The Two-Stage Analog Neural Network Model and Hardware Implementation

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***Abstract*—In the neural network field, many application models have been proposed. A neuro chip and an artificial retina chip are developed to comprise the neural network model and simulate the biomedical vision system. Previous analog neural network models were composed of the operational amplifier and fixed resistance. It is difficult to change the connection coefficient. In this study, we used analog electronic multiple and sample hold circuits. The connecting weights describe the input voltage. It is easy to change the connection coefficient. This model works only on analog electronic circuits. It can finish the learning process in a very short time and this model will enable more flexible learning.**

Keywords—electronic circuit; neural network; multiple circuit

I. INTRODUCTION

We propose the dynamic learning of the neural network by analog electronic circuits. This model will develop a new signal device with the analog neural electronic circuit. One of the targets of this research is the modeling of biomedical neural function. In the field of neural network, many application models have been proposed. And there are many hardware models that have been realized. These analog neural network models were composed of the operational amplifier and fixed resistance. It is difficult to change the connection coefficient.

A. Analog Neural Network

The analog neural network expresses the voltage, current or charge by a continuous quantity. The main merit is it can construct a continuous time system as well as a discrete time system by the clock operation. Obviously, the operation of the actual neuron cell utilizes analog. It is suitable to use an analog method for imitating the operation of an actual neuron cell. Many Artificial neural networks LSI were designed by the analog method. Many processing units can be installed on a single-chip, because each unit can be achieved with a small number of elements, addition, multiplication, and the nonlinear transformation. And it is possible to operate using the super parallel calculation. As a result, the high-speed offers an advantage compared to the digital neural network method [1][2]. In the pure analog circuit, the main problem is the achievement of an analog memory, how to memorize analog quantity [3].This problem has not been solved yet. The DRAM method memorizes in the capacitor as temporary memory, because it can be achieved in the general-purpose CMOS process [4]. However, when the data value keeps for a long term, digital memory will also be needed. In this case, D/A and A/D conversion causes an overhead problem. Other memorizing methods are the floatage gate type device, ferroelectric memory (FeRAM) and magnetic substance memories (MRAM) [5][6].

B. Pulsed Neural Network

Another hardware neural network model has been proposed. It uses a pulsed neural Network. Especially, when processing time series data, pulsed neural network model has good advantages. In particular, this network can keep the connecting weights after the learning process [7]. Moreover, the reason the learning circuit used the capacitor is that it takes a long time to work the circuits. In general, the pulse interval of the pulsed neural network is about 10μS. The pulsed neuron model represents the output value by the probability of neuron fires. For example, if the neuron is fired 50 times in a 100 pulse interval, the output value is 0.5 at this time. To represent the analog quantity using the Pulsed Neuron Model, it needs about 100 pulses. Thus, about 1mS is needed to represent the output analog signal on a pulsed neuron model.

In this study, we used the multiple circuits. The connecting weights describe the input voltage. It is easy to change the connection coefficient. This model works only on analog electronic circuits. It can finish the learning process in a very short time and this model will allow for more flexible learning. Recently, many researchers have focused on the semiconductor integration industry. Especially, low electrical power, low price, and large scale models are important. The neural

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network model explains the biomedical neural system. Neural network has flexible learning ability. Many researchers simulated the structure of the biomedical brain neuron using an electronic circuit and software.

C. Overview

The results of the neural network research provide feedback to the neuro science fields. These research fields were developed widely. The learning ability of a neural network is similar to the human mechanism. As a result, it is possible to make a better information processing system, matching both advantages of the computer model and biomedical brain model. The structure of the neural network usually consists of three layers, the input layer, intermediate layer and output layer. Each layer is composed of the connecting weight and unit. A neural network is composed of those three layers by combining the neuron structures [8][9].

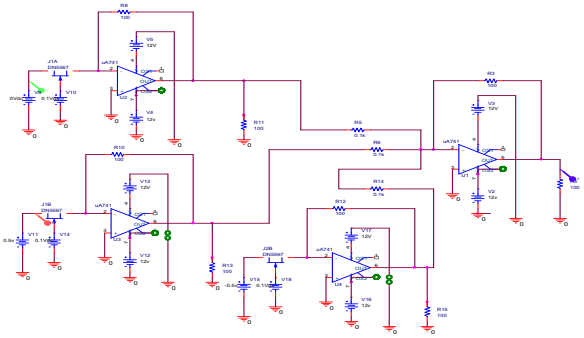
In the field of neural network, many application methods and hardware models have been proposed. A neuro chip and an artificial retina chip are developed to comprise the neural network model and simulate the biomedical vision system. In this research, we are adding the circuit of the operational amplifier. The connecting weight shows the input voltage of adding circuits. In the previous hardware models of neural network, changing connected weights was difficult, because these models used the resistance elements as the connecting weights.

Moreover, the model which used the capacitor as the connecting weights was pro-posed. However, it is difficult to adjust the connecting weights. In the present study, we proposed a neural network using analog multiple circuits. The connecting weights are shown as a voltage of multiple circuits. It can change the connecting weights easily. The learning process will be quicker. At first we made a neural network by computer program and neural circuit by SPICE simulation. SPICE means the Electric circuit simulator as shown in the next chapter. Next we measured the behavior confirmation of the computer calculation and SPICE simulation. We compared both output results and confirmed some extent of EX-OR behavior [10].

II. SPICE

In this research, we used the electric circuit simulator SPICE. Electric circuit simulator (SPICE) is the abbreviation of Simulation Program with Integrated Circle Emphasis. It can reproduce the analog operation of an electrical circuit and the electric circuit. After this, the circuit drawn by CAD, set the input voltage. SPICE has the function of AC, DC and transient analysis. At first, we made the differential amplifier circuits and Gilbert multipliers circuits. And we confirmed the range of voltage operated excellently. The neuron structure was composed of multiple circuits by an operational amplifier for multiplication function achievement, current mirror circuits to achieve nonlinear function and differential amplifier circuits.

In the previous hardware model of neural network, we used the resistance element as a connecting weight. However, it is difficult to change the resistance value. In the neural connection, it calculates the product the input value and connecting weight. We used the multiple circuit as the connecting weight. Each two inputs of multiple circuits means an input value and connecting weight. The connecting weight shows the voltage value. It is easy to change the value in the learning stage of neural network.



a.

Fig. 1. Neural Circuit (Two-input and One-output).

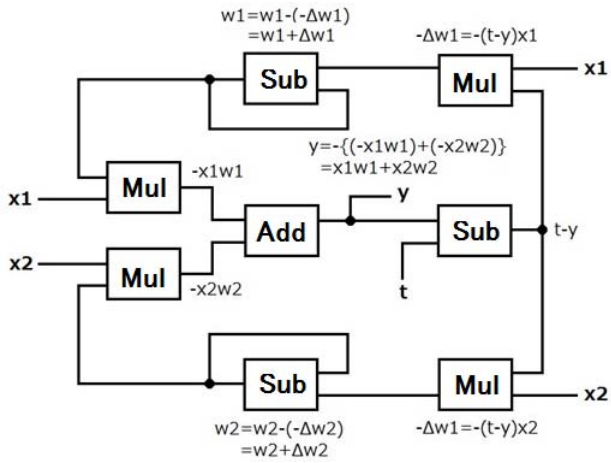


Fig. 2. The Architecture of Perceptron

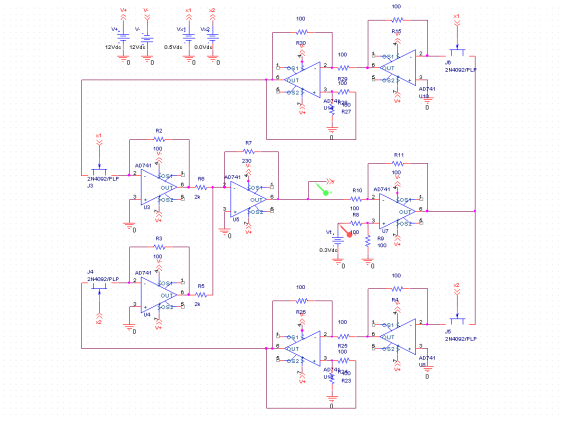


Fig. 3. The Circuit of perceptron

Figure 1 is the neural circuit of two inputs and one output which reproduces the characteristic of one neuron, using current addition by current mirror circuits, the product of the input signal and connecting weights.

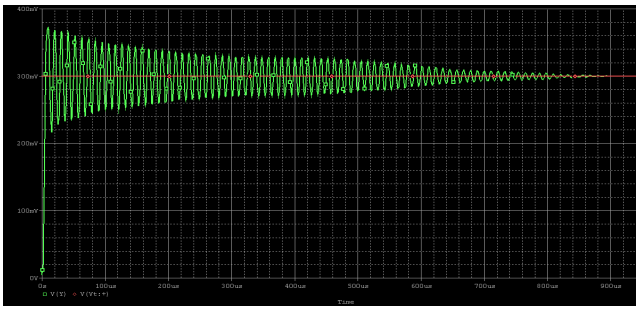


Fig. 4. The Simulation Result of Perceptron(1).

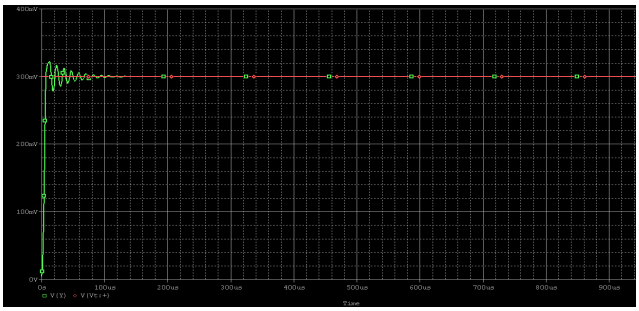


Fig. 5. The Simulation Result of Perceptron(2).

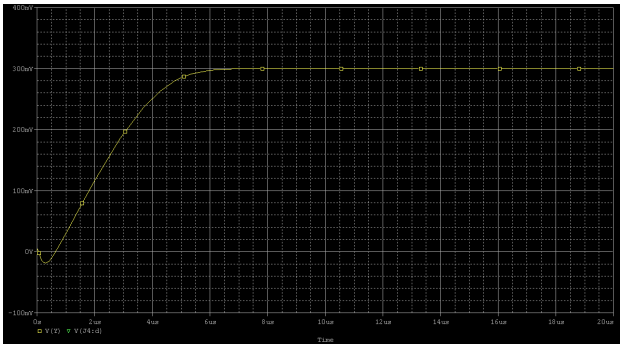
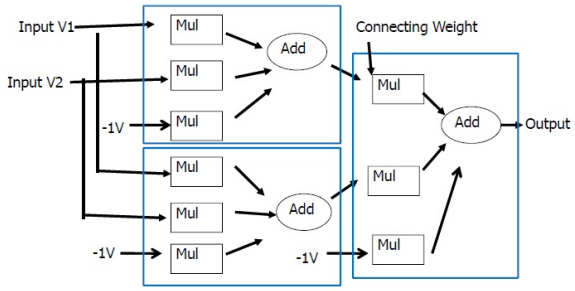


Fig. 6. The Output Response Characteristic of Perceptron Model.

III. Perceptron Network by Analog Circuits

At first, we constructed a two-input and one-output perceptron neural network. In Figure 2, we show the block diagram of perceptron neural network. "Mul" means multiple circuits, "Add" means addition of circuits and "Sub" means Subtraction circuits in Fig. 2. Figure 3 shows the perceptron circuits, two-input and one-output. In Figure 4, we show the output converges to 300mV. The parameter values are w1=870.25mV and w2=864.40mV. The learning time is about 900μS. However, another parameter, the learning time is only 150μS. shown in Fig. 5. There is a difference in the learning time. As a result of repeated experiments, the learning time is within 1mS at the longest. Moreover, the response time of the neuron model is 7μS shown in Fig. 6.



b.

Fig. 7. The Architecture of Three-Layers Neural Circuits.

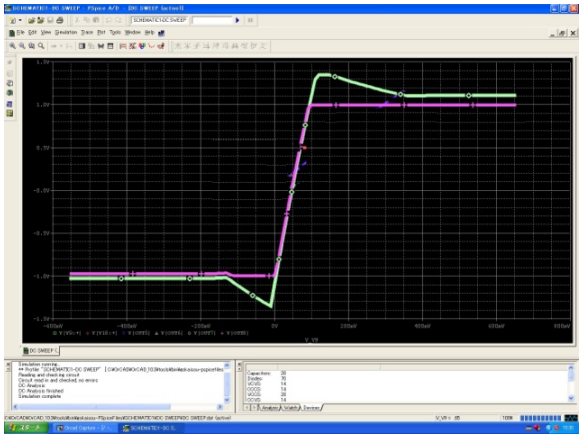


Fig. 8. Experimental Result of Three-Layers Neural Circuits.

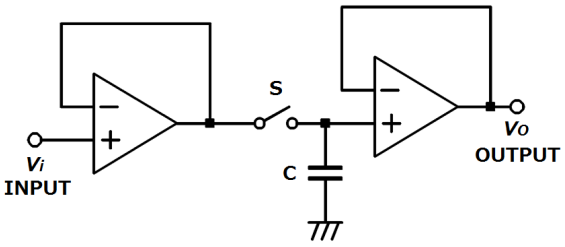


Fig. 9. Sample Hold Circuits.

IV. Three Layers Neural Network

We constructed a three layer neural network, an input layer, middle layer and an output layer. There are two input units, two middle units and one output unit. We combined the neural unit described in the preceding chapter. In Figure 7, we show the block diagram of a general neural network model. However it uses the multiple circuit for easy changing of the connecting weight. "Mul" means multiple circuits and "Add" means addition of circuits in Fig. 7. The experimental result is shown

in Fig. 8. We confirmed when the range of the voltage is between -0.05V and 0.15V, this circuit operated normally. The linear graph is the output of the middle layer and the nonlinear graph is the output of the final layer in Fig. 8 [11]. In the middle layer, we achieved a good output signal. In the output layer, there was a little distortion signal. However, this will not present a significant problem on the neural network output.

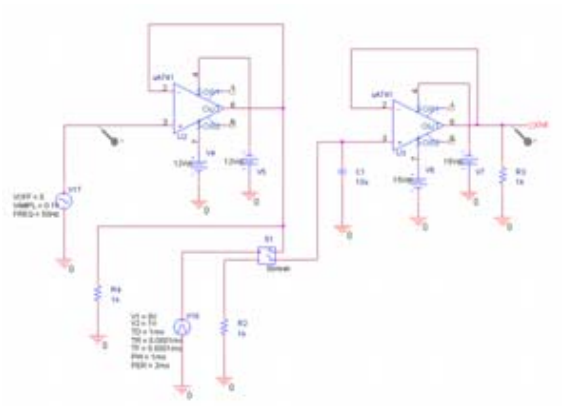


Fig. 10. Sample Hold Circuit by SPICE

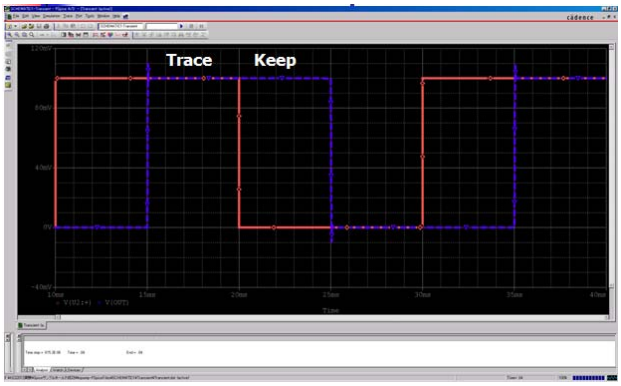


Fig. 11. Confirm Experience of Sample Hold Circuit –square wave

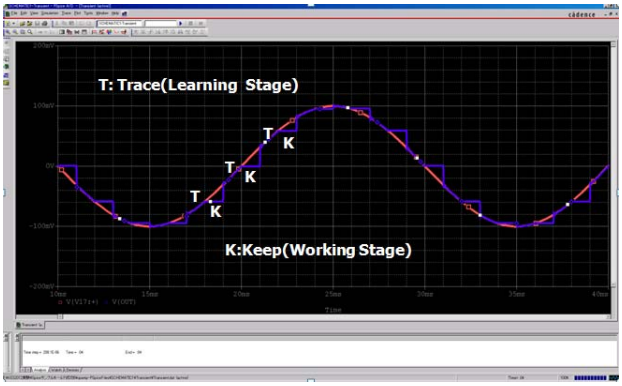


Fig. 12. Simulation Result of Sample Hold Circuit

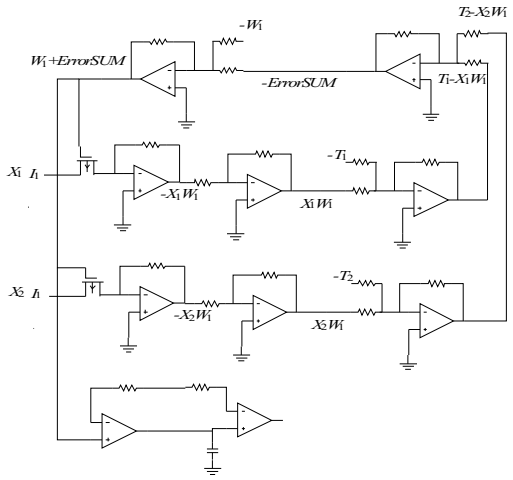


Fig. 13. The Circuit of Learning Stage.

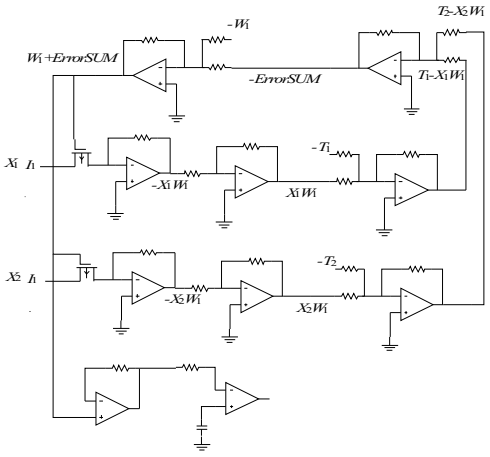


Fig. 14. The Circuit of Working Stage.

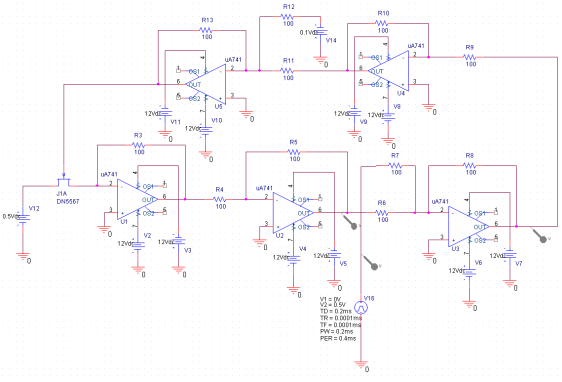


Fig. 15. The Learning Neural Circuit on Capture CAD by SPICE.

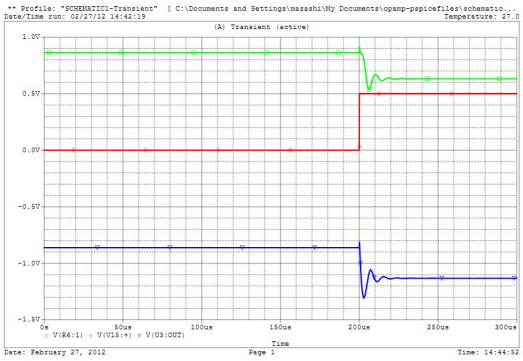


Fig. 16. The Simulation Result, input Square Wave

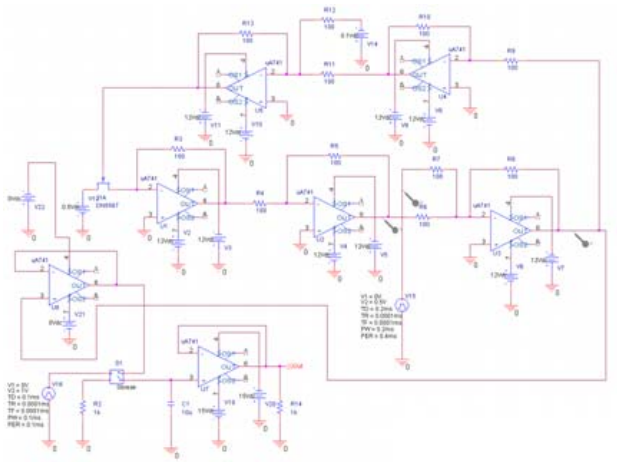


Fig. 17. Basic Neural Circuit with Sample Hold Circuits

V. Dynamical Learing Model

We propose the dynamical learning model using a pure analog electronic circuit. We used analog neural network, explained in a previous chapter. In the learning stage, we used analog feedback circuits. We use a separate neural network of each teaching signal. Real time learning is possible. We used the sample hold circuit in the working stage. It can hold the connection weights. In the working stage, this neural network is working. This circuit can perform periodical work, learning mode and working mode [12]. In Fig. 9, we show the Sample Hold Circuits. They can keep the output value for a brief time in the holding mode when the switch "S" is turn off. However, when the switch is turn on, this circuit situation is in "sampling mode". In the sampling mode, it is the same value for the input signal and output signal.

We constructed the Sample Hold Circuit by CAD and simulated by SPICE. We show the experimental Sample Hold Circuit in Fig. 10 and confirm experimental result in Fig. 11. In Fig. 12, we show the simulation result of sample hold circuits. It represents the learning stage and working stage of Neural Circuit. We show each stage in Fig.13 and Fig. 14.

Fig. 13 shows the circuit of Learning Stage. The sample hold circuit is in the sampling mode. Fig. 14 shows the circuit of the working stage. The sample hold circuit is in holding mode. In the base of our previous paper [12], we have the additional experiment. We sated each resistance or capacitor value on the Capture CAD by SPICE, in Fig. 15. In Fig. 16, we show the result when the input signal is a square wave. We got the result, the learning time is about 20μs. After spending 20μs, the output value is constant. We assume that the working time is also 20μs. The learning cycle of this circuit is 25,000 times per second. The learning speed of this model is very high in spite of a very simple circuit using low cost elements. Repeating the learning mode and working mode, the circuits can realize flexible learning. We show the Basic Neural Circuit with Sample Hold Circuits in Fig. 17.

On the other hand, the pulsed neural Network has an advantage. Particularly, this network can also keep the connecting weights after the learning process. However, it takes a long time for the learning process when many pulses are required. As the typical pulsed neuron model, about 1000 pulses were required for the learning process. However, our proposed model is constructed with a cheap electrical device. If we use the high quality analog electrical device, the learning speed will be improved more than pulsed neuron model. In the result of this experiment the performance is low because of using general-purpose, inexpensive parts. The operating speed will be improved by using a high-performance element which has a good slew rate. However, this system is a simple circuit. The number of parts is few. The cost will not rise much even if good performance parts are used.

VI. Conclusion

We constructed a three layer neural network, two-input layers, two-middle layers and one output layer. We confirmed the operation of the three layer analog neural network with the multiplying circuit by SPICE simulation.

The connection weight can change by controlling the input voltage. This model has extremely high flexibility characteristics. When the analog neural network is operated, the synapse weight is especially important. It is how to give the synapse weight to this neural network. To solve this problem, it is necessary to apply the method of the back propagation rule that is a general learning rule for the multiple electronic circuits. This neural circuit model is possible the learning. The learning speed will be rapid. And dynamic learning will be realized. The method is calculating the difference between the output voltage and the teaching signal of the different circuits and the feedback of the difference value for changing connecting weights. The learning cycle of this circuit is 25,000 times per second. The learning speed of this model is very high in spite of a very simple circuit using low cost elements.

The learning time of this model is very short and the working time of this model is almost real-time. The pulsed neuron model represents the output value by the probability of neuron fires. To represent the analog quantity using the Pulsed Neuron Model, enough time for at least a few dozen pulses is needed. The output value of this model is the output voltage of this circuit. We don't need to convert the data; we can use the

raw data from this model. This model allows for switching the working mode and learning mode. It is always necessary to input the teaching signal. However, the connecting weight changes according to the changing the teaching signal. This model can also easily accommodate changes in the environment. In each scene, optimal learning is possible. Moreover, deep learning method is proposed recently[15]. If this system improved toward the deep learning model, many applications will be realized.

It will improve the artificial intelligence element with self dynamical learning. The realization of an integration device will enable the number of elements to be reduced. The proposed model is robust with respect to fault tolerance. Future tasks include system construction and mounting a large-scale integration.

REFERENCES

[1] C. Mead, Analog VLSI and Neural Systems, Addison Wesley Publishing Company, Inc., 1989

[2] C. P.Chong, C. A. T. Salama, K. C. Smith, "Image-Motion Detection Using Analog VLSI, " IEEE Journal of Solid-State Circuits vol.27, No.1, pp. 93–96, 1992

[3] Z. Lu, B. E. Shi, "Subpixel Resolution Binocular Visual Tracking Using Analog VLSI Vision Sensors, " IEEE Transactions on Circuits and Systems-II: Analog and Digital Signal Processing, vol.47, No.12, pp. 1468-1475, 2000

[4] T. Saito and H. Inamura, "Analysis of a simple A/D converter with a trapping window, " IEEE Int. Symp. Circuits Syst., pp. 1293-1305, 2003

[5] F. Luthon, D. Dragomirescu, "A Cellular Analog Network for MRF-Based Video Motion Detection, " IEEE Transactions on Circuits and Systems-I: Fundamental Theory and Applica-tions, vol.46, No.2, pp. 281-293, 1999

[6] H. Yamada, T. Miyashita, M. Ohtani, H. Yonezu, "An Analog MOS Circuit Inspired by an Inner Retina for Producing Signals of Moving Edges, " Technical Report of IEICE, NC99-112 , pp. 149-155, 2000

[7] T. Okuda, S. Doki, M. Ishida, "Realization of Back Propagation Learning for Pulsed Neural Networks Based on Delta-Sigma Modulation and Its Hardware Implementation," ICICE Transactions, J88-D-II-4, pp 778-788, 2005

[8] M. Kawaguchi, T. Jimbo, and M. Umeno, "Motion Detecting Artificial Retina Model by Two-Dimensional Multi-Layered Analog Electronic Circuits, " IEICE Transactions, E86-A-2, pp. 387-395, 2003

[9] M. Kawaguchi, T. Jimbo, and M. Umeno, "Analog VLSI Layout Design of Advanced Image Processing For Artificial Vision Model, " IEEE International Symposium on Industrial Electronics, ISIE2005 Proceeding, vol.3, pp. 1239-1244, 2005

[10] M. Kawaguchi, T. Jimbo, and M. Umeno, "Analog VLSI Layout Design and the Circuit Board Manufacturing of Advanced Image Processing for Artificial Vision Model, " KES2008, Part II, LNAI, vol. 5178, pp. 895-902, 2008

[11] M. Kawaguchi, T. Jimbo, and M. Umeno, "Dynamic Learning of Neural Network by Analog Electronic Circuits, " Intelligent System Symposium, FAN2010, S3-4-3, 2010

[12] M. Kawaguchi, T. Jimbo, and N. Ishii, "Dynamic Learning of Neural Network by Analog Electronic Circuits, " KES 2011, Part IV, LNAI 6884, pp. 73-79. Springer, Heidelberg, 2011

[13] M. Kawaguchi, T. Jimbo, and N. Ishii, "Analog Learning Neural Network using Multiple and Sample Hold Circuits, " IIAI/ACIS International Symposiums on Innovative E-Service and Information Systems, IEIS 2012, pp243-246, 2012

[14] M. Kawaguchi, T. Jimbo, and N. Ishii, Analog Real Time Learning Neural Network using Multiple and Sample Hold Circuits, Frontiers in Artificial Intelligence and Applications Volume 243, pp1749-1757, 2012

[15] Yoshua Bengio, Aaron C. Courville, Pascal Vincent: Representation Learning: A Review and New Perspectives. IEEE Trans. Pattern Anal. Mach. Intell. 35(8): 1798-1828, 2013