An Analog-Digital Hybrid LSI for Hough Transformation

Tetsuya Asai and Yoshihito Amemiya
Department of Electrical Engineering, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, 060-8628, Japan.
E-mail: asai@sapiens-ei.eng.hokudai.ac.jp

Feature extraction is an important visual modality for higher-order visual processing in both biological and artificial systems. Recently, a number of vision systems utilizing Hough transformation have been proposed for developing the feature extraction systems. This means that high-speed custom co-processors for Hough transformation will be in great demand in the future. In this paper, aiming at the development of co-processors for such vision systems, we propose an analog-digital hybrid LSI that can perform high-speed Hough transformation.

Hough transformation represents lines in an input space as points in a parameter space. Each point is represented by intersections of trigonometric curves obtained by projection of the input space (x, y) to the parameter space (ρ, θ) with $\rho = x\cos\theta + y\sin\theta$. To execute the projection and detection of the intersection points by hardware, we propose the following algorithm : i) calculate ρ_i $(i = 1, 2, \cdots, L)$ that correspond to all pixels of binary input images $(P_1, P_2, \cdots, P_L)$ for all values of θ, ii) determine the θ values that make ρ_i equal to $\rho_{j\neq i}$.

Figure 1 shows an architecture of the LSI implementing the proposed algorithm for Hough transformation. The LSI consists of a ρ-device that parallely calculates the values of $\rho_{i,j}$ for all pixels (i, j) of an input image, and two voting circuits that detect the intersection points (point overlap). The ρ-device consists of resistor circuits and $2N \times 2N$ analog voltage adders $(S_{i,j})$, and receives external AC voltages $(\pm E_0 \cos\omega t, \pm E_0 \sin\omega t)$. The node voltages of the resistive circuit ($V_{i,0}$ and $V_{0,j}$) are given by $E_0\ i\ dx \cos\omega t$ and $E_0\ j\ dx \sin\omega t$, respectively, where dx and dy are the values of the discrete step in the input space. Then, outputs of the voltage adders are obtained as $S_{i,j} = E_0\big(i\ dx \cos\omega t + j\ dy \sin\omega t\big)$, which is equivalent to the equation of Hough transformation when $E_0\ i\ dx$, $E_0\ j\ dy$ and ωt are replaced with x, y and θ, respectively.

To detect the point overlap in the parameter space, we propose the following scheme: i) calculate $X_i = 1/d_i \sum_{j\in\mathcal{D}} S_{i,j}$ and $Y_j = 1/d_j \sum_{i\in\mathcal{D}} S_{i,j}$ for i-th column and j-th row, where $\mathcal{D}$, d_i and d_j represent a set of points in the i-th column and j-th row, the number of points in the column and row, respectively; ii) map X_i and Y_i to M-dimensional position vectors ($\mathbf{X}_i$ and $\mathbf{Y}_i$): for example, when M, $|X_i|$, maximum and minimum values of X_i are 2, c, $-\alpha$ and α, respectively, $\mathbf{X}_i$ is represented as $(c, 0)$ for $-\alpha \leq X_i \leq 0$. For $0 < X_i \leq \alpha$, $\mathbf{X}_i$ is represented as $(0, c)$; iii) calculate $\mathbf{X} = 1/k_i \sum_{i\in\mathcal{K}} \mathbf{X}_i$ and $\mathbf{Y} = 1/k_i \sum_{i\in\mathcal{K}} \mathbf{Y}_i$, where k_i and $\mathcal{K}$ represent the number and a set of nonzero d_i of $\mathbf{X}_i$ and $\mathbf{Y}_i$, respectively; iv) determine element numbers in which element values of $\mathbf{X}$ and $\mathbf{Y}$ are larger than c/M; v) transform the element number to values by the inverse vector transformation of step ii). In step iii), the point overlap is detected when the element values exceed c/M. The value of ρ is obtained in steps iv) and v). In Fig. 1, the calculation of vector summation in steps i) and iii) is executed by MOS resistor circuits, and the point overlap is detected by parallel AD and DA converters and additional MOS resistor circuits .

Figures 2 through 5 show input and output data of numerical simulations. An input image consisting of three points was given to the LSI (Fig. 2). The time course (single cycle) of point overlap signals is shown in Fig. 3. Figure 5 shows the results of an inverse Hough transformation for ρ and θ $(= \omega t)$ obtained from Fig. 4 ($N = M = 40,\ \omega = 2\pi,\ c = 1,\ E_0 = 1$ V). When ρ was quantized as 5.3 bit ($\log_2 40$), the lines connecting the input points were successfully reconstructed with acceptable precision, as shown in Fig. 5.

With the proposed LSI architecture, all the ρ values can be obtained by simple analog ρ-device. However, the construction of the voting circuit is rather complicated because of the digital circuits for the overlap detection. We will hereafter develop simple scheme for the overlap detection aiming at the development of analog voting circuits, and will construct compact circuit systems for inverse Hough transformation.