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Simple-Architecture Motion-Detection Analog VLSI Based on Quasi-Two-Dimensional Processing

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1. Introduction

Since motion detection algorithms are computationally very expensive, dedicated VLSI chips have been developed [1-2]. In these focal plane processing chips, processing elements are integrated with photo sensors in every pixels, which reduces the area for photo diodes, thus degrading the resolution and sensitivity in capturing images.

A simple motion detection system was developed using neuron MOS circuits where pixel data were projected onto x- and y- axes and motion vectors were detected by matching the projection data sets at two consecutive time frames in a fully-parallel hardware configuration [3]. We have introduced the concept of time derivative to the projection data to cancel out the background scenery and robust moving objects detection was demonstrated by extensive computer simulation [4]. A test chip composed of integrated image sensors and time-derivative data generators using absolute-value circuits was fabricated and its basic operation was demonstrated in our previous work [5].

The purpose of this study is to develop new circuits for the entire motion detection system and verify its operation by experiments. We employed a signed-subtraction circuitry in the place of the absolute-value-of-difference circuitry in Ref. [5], which enhances the robustness in matching characteristics while simplifying the circuit configuration. Two test chips were fabricated in a 0.6-μm double-poly triple-metal CMOS technology: one chip for image capture, projection and time derivative data generation; the other for velocity detection in a fully parallel matching architecture. Real time motion detection was experimentally demonstrated by connecting two test chips by external wiring.

2. Quasi-Two-Dimensional Processing

The motion detection algorithm employed in the present system is illustrated in Fig. 1. Four image frames are taken from a video sequence and the pixel data are projected onto principal axes (x-, y- and diagonal axes). The time-derivative data at t_1 are generated by subtracting the projection data at t_1 from the projection data at $t_1+\tau$. The time derivative data at t_2 (= $t_1+\Delta t$) are generated similarly. If we assume there is no movement in the camera position, these time derivative data sets represent the information from moving objects. Then the shift and match of the time-derivative data sets at t_1 and t_2 yields the motion of objects as the minima in the matching residue. The algorithm is applicable to multiple moving objects detection in complicated background sceneries [4].

3. System Organization and Test Chips

Organization of the motion detection system is illustrated in Fig. 2. The top part contains a 64 X 64 photo sensor array and subtraction circuits generating time derivative data for x-axis projection data and y-axis projection data. The two time-derivative generator modules are placed only on two sides of the photo sensor array at the periphery. Vertical, horizontal and diagonal metal lines are connected to each photo sensor circuitry and one of the connections is selected by switches for projecting pixel data to respective directions. A large fill factor of 41% is achieved since no computing circuits are included in the pixel element. The diagonal line is equipped to provide additional information to identify multiple moving objects in the scenery [5]. The circuit diagram of the time-derivative generator is shown in Fig. 3. The subtraction operation is carried out by a simple floating gate MOS technique and the zero level of subtraction is determined by the floating gate reset voltage V_{sup1}. As compared to the absolute-value subtraction circuit employed in Ref. [5], sampling and buffer circuitries are not necessary in signed subtraction, thus reducing the number of elements from 30 to 13. The signed subtraction further provides better performance of motion detection when two objects are moving in opposite directions [4].

The bottom part of Fig. 2 is the shift and matching circuitry for detecting the motion. The time derivative data at t_1 are intentionally shifted from -7 to +7 pixels by hard wiring and provided to the matching cell array, while the time derivative data at t_2 are directly provided without shift. The matching cell is the absolute value circuit as used in Ref. [5] and the matching residue is accumulated by a νMOS source follower. Then the winner take all (WTA) circuit developed in Ref. [6] identifies the location of the minimum of the residue.

The system was implemented as separate two test chips: the image sensor and time-derivative generator chip; the shift and matching chip, to evaluate the characteristics of key components. Photomicrographs of the test chips fabricated in a 0.6-μm double-poly triple-metal CMOS technology are shown in Fig. 2. In the present test chip, however, the WTA was not included and the result of residue calculation at each shift was directly evaluated.

4. Experimental Results and Discussion

Fig. 4 shows the experimental setup for measurement of motion detection. The image sensor/time-derivative generator chip was mounted on the board on which the lens with the focal length of 12mm was attached. The rotating propeller with a sticking bar represents a moving object and the fixed bar standing behind the motor represents a background object which was placed on the right hand side of the motor. The outputs from the time-derivative generator were transferred to the shift and matching chip by external wiring. The integration time for each image capture and the time interval for image sampling were both set at 2msec. Therefore, Δt = 2 msec and τ = 4 msec in this experiment.

Fig. 5 shows the time-derivative data for x projection of the moving bar crossing the image plane. The data are shown for both clockwise and counterclockwise rotations. They are mirror images to each other, thus properly representing the direction of the movement. It should be noted that the background image is completely erased in the measured result.

The outputs obtained from the shift and matching chip based on the x projection data are demonstrated in Fig. 6. The minimum in the accumulated residue is observed at +3-pixel shift for clockwise rotation and –3-pixel shift for counterclockwise rotation. Thus the correct velocity component is obtained according to the definition specified by the circuit in Fig. 2.

5. Conclusions

A hardware-efficient motion-detection algorithm, the quasi-two-dimensional processing, has been developed and implemented as an analog VLSI system. Due to the simple architecture of the circuits, a large fill factor of the pixel sensor of 41% was achieved. The system can detect moving objects in a cluttered background scenery. The proper functioning of the system has been experimentally demonstrated.

ACKNOWLEDGEMENTS

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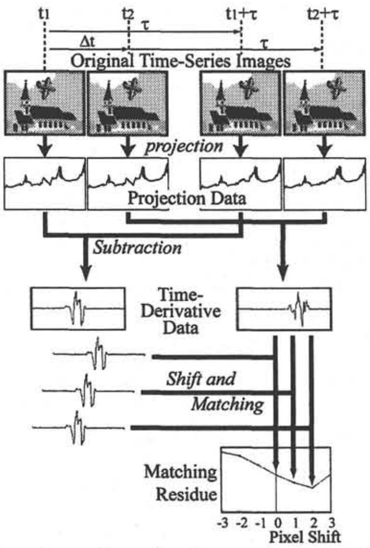

Fig. 1. Algorithm of quasi-two-dimensional processing for motion detection.

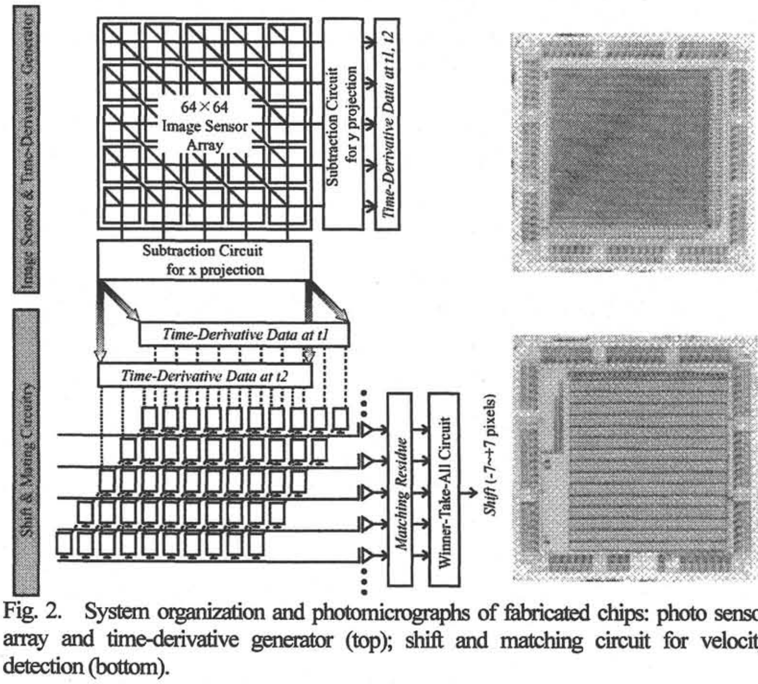

Fig. 2. System organization and photomicrographs of fabricated chips: photo sensor array and time-derivative generator (top); shift and matching circuit for velocity detection (bottom).

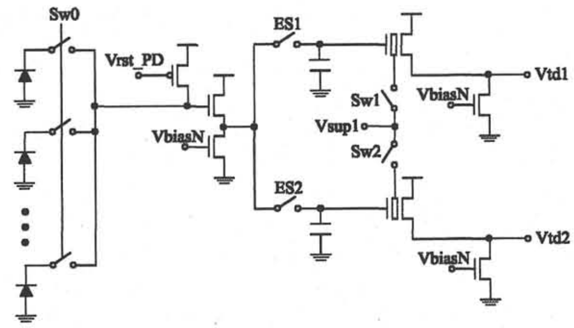

Fig. 3. Circuit diagram of time-derivative generator connected to single line of photo sensors.

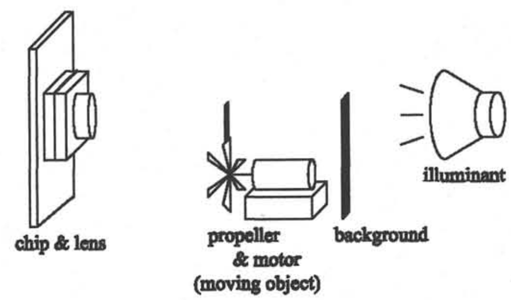

Fig. 4. Experimental set up for measurement.

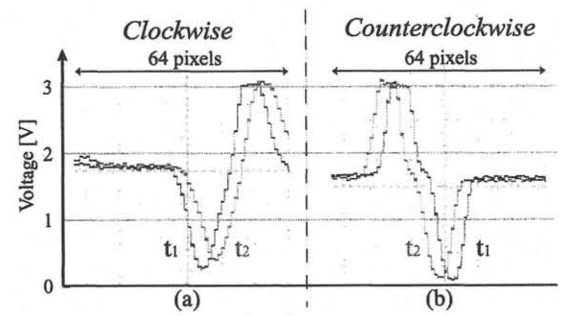

Fig. 5. Time-derivative data obtained from the x-projection data of a rotating bar in clockwise (a) and counterclockwise (b) directions.

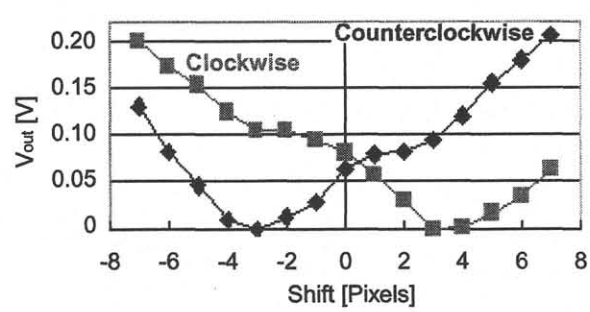

Fig. 6. Measurement results of a rotating bar based on the x-projection data.