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Dynamical AD Converter by Saito's Rotation Map in Functional Cellular Neural Sensor Network

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Abstract—This paper describes dynamical AD Converter in which each spiking neuron was proposed by Saito's Rotation Map(SRM) in a general functional Cellular Neural Sensor Network. In general, a Cellular Neural Network (CNN) is defined as a local connected circuit which has continuous state variables $\boldsymbol{x} \in \boldsymbol{R}^n$. The importance is in that the piece-wise linear function of the CNN has a linear region $|x| \leq 1$ for $x \in \boldsymbol{x}$ because the linear region can be quantized from the continuous variable x to the multi-level quantized variable$f(x)$ by each 1-bit $\Sigma\delta$ modulator which is corresponding to a spiking neuron model. The Saito's Rotation Map(SRM) is considered as one of the efficient $\Sigma\delta$ modulators. The firing rate is corresponding to the information. The SRM is used as local dynamics for the nonlinear function $f(x)$ and the global dynamics by A-and B-templates are used by many image processing.

1. Introduction

In general, a semiconductor imaging device includes an array of many pixel cells for capturing image. Each pixel includes a circuit which has a photo detector, a floating diffusion region, a transfer transistor between the photo detector and the floating diffusion. The Bayer pattern pixels are read. The current flows from the top of the pixel column to a reference potential (e.g. ground) thereby producing a voltage on the column. Each of the color columns is connected to a readout circuitry wherein the pixel values are read. Here, the column bus resistance of the pixel array is increasing. Finally, these voltages are sampled and digitized to generate digital pixel values. The readout result is large DC analog voltage difference between top and bottom readout signal paths for a given column. This analog DC voltage difference is mainly due to the resistance of the pixel output bus. A high conventional resolution AD converter is used after the analog reading. The digital outputs are transferred to a digital image processing. In future, it is very important to build 3D imaging device in which spiking pulses are read by directly converting from photo information in each pixel like a human retina system.

The $\Sigma\Delta$ modulation(SDM) [5] [6] [8] is a technique for converting the analog signal into the digital pulse sequence. So, it is widely used by analog-to-digital converter (ADC). The main character of the SDM is high original signal reproducibility by the noise shaping characteristic. The quantization noise is distributed to the high frequency area by the over sampling technology. Moreover, if the outputs of the digital pulse signals are added, the DC information can be obtained as the average of sum of the pulse sequence. and the analog signal of the input is reconstructed by a low-pass filter.

The CNN[7] has been applied to the image processing such as image compression, filtering, and the pattern recognition, etc. The CNN with symmetrical A-template has a stable equilibrium point and if the center parameter a_{ii} of the A-template is larger than 1, the equilibrium point is in ± 1 saturation region corresponding to the black and the white of the image. In a word, global dynamics of the CNN in which each cell uses the piece-wise linear function can be to generate the halftoning image. However, the halftoning images are too low resolution for image processing. It is very important to construct high resolution and high intensity digital images from real analog images.

We have paid attention to the CNN in which each cell is build as SDM and in which local connection can be used to generate the multi-quantization in the linear region for piece-wise linear function and and to construct high resolution intensity digital image from real analog image[2] [1]. Of course, it is not necessary to have local connection if the output digital image is same as the input digital image with same resolution as D-D conversion. It is very important to get the high resolution digital image from more high resolution image like analog image by local connection defined by Gaussian A-template with standard deviation $\sigma > 0$. For the SDM type of CNN, the halftoning images produced from each cell connected in its neighborhood are added dynamically to the direction of the time sequence to construct the equivalent multi-level quantization function $f(x)$. The quantization noise in space can be decreased by the space integration effect of C-template and by over sampling effect. That is, a good quality halftoning image is generated in each time interval of CNN dynamics and the original image can be re-constructed through a low Gaussian filter for the sum of many halftone images[2].

But, the disadvantage of SDM type of CNN is in that the local and global dynamics corresponding to the generation of multi-quantization and image processing by A-templates have synchronization and it is difficult to perform many image processing with different A-templates.

This paper describes dynamical AD Converter in which each spiking neuron was proposed by Saito's Rotation Map(SRM) [3] in a general functional cellular neural sensor network. Many image processing by templates can be generated by local and global dynamics corresponding to the high resolution AD conversion and to many templates image processing which proposed by CNN researchers, respectively. In local dynamics by the SRM, the area intensity method is used to have independent high resolution digital pixel image to generate the sum of ± 1 halftone sub pixels image at each pixel area corresponding to the rate of black and white area. When the size of the area elements of each pixel of the image is different, the different color images are generated. That is, In the area intensity method, there are sub pixels called area elements in each pixel. In CNN, on/off states of these area elements will be controlled by internal spiking neuron cells in each pixel according to the SRM. The proposed method is a hierarchical dynamics in which the space dynamics is divided into global and local dynamics in the CNN with SRM. The global dynamics executes the image processing based on the CNN state equation. On the other hand, the SRM local dynamics generates high resolution and high area intensity of each pixel according to the CNN state equation as a SDM with trapping window(WADC)[3]. Conventionally the digital image for 8-bit SDM generates up to minimum 256 steps from analog image. If the rotation map with a window by SRM is used, the trapping window effect by the SRM will work as encoding source for analog-to-digital CNN sensor device with higher resolution by local dynamics in more than 256 steps equivalently.

2. Dynamical Area Intensity Method

The quality of the image depends on both of intensity and resolution for displays or printers. The area intensity method expresses image as the rate of number for white and black sub elements for each pixel area. By local dynamics of each cell in SDM type of CNN, the sum of on/off states of these sub elements will be controlled to have equilibrium point in each pixel or to have pulse density average approaching to a given input pixel image. The SDM type of CNN has periodical pulses such that the average number of logical "1" pulses in a period approaches to a given input pixel DC intensity by dynamics using cells in its neighborhood.

Let $M \times N$ be the number of pixels, then each pixel position is defined by $(I, J), I = 1, 2, \cdots, M; J = 1, 2, \cdots, N$. There are off-area element of black and on-area element of white in each pixel. The sum of the on and off area is assumed to be $S_{on}(I, J)$ and $\hat{S}_{on}(I, J) = S(I, J) - S_{on}(I, J)$. respectively. the sum is corresponding to the pixel intensity. That is, the gray level is described by :

$$v = \frac{S_{on}(I, J)}{S_{on}(I, J) + \hat{S}_{on}(I, J)} = \frac{S_{on}(I, J)}{S(I, J)} \qquad (1)$$

The pulse density is almost proportional to the area ratio. In the area in pixel (I, J), there are sub internal cells $P(I, J) = \{C_{ij} | i = 1, 2, \cdots, p; i = 1, 2, \cdots, q\}$ of $p \times q$. And the area element is assumed to be $\{S(i, j) | i = 1, 2, \cdots, p; i = 1, 2, \cdots, q\}$. Also, $S(k, l)$ is assumed to be the area element for which cell $C_{kl} \in P(I, J)$ handles. At this time, the pixel area intensity $S_{\pm}(I, J) = S_{on}(I, J) - \hat{S}_{on}(I, J)$ with the sign is controlled by on/off of cell $C_{kl} \in P(I, J)$ and is described by

$$S_{\pm}(I, J)(t) = \sum_{C_{kl} \in P(I,J)} S(k, l) sign(x_{kl}(t)). \qquad (2)$$

All area elements are same, the number of cells increases. And, two or more state patterns of on/off with the same sum area exist and the problem such as taking time to process is caused. However, large different area for sub elements generate area noise for printer device.

As shown in Fig 1, the hierarchical CNN with SDMs has global dynamics and local dynamics. Global dynamics executes the image processing functionally according to the design templates as:

$$\begin{aligned} x_{IJ}(t+1) &= \sum_{C(K,L) \in N_r(I,J)} A(I, J; K, L) y_{\pm}(K, L)(t) \\ &+ \sum_{C(K,L) \in N_r(I,J)} B(I, J; K, L) u_{KL} + T (3) \end{aligned}$$

where $u_{KL}$is an analog input, and $y_{\pm}(I, J)(t)$ is a multi-quantized function regularized by $[-1, +1]$ and described by

$$y_{\pm}(I, J)(t) = \frac{S_{\pm}(I, J)(t)}{S(I, J)} \qquad (4)$$

Local dynamics is SDM to get the pixel intensity for the state variable input $x_{IJ}(t+1)$ made by the amount

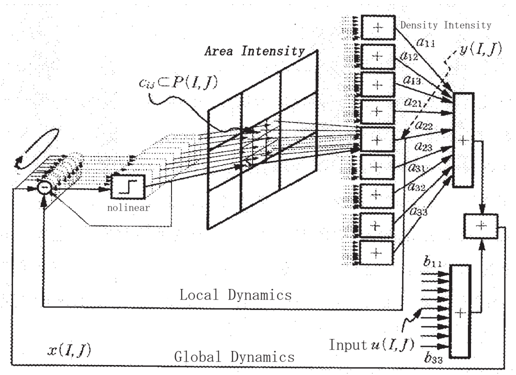

Figure 1: Hierarchical ΣΔ CNN (SDM type of CNN)

of pixel area intensity $S_{\pm}(I,J)$. Internal each sub cell $C_{ij} \in P(I,J)$ operates asynchronously by

$$
\begin{array}{rcl}
x_{ij}(\tilde{t}+1) & = & x_{ij}(\tilde{t}) \quad + \\
\sum\limits_{C_{kl}\in P(I,J)} w_{i,j;k,l} f(x_{kl}(\tilde{t})) & + & x_{IJ}(t+1)
\end{array} \quad (5)
$$

where $f(x_{kl}(\tilde{t}))$ which is a nonlinear quantization function and the $w_{i,j;k,l}$ are described by

$$
f(x_{kl}(\tilde{t})) \;=\; \frac{S(k,l)}{S(I,J)} sign(x_{kl}(\tilde{t})) \quad (6)
$$

$$
w(i,j;k,l) = \begin{cases} -1 & for\ (k,l) \neq (i,j) \\ -1 + \frac{h}{S(I,J)} & for\ (k,l) = (i,j) \end{cases}
$$

where h is controlling parameter. It is assumed $A(I,J;I,J) = 0$ now. The A-template is designed from GF by :

$$
\sum_{C(K,L)\in N_r(I,J)} \tilde{A}(I,J;K,L) S(K,L) + \xi S(I,J) = 1 \quad (7)
$$

$$
A(I,J;K,L) = \tilde{A}(I,J;K,L).S(K,L) \quad (8)
$$

3. Saito's Rotation Map(SRM)

The basic ADC with trapping window (WADC) by the SRM encodes a dc input into a binary output sequence and the trapping window extracts an available part of the output sequence automatically. Using the available part, the decoder provides an estimation by a fraction with variable denominator and realizes higher resolution.

Figure 1 shows the WADC by the SRM. The WADC encodes a dc analog input u to binary digital output sequence $\{y_n\}$ via a one-bit qunatitizer Q. Let $x_n \in \mathbf{R}$ $(n = \tilde{t})$ be the internal state at discrete time n and let l be the upper limit of the output code length. Now, we consider the case that the number of sub elements in each pixel is only one here for a display not a printer. As an initial value x_0 is given, the WADC is updated as the following like a SDM.

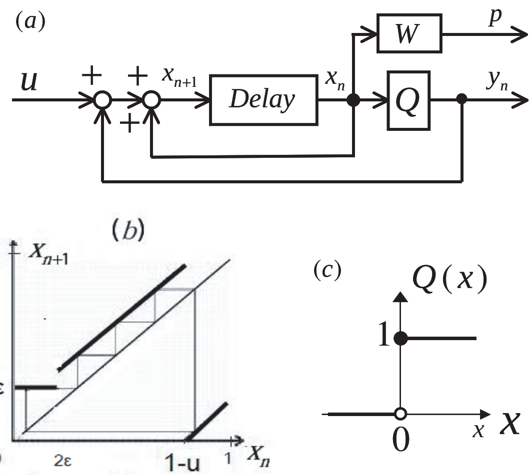

Figure 2: The A/D converter with trapping window

$$
x_{n+1} = f(x_n) \equiv x_n - Q(x_n) + u \quad \text{for } 0 \le n < l
$$

$$
y_n = Q(x_n) = \begin{cases} 1 & \text{for } x_n \ge 0 \\ 0 & \text{for } x_n < 0. \end{cases} \quad (9)
$$

We then prepare the trapping window W that extracts the trapping time p [3]:

$$
x_p \in W \equiv [0, 2\epsilon], x_n \notin W \text{ for } 0 < n < p \quad (10)
$$

where ϵ is a small positive parameter and $\epsilon < u < 1-\epsilon$. If the trapping window does not exist for window interval parameter ($\epsilon = 0$), it is to be the well-known single loop SDM. After the trapping time p, the output y_n $(n > p)$ is to be unavailable. Using the available output sequence $\{y_0, \cdots, y_{p-1}\}$ with length p, our decoder produces an estimate $\tilde{u}$.

$$
\tilde{u} = \frac{1}{p}\sum_{n=0}^{p-1} y_n,\ u - \tilde{u} = \frac{1}{p}(x_p - x_0) \quad (11)
$$

If the state x_n is not trapped into the window by time l, the update is terminated at time l and $p = l$ is used in Equation (11). The WADC can estimate the input u by a fraction with variable denominator. The WADC is characterized by two parameters ϵ and l. Figure 2 (Top) shows the basic conversion characteristics of the WADC. Figure 2 (Bottom) shows the basic conversion characteristics for $l = 8$. Figure 2 (Top) suggests that the WADC generates higher resolution than SDM.

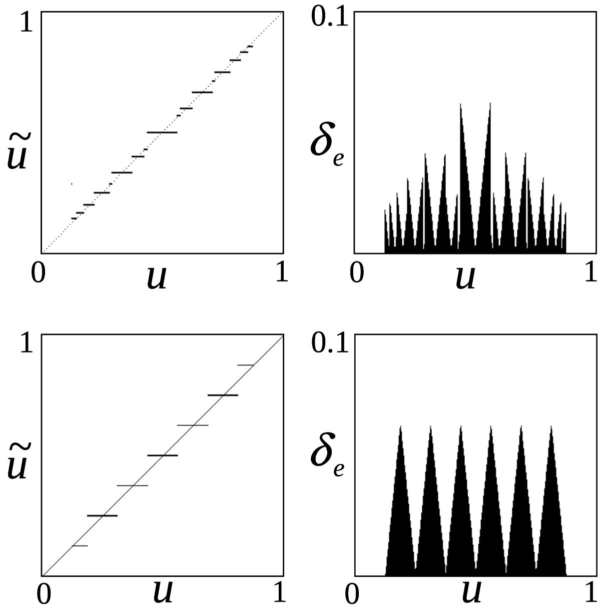

Figure 3: Conversion characteristics for $l = 8$. (Top) WADC with $\epsilon = \frac{1}{9}$, (Bottom) l-estimation.

4. Experiment Result

The simulation result shows the image of the re-composition by the WADC type of CNN which generates the input image of 8 bit gray scale image from high resolution 16 bit medical image of 512×512 instead of analog image. And, we show the result for PSNR of the output image as shown in Fig.4. We can confirm

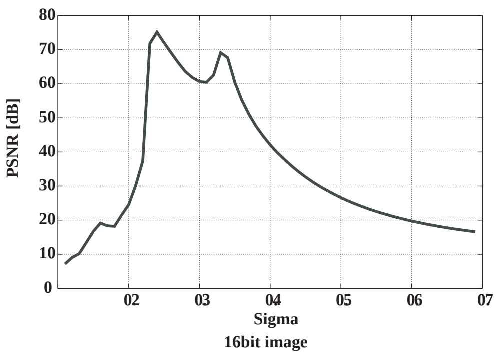

Figure 4: Relation of σ and PSNR from 16 to 8 bit gray scale images

that the PSNR by the proposal method that the proposal method has better original image reproducibility to give a good quality image of the re-construction.

5. Conclusion

In this paper, we proposed the hierarchical dynamics CNN which has pipelining global and local dynamics. The proposal system can realize higher resolution by using WADC as $\Sigma\Delta$ modulation in the local dynamics. The WADC is one of spiking neurons. The high resolution and high intensity(about 70dB PSNR) of a image can be generated according to the SRM. The system will be used as cellular neural sensor network in which each spiking neuron in a pixel generates digital pulses from photo sensor to its corresponding column lines in terms of digital 1-bit digital pulse sequence. In future, our CNN will be used in 3D sensor imaging device.

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