Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 366–367

E-4-3

A High-Resolution Hadamard Transform Circuit Using Pulse Width Modulation Technique

Kousuke Katayama, Makoto Nagata, Takashi Morie, and Atsushi Iwata

Faculty of Engineering, Hiroshima University, Higashi-Hiroshima, 739-8527 Japan
Phone: +81-824-24-7643, Fax: +81-824-22-7195, E-mail: kata@dsl.hiroshima-u.ac.jp

1. Introduction

Among many kinds of orthogonal transformation, Hadamard transform is often used for implementing image compression because it does not require multiplication operations. Usually, high resolution input image data, which have larger than 100x100 pixels, are divided into sub-blocks (ex. 16 x 16) and transformed. We propose a novel Hadamard transform circuit which can entirely transform large size image by utilizing the analog-digital merged processing and non-destructive CMOS image sensing techniques using pulse-width-modulation (PWM) signals [1, 2].

The transformation chip has been designed with 0.35μm CMOS and its operations and accuracy have been confirmed using SPICE simulations. This chip does not have to divide into sub-blocks because it is able to calculate an image entirely. The proposed chip provides new implementation of not only image compression, but also image shape detection and feature detection, and is applicable to intelligent machine visions.

2. PWM processing circuits

The analog-digital merged circuit architecture using PWM approaches is applied to a basic processing circuit. Pixel intensity is detected by a p-n junction photo detector (PD) as an integrated charge and converted to a PWM signal by comparing with a reference ramp signal as shown in Fig. 1(a). The capacitor (C_p) works as an analog memory for non-destructive readout. [2] The PWM current-mode signal is integrated with sign bit, which corresponds to each element of the transform matrix, and converted to charge using the switched current integration circuit as shown in Fig. 1(b). Average operation of a vast number of charge data is realized with the charge sharing circuit, shown in Fig.1 (c). [3]

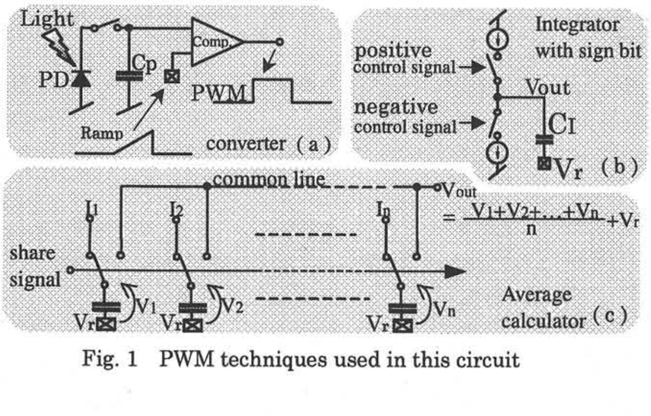
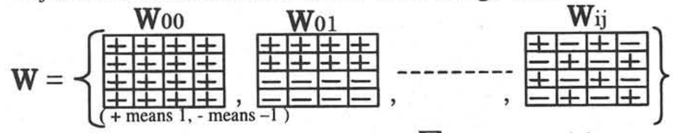


Fig. 1 PWM techniques used in this circuit

3. Hadamard Transform & Inverse Transform circuits

Hadamard coefficient c_{ij} is obtained by Eq. 1. Where $\mathbf{W}_{ij}$ is a Hadamard matrix and $\mathbf{F}$ is an image matrix.



$$c_{ij} = \mathbf{W}_{ij} \otimes \mathbf{F} \qquad (\mathbf{A} \otimes \mathbf{B} : \sum_{l,m} a_{lm} b_{lm}) \quad (1)$$

We propose the Hadamard transform circuit shown in Fig. 2. Hadamard function generators (Row and column) provide the Hadamard transform matrices generated with a simple logic circuit [4]. The integration capacitor C_{Iij} is charged by product of each input PWM and transfer matrix element. All charges are shared by closing all switches (S_{ij}) and averaged instantaneously. The output voltage of C_{Iij} is converted to digital with an ADC.

Inverse Hadamard transform is described by Eq. 2.

$$\mathbf{F} = \sum_{i,j} c_{ij} \mathbf{W}_{ij} \qquad (2)$$

The circuit shown in Fig. 2 also realizes Eq. 2. Each cell is provided with the same PWM signal corresponding to the Hadamard coefficient sequentially. Summation for all coefficients is performed by integrating charges on C_{Iij} and reconstructs pixel value, which is readout by closing S_{ij} sequentially.

We can easily implement Hadamard transform and inverse Hadamard transform on the same circuit.

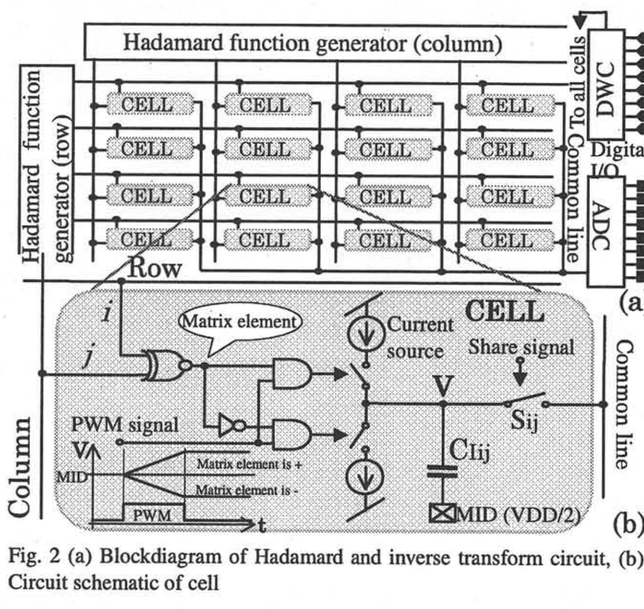


Fig. 2 (a) Blockdiagram of Hadamard and inverse transform circuit, (b) Circuit schematic of cell

The capacitors Cp and CI and PD dominate chip area of the cell. If we design the values of Cp and CI are 2pF, these require 2000μm^2 chip area. A PD with a 1000μm^2 junction area is required for light sensitivity. An estimated cell size is around 4000μm^2. Therefore, high-resolution transform chip with 128 x 128 cells is integrated in a 10mm x 10mm chip, including transfer matrix generators, ADC and DWC. SPICE simulated power consumption of the cell array is 178mW at a 3V supply.

4. Simulation results

Fig. 3 shows simulated waveforms of the charging and sharing with 2x2 cells. Input PWMs (Hadamard matrix elements) were set 1us(+), 1us(-), 500ns(+) and 500ns(-). To average charged values, Sij were closed (Fig. 3). We verified charging and sharing behavior.

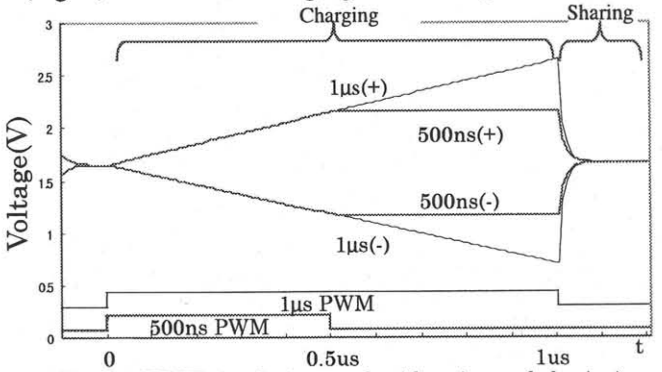


Fig. 3 SPICE simulation results (charging and sharing)

Transformation rate of 1μs/coefficient is obtained with pipeline operation of matrix generation, matrix processing and A-D conversion.

We applied "Standard Image Lena" reduced resolution of 32x32 to the circuit. We compare Hadamard coefficients between calculation and SPICE simulation as shown in Fig. 4. Both have a good agreement and the accuracy is more than 7bits.

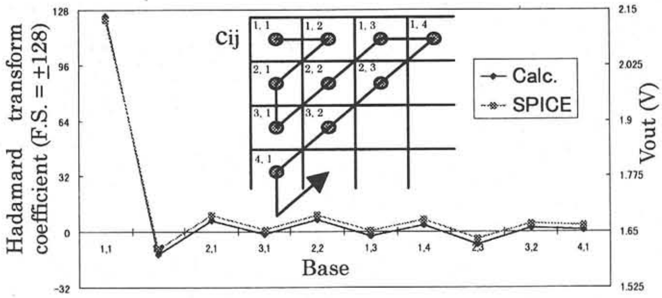


Fig. 4 Comparison between calculation and SPICE simulation

5. Applications

5. 1 Hadamard Transform & Inverse Transform

This circuit easily transforms form whole of image to Hadamard coefficients mutually. Entirely transform leads that each Hadamard coefficient has whole of image information. It is important to apply to vision processing.

5. 2 Center of Gravity

We can obtain the center of gravity by using this circuit. For example, we can obtain the y coordinate of the center of gravity, by performing the process shown in Fig. 5. We can calculate coefficients only 7 times ($128 = 2^7$) as shown in Eq. 3. and reduce calculation cost drastically. In this example, number of multiplication is reduced 1/18.

$$g_y = \begin{cases} \left(\sum_{j=1}^{\log_2 n} c_{0j} \times 2^{-(j-1)} \right) \Big/ c_{00} & \text{(Proposed)} \\ \left(\sum_{j=1}^{n} j \times \sum_{i=1}^{n} f(i,j) \right) \Big/ \left(\sum_{i=1}^{n} \sum_{j=1}^{n} f(i,j) \right) & \text{(Conventional)} \; (f(i,j): \text{Image}) \end{cases} \quad (3)$$

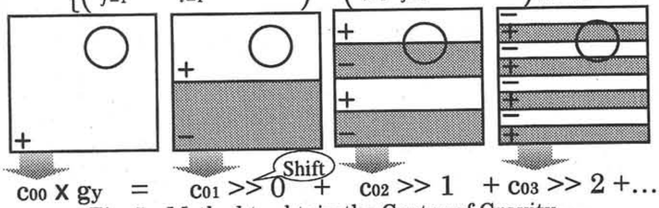


Fig. 5 Method to obtain the Center of Gravity

5.3 Image filtering

This circuit can reconstruct an image from an arbitrary part of the coefficient matrix. Figure 7 shows examples of inverse transformed image using a part of Hadamard transform coefficients. It realizes not only usual spatial filtering (low pass or high pass) but also more complex filtering like texture extraction and feature.

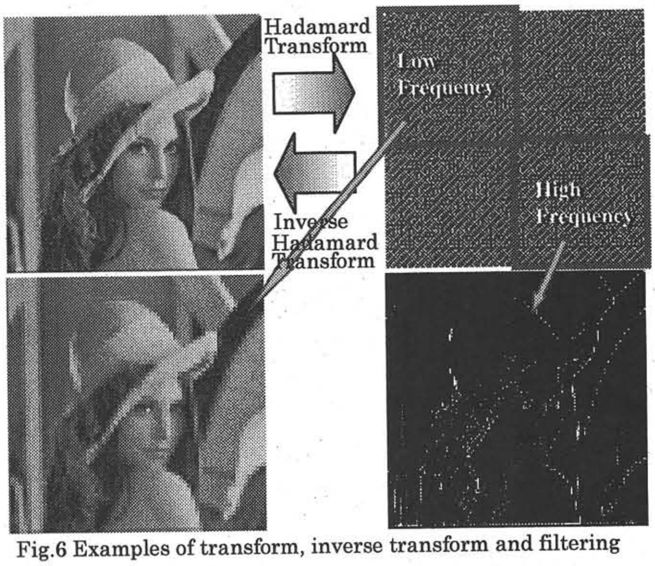


Fig.6 Examples of transform, inverse transform and filtering

6. Conclusion

A novel high-resolution Hadamard transform circuits was proposed. Basic operation and accuracy were confirmed with SPICE simulation. Applications of the high-resolution Hadamard transform are demonstrated.

Acknowledgments

This work has been supported by the Core Research for Evolutional Science and Technology (CREST) from Japan Science and Technology Corporation (JST).

References

[1] A. Iwata, et al.: IEICE Trans. Fundamentals. E79-A (1996) 145

[2] M. Nagata et al.: 1999 Symposium on VLSI Circuits Dig. of Technical Papers, #14.4, pp. 141-144, Kyoto, June 17-19, 1999.

[3] T. Morie, et al.: IEICE Trans. Fundamentals. E82-A (1999) 356

[4] S. Murakami, et al.: IEICE Trans. Electronics. 54-C (1971) 183