, the ability of real-time operation was utilized, and lf-AGC (line feedback Auto Gain Control) was performed for every read-out line. The lf-AGC algorithm is a threshold value where the luminosity sum total of the read line is exceeded, and the read-out gain of the following line is changed. Here, the gain was changed by the ratio of 6:1. Moreover, there is an advantage that the difference between frames is also small in image processing under high frame rate. Therefore, it is also possible to adjust a gain for every transverse direction line from the information on a last frame. In order to control the rate of amplification within the same frame in both cases, the image by which adaptation processing was carried out according to the reflectance for every portion of a subject is obtained. An acquired image using lf-AGC is shown in Fig. 6. The gain increases by section with low reflected light intensity, such as the side and arm of a doll, adaptive gain control is performed. We have measured that noise generated during amplification would affect measurement accuracy. As can be seen by the experiment result shown in Fig. 7. Variance

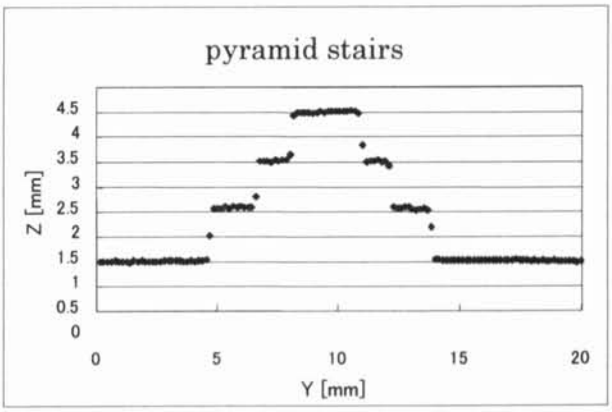
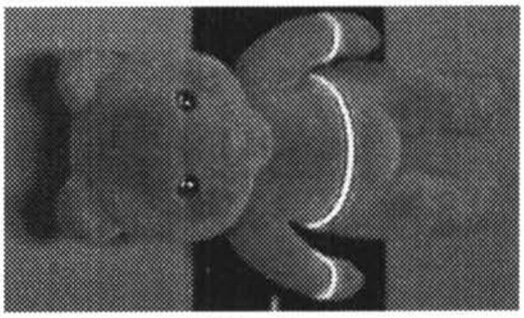
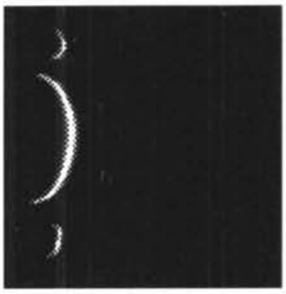


Fig.5 Experimental result of 3D measurement

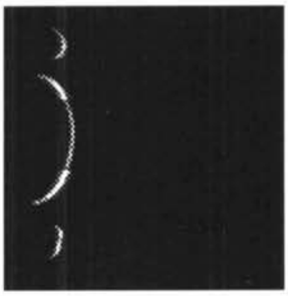


(a)Object image



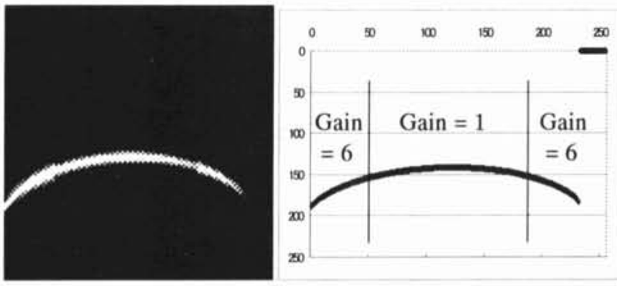
(b) Gain = 6 (High)

(c) Gain = 1 (Low)

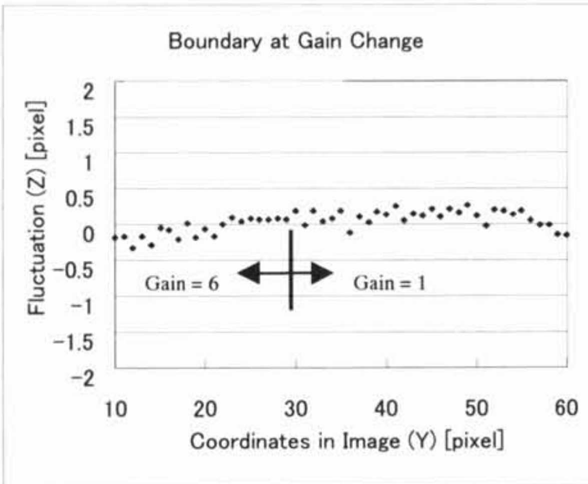


(d) Gain = lf-AGC

Fig.6 Experimental results of AGC



(a) Experimental result by If-AGC



(b) Boundary at gain change

Fig.7 Evaluation of accuracy on If-AGC measurement

from the curve of 2nd degree shows the difference was not appeared at the point of gain change (as shown in Fig. 6) and fixed part of the rate of amplification, but it checked that the measurement accuracy of the height direction was 0.4 pixels (0.12mm of height). That is, as the application of If-AGC to the light section method, the dynamic range of a measurement system contributes to an improvement in measurement accuracy.

5 Conclusion

We have advanced the applied research of the high-speed image-processing system. It can perform input and output processing of an image at intervals time of 1 milli-second. And the compact small functional camera system of size 65x65x55 mm was built. As examples of general-purpose image processing realized in this system, 1 or 2-dimensional center-of-gravity operation function, arbitrary filtering function of 3x3 or 5x5, and the position detection function of multi brightness points are implemented. The highly precise measurement could be performed at 1000 frames per second. The application experiment to 3-dimensional measurement by the light section method was demonstrated as a concrete case of the operation. Moreover, by performing image capturing with If-AGC showed that highly precise 3-dimensional measurement could be achieved due to the large dynamic range.

From here on, the progression of an image-processing function IP library and the miniaturization of a camera system are due to be advanced.

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References

[1] Ishikawa, M., Morita, A., and Takayanagi N., "High speed vision system using massively parallel processing", Proc. IEEE/RSJ Int. Conf. On Intelligent Robots and Systems, pp373-377 (1992)

[2] Komuro, T., Ishii, I., and Ishikawa, M., "General-purpose vision chip architecture for real-time machine vision", Advanced Robotics, Vol. 12, No.6, pp619-627 (1999)

[3] Nakabo, Y., Ishikawa, M., Toyoda, H., and Mizuno, S., "1ms column parallel vision system and its application of high speed target tracking", Proc. IEEE Int. Conf. Robotics and Automation, pp650-655 (2000)

[4] Toyoda, H., Mukozaka, N., Mizuno, S., Nakabo, Y., and Ishikawa, M., "Column parallel vision system (CPV) for high-speed 2D-image analysis", Proc. SPIE, Vol.4416, pp256-259 (2001)

[5] Mukozaka, N., Toyoda, H., Mizuno, S., Wu, M., Nakabo, Y., and Ishikawa, M., "Column parallel vision system : CPV", Proc. SPIE Vol. 4669, pp21-27 (2002)