Neuromorphic Visual Information Processing – Bio-Inspired Vision

Woo Joon Han and Il Song Han

***Abstract*—This paper describes the early vision of bio-inspired neuromorphic system, mimicking the primitive behaviour of visual cortex. The proposed bio-inspired vision exhibits the biologically plausible function of mimicking the cat's visual cortex experimentation of Hubel and Wiesel. The neuromorphic implementation of vision is inspired by the directional visual signal selectivity of cortex and the CMOS spiking neuron based on Hodgkin-Huxley formalism. The feasibility of neuromorphic early vision is demonstrated for applications of the transportation safety system of passengers' occupancy detection of 95%, based on the recognition of human head figures.**

***Index Terms*—Neuromorphic, CMOS, vision, visual cortex.**

I. Introduction

There have been many works proposed recently for bio-inspired vision and neuromorphic vision devices. Although, computer vision algorithms are effective in their condition of usage, they at most times lack the robustness of the human vision. We describe here the early vision of 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 visual signal processing is evaluated with the robustness for the gray scale image or color component image, with demonstrated vision application of the passenger occupancy in the vehicle based on the human head figure detector.

II. 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 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 employ 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. The experimentation of spike burst for given static line input 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 an element of the proposed neuromorphic system, which have been studied for the biologically plausible analog-mixed neural networks [4, 5].

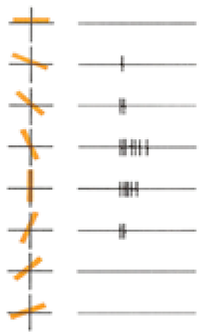
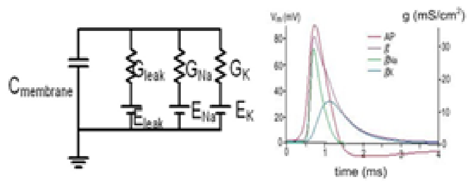


Fig. 1. Response of the cat's cortex to shining a rectangular slit of light in various orientations [1].

III. Bio-Inspired Visual Information Processing and Application to Object Detection



(a) (b)

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

Hodgkin-Huxley (H-H) formalism is a widely adopted idea of neuron's biophysical characterisation and dynamics. An electrical equivalent circuit model of Fig. 2a is known as the empirical model of H-H formalism, which describes

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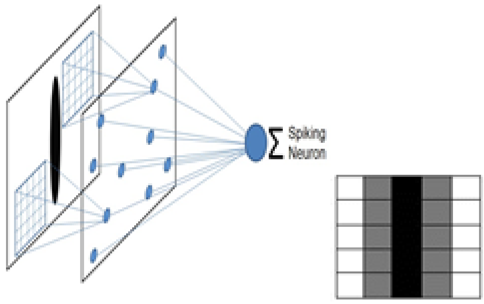
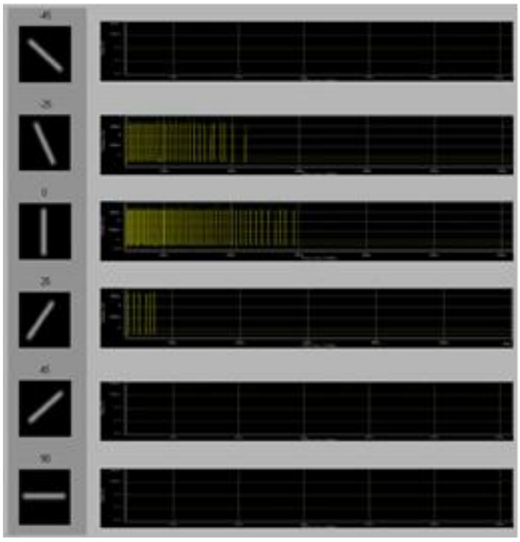
quantitatively the dynamics of the voltage-dependent conductance. Although the particular advantages of H-H formalism were not exhibited in neural networks tasks of vision or recognition yet, asynchronous spikes based on H-H formalism are considered as a principle element of high level or large scale neural computing or application 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.



(a)



(b)

Fig. 3. (a) The artificial primary visual cortex model with orientation selective synaptic weights to mimick the simple cell of visual cortex (b) the simulated spike burst of VLSI visual cortex to the stimulus in various orientations.

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. To mimick this response, a simple model was implemented as illustrated in Fig. 3, though some modifications are likely necessary for being more plausible to the natural system. The tuned feature map (or connection) of 5×5 synaptic weights is used, 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. 3a, while the synaptic weights of Fig. 3a are in the ration of (1: -0.6: 0.1 for black : grey : white). The six types of input stimulus (50×50 pixels) are experimented with the feature map (as synaptic connections) and spiking neurons based on H-H formalism [4]. The spike burst output of Fig. 3b is observed through a SPICE simulation, where the neuromorphic visual cortex response mimics that of 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. 3b. The tuned feature characteristics of other orientations (-45° , 25°) are evaluated with the consistent outcomes as expected in the original experimentation shown in Fig. 1.

The proposed bio-inspired neuromorphic system is applied to example cases for evaluating its feasibility in forming competent visual processing system with the robustness that is characteristic of animal or human vision. 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 challenges 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 human heads in the driving vehicle of changing background and illumination. The human torso template in Fig. 4 is applied to the head detection, as the property of rectangle was utilized in the license plate detection [5].

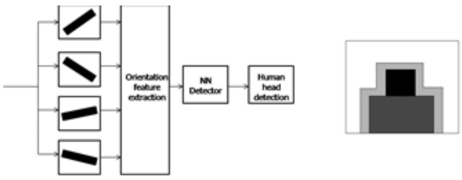
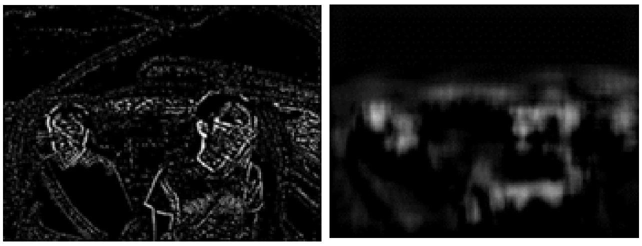


Fig. 4. Neuromorphic vision for human detection, inspired by the visual cortex, and based on the neural network detector of head-torso shape.

Fig 5b shows the successful detection of the two passengers in the car from input image of Fig 5a. Since tests were done on an image sequence, slightly different approach could be made than when input data were still images. As seen in Fig. 6a, the frame difference was made between current and previous bio-inspired directional selective processed image to decrease any orientation features that were stand-still. Although it is true that passengers sitting in their seats rarely have any or no body movement, all human has slightest movement in their head whether that is tilting of head or changes in facial expression whereas other unwanted signals such as from the interior of car is decreased. For the orientation selectivity, the 6 simulated synaptic connections of 9×9 were used for the orientation feature extraction. Six were orientations were used as six different orientation, more or less, can describe the basic outline of human head while reducing the chance of other unwanted objects being detected. The orientation features extracted shown in Fig. 6b shows heavy density in the head area which yields the high lightened head area. And lastly, neural net detection were made from Fig. 6b resulting the yellow boxes in Fig. 5b, which was decided by performing ‘winner takes all’ approach to get strongest signal. Note that for the detection, number of human head in the input date is known, i.e. for the image shown in Fig. 5b, two strongest signals were taken.

(a) (b)

Fig. 5. (a) Input image with resolution of 640 ×480 (b) detection result where yellow box denotes the passenger head detected from the bio-inspired visual processing and green box denotes the detected passenger.



(a) (b)

Fig. 6. (a) Bio-inspired processing of current and previous image of Fig. 5a (c) torso template-based neural network detector of Fig. 4.

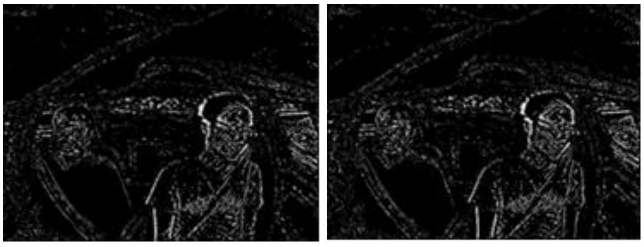
The driving vehicle is subject to the wide range of changes in the illumination level and background. There is a difficulty of detecting every passenger from image of Fig. 7a, likely due to the change in both the illumination and background. The processed information from color component of image was added to improve the robustness, reflecting on the fact that animals also see the color though different from human. Animals are known to use particular color information only so red color image was taken shown in Fig. 7b. There is a small difference; the head area became slightly lighter, and all passengers were successfully detected with the mixed combination of gray image and red-color component image as in Fig. 8b. There is only slight difference from Fig. 9 or Fig. 10 after bio-processing or neural net detector. Other mixtures of color components were evaluated not suitable for the improvement of an example application, while the mixed gray image illustrated the better detection accuracy of 95% than the single red-color component image.

(a) (b)

Fig. 7. (a) The gray input image converted from the colour image (b) the image of red-color component extracted from the colour image.

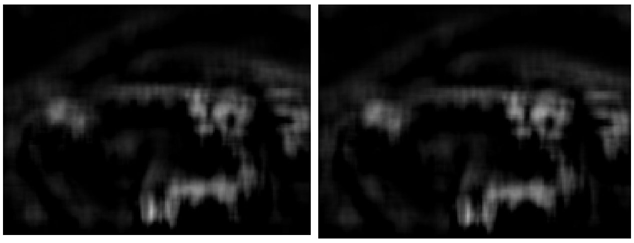
(a) (b)

Fig. 8. (a) Imperfect detection of passenger based the gray image converted from the colour image (b) improved detection of passenger based on the combination of the gray image and the red-colour component image .



(a) (b)

Fig. 9. Bio-inspired processing of current and previous (a) gray image of Fig. 7a (b) mixed image of gray and red-component images of Fig. 7a and Fig. 7b.



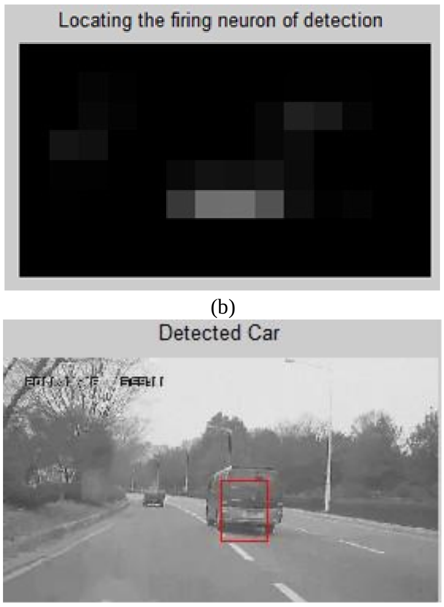
(a) (b)

Fig. 10. The output of the template-based neural network detector applied to (a) Fig. 9a and (b) Fig. 9b.

IV. Applications to Vehicle Safety Enhancement

The basis for proposed algorithm came from biological eye and brain to give robustness so that it can be used in different applications without modifications to the principles. The algorithm did prove to possess such robustness as with minor modification such as change in template used in neural network detector made it possible for the algorithm in other applications such as pedestrian detection and vehicle detection. Example of successful vehicle detection is shown in Fig 11. Notice that the image was captured at the cloudy day as it is shown from the fact that the detection image shown in grey image looks similar to the original image which is in colour.

(a)



(c)

Fig. 11. The detection of vehicle using the same algorithm with minor modification to the template used in neural network detector. (a) Original image captured (b) resulting image after neural network is applied (c) the resulting detection image.

V. Conclusion

The bio-inspired neuromorphic vision is proposed as a feasible way of early vision by mimicking the primitive function of visual cortex, with an application example of detecting human heads. The example cases successfully illustrate the neuromorphic processing with the neural network detector. The bio-inspired early vision is based on the neuromorphic processing of one-fourth scale of original image (640x480), while the gray-and-color mixed combination of input video image improved the robustness substantially.

The object detection in the moving vehicle shows the successful passenger detection for every input image frame through more than the 30 consecutive frames under the changing environment. The neuromorphic detection of passenger occupancy in the moving vehicle demonstrated the robust vision, and the feasibility of neuromorphic vision is exhibited for various applications in the limited operation environment.

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