Bio-inspired Visual Information Processing – The Neuromorphic Approach

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Abstract. This paper describes the bio-inspired visual information processing by neuromorphic system, mimicking the primitive behavior of visual cortex. The neuromorphic components are investigated for implementation of the visual signal selectivity of cortex, based on the CMOS conductance-based synaptic connections and neurons of Hodgkin-Huxley formalism. The proposed neuromorphic system exhibits the biologically plausible function mimicking the cat's visual cortex experimentation of Hubel and Wiesel. The detection of human head figure or pose demonstrates the feasibility of vision applications.

Keywords: neural networks, CMOS, vision, neuromorphic, visual cortex, simple cell, Hodgkin-Huxley formalism.

1 Introduction

There have been many works proposed recently for neuromorphic circuits and system, by mimicking both the functional and physiological characteristics of biological systems. We describe here the bio-inspired implementation of primary visual cortex, based on the neuron of Hodgkin-Huxley formalism and the visual cortex experimentation of Hubel and Wiesel. In this paper, the elements of neuromorphic implementation of visual cortex are presented with the orientation tuned map of synaptic weights and the spiking neuron, based on the electronically programmable MOSFET conductance.

The feasibility of neuromorphic VLSI visual cortex is investigated by simulated experimentation based on the CMOS 0.18um technology, with demonstrated vision applications of detecting the fire, human head figure, or pose from image sequences.

2 Primary Visual Cortex Function and Bio-inspired Spiking Neuron Based on CMOS Circuit

The physiological studies about visual cortex from the investigation of cat's striate cortex by Hubel and Wiesel have confirmed the consensus of knowledge [1], though there are many models about visual cortex. The idea on the primary visual cortex of simple cell motivated various theories of object recognition from characters to complex

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natural images [2]. For an idea of neural system implementation, the research about neurophysiology introduced the principles and demands of biologically plausible electronic implementation. In this paper, we propose the new way of implementing the neuromorphic VLSI for the primary visual cortex, inspired by the ideas on the primary visual cortex by Hubel and Wiesel's experimentation and the neurophysiological model of neuron by Hodgkin and Huxley [3]. The design motivation is from the well-known experimentation of simple cell in Fig 1. by Hubel and Wiesel.

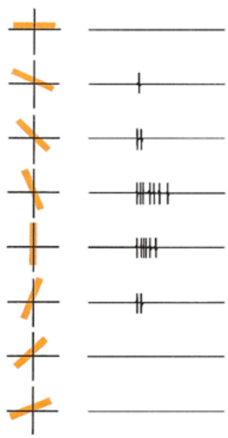

Fig. 1. Response of the cat's cortex to shining a rectangular slit of light, in various orientations [1]

The experimentation of spike burst with static line is aimed to mimic, while there is another experimentation of complex cell based on moving stimulus by Hubel and Wiesel.

The controlled conductance by CMOS transistors is used as an element of our neuromorphic system, which have been studied for biologically plausible analog-mixed neural networks VLSI [4, 5].

2.1 Neuromorphic Neuron Based on Voltage-Controlled CMOS Conductance

The Hodgkin-Huxley (H-H) formalism is a widely adopted idea of neuron's biophysical characterisation and dynamics. An electrical equivalent circuit model of Fig. 2 (a) is known as the empirical model of H-H formalism, which describes quantitatively the dynamics of the voltage-dependent conductance. Although most of particular neural networks tasks do not exhibit any major advantages based on H-H formalism, asynchronous spikes are considered as a principle element of high level or large scale neural computing system. The H-H formalism is widely of interest for its biophysical dynamics, though its complexity in computation is prohibitively high. Hence asynchronous dynamics of the H-H formalism is adopted as the idea of neuron model.

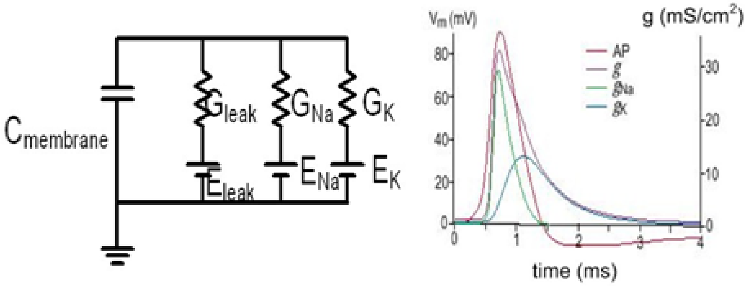

Fig. 2. (a) An electrical equivalent circuit of a neuron, Hodgkin-Huxley formalism (b) dynamics of asynchronous spike and refractory period vs. the membrane potential [3]

The overall dynamic behaviour of biological neuron is illustrated by the ion-based conductance controlled by membrane potential (or Action Potential), with the illustrated dynamics of conductance in Fig. 2(b) [4].

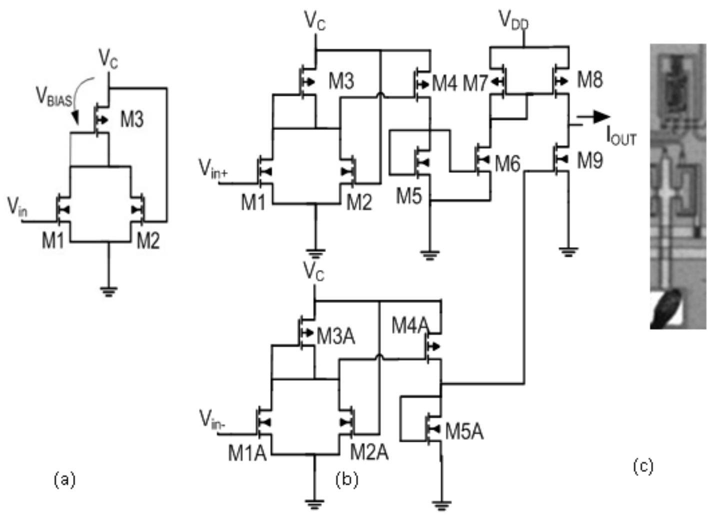

Fig. 3. (a) Voltage-controlled linear conductance by a pair of MOSFETs in the triode region, (b) the tunable linear transconducance circuit, (c) the chip photograph of CMOS transconductor

A circuit of Fig 3 (a) was proposed as a voltage-controlled linear conductance circuit by a PMOS transistor and a pair of identical NMOS transistors M1 and M2, while the conductance of MOS transistors is one of essential components in the analogue circuit design. The circuit of Fig. 3 has been investigated for various neural networks applications, from implementing synapses to neuron [4, 5].

The total drain current I_D of M1 and M2 can be expressed as

$$I_D = \alpha\,(V_{GS} - V_{BIAS} - 2V_{TH})(V_C - V_{BIAS})\ . \quad (1)$$

where $V_{GS} = V_{inDC} \pm \Delta V_{in}$ is the gate-source voltage of transistor M1, $V_{DS}=V_C-V_{BIAS}$ is the drain-source voltage of transistors M1 and M2, and V_C is the tuning voltage of transconductance.

As the repeated two circuit in Fig. 3(b) operate in the same condition, the output current I_{OUT} is

$$I_{OUT} = Gm\,\Delta V_{in} \tag{2}$$

where $I_{OUT}= I_{D3}-I_{DA}$. The transconductance circuit of Fig. 3(b) can be used as a programmable conductance of neuron's ion-channel or a synaptic connection with pulse/spike inputs.

2.2 Spiking Neuromorphic Circuit Mimicking the Primary Function of Visual Cortex

The tuning properties of orientation selectivity have been believed to play the key role for perception in visual cortex. As shown in Fig. 1, the tuning of specific neurons to the orientation of visual stimulus probably depends on the tuning features after passive or active learning for the earlier processing of natural image. The rule we assume is very simple as illustrated in Fig. 4, though some modifications are likely necessary for being more plausible to the natural system. Here, the tuned feature map (or connection) of 5 x 5 synaptic weights is based on the reference stimulus to match, with the minor adjustment depending on the output. The tuned feature map of vertical orientation is illustrated in Fig. 4(b), with the synaptic connections to 24 neurons (visual sensor, equivalent to a pixel) and itself. The synaptic weights of Fig. 4(b) are in the ration of (1: -0.6: 0.1 for black : grey : white). The six types of input stimulus (50 x 50 pixels) are experimented with the feature map (as synaptic connections) and spiking neurons based on H-H formalism.

The VLSI neuron is implemented by CMOS transconductance circuit of Fig. 3 in 0.18 μm CMOS technology. The spike burst output of Fig. 5 is observed by SPICE simulation, where the neuromorphic visual cortex mimic the biological spike burst of Fig. 1 from the experimentation work of Hubel and Wiesel.

The feasibility of bio-inspired neuromorphic system is demonstrated with its plausibility to primary simple cell function of visual cortex as exhibited in Fig. 5. The tuned feature characteristics of other orientations (-45˚, 25˚) are evaluated with the consistent outcomes as expected in the original experimentation of Fig. 1.

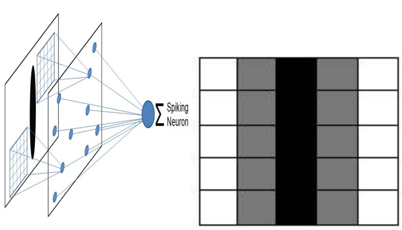

Fig. 4. The artificial primary visual cortex model with orientation selective synaptic weights to mimick the simple cell

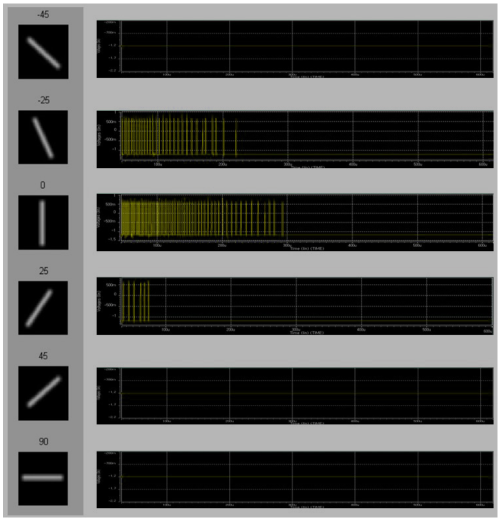

Fig. 5. The simulated spike burst of VLSI visual cortex to stimulus in various orientations

3 Bio-inspired Visual Information Processing and Application to Object Detection

The visual signal processing, particularly for vision application has been widely investigated, however, there is always a challenge such as the robustness to environmental change. The proposed bio-inspired processing is applied to example cases for evaluating its feasibility, as animal or human usually has the reasonable robustness. The previous research demonstrated the robustness to a certain application of object detection, i.e. the vehicle license plate detection. The license plate detection was investigated for the flexible detection based on the rectangle with the right angle, regardless of the aspect ratio or the whole size. It is based on the particular selective response to orientation at the right angle, i.e. presenting both components of horizontal and vertical orientation of the still image. It demonstrated the robust detection under some environmental interference such as the shiny reflection from the nearby area of license plate, in addition to the different sizes from the various distance [5]. In this paper, the application of multi-directional selectivity on the video information is investigated further for the detection of outdoor fire and human pose.

3.1 Human Pose Detection Based on the Edges of Multi-Direction

The visual perception processing is the one with the fast growing interests, with the emerging demands in applications of human detection or intelligent man-machine interface. In this paper, the neuromorphic vision system is evaluated for detecting human or human pose based on the video image. There are two major principles employed – first, the head of human has the high density if orientation components regardless of front view or side view. The other principle is the head linked to torso, while the arm is also linked to torso. Example cases are illustrated in Fig. 6, where the multi-directional orientation components (based on Fig. 4) are used prepare the orientation feature [6].

Fig. 6. Detection of passengers in different poses based on the multi-directional edges

The image of Fig. 7 illustrates the complex orientation features, which are caused by both the poor illumination condition and complicated environment. The orientation features of test image shows the complicated non-human objects, such as the glossy pattern of marble floor, reflection on the mirror like floor, wall-mounted art work and etc. In fact, the outside wall of the building is the transparent glass which causes the continuous and substantial changes in the illumination level and direction. Those features from the environmental cause is reduced by taking the difference of extracted orientation features of two video frames, as the background of two video frames has the similar features. The noise characteristics in the shadow area on the floor still remain in the reference features by two video frames. The application of neural net head detector generates the neuromorphic visual image, which has the high lightened area of human head. The equivalent of action potential locates the human head in the image, based on the winner neuron. The head area is successfully detected, while the head detection is successful throughout the entire video from appearing to disappearing. During the video experimentation of human head detection, the pose detection is evaluated with the movements of right arm. The pose detection is motivated for the alternative user interface of TV like haptic input to smart phone, which allows the unconstrained natural environment. The additional process is to introduce another neural network detector to characterize the arm, torso and background. The prior head detection can determine the region of interest as the arm is attached to the torso, as the head is also attached to the torso.

Fig. 7. Detection of human pose based on the neuromorphic vision: top-left to bottom-right, object video image, difference of detected edge components from two video frames, Action level of detection neuron, identified region of interest for detecting the pose of arm, neuromorphic visual image with the neural network arm pose detector, detected human head (yellow box) and arm pose (blue box)

The detected objects in Fig. 7 illustrate the successful feasibility of proposed pose detection, while the test on the entire video process shows the successful detection of arm when posed.

4 Conclusion

The bio-inspired neuromorphic vision is proposed as a feasible way of implementing the electronic hardware mimicking the primitive function of visual cortex, with application examples of object detection of various human pose. The example cases are successfully demonstrated by neuromorphic processing with the neural network detector or histogram detector. The neuromorphic circuit design is based on the linear controlled conductance of CMOS transistors, and is feasible for intelligent image sensors with the primitive visual cortex function by bio-plausible neurons of 10um x 10um in 0.18um CMOS technology.

The successful detection of outdoor fire or human pose is demonstrated with the simple bio-inspired principles, and the feasibility of neuromorphic vision is exhibited for various applications in the limited operation environment.

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