

Bio-inspired Computing of Vision- Fuzzy and Neuromorphic Processing

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Abstract— This paper describes the early vision of bio-inspired neuromorphic system enhanced by fuzzy processing, mimicking the primitive behaviour of visual cortex. The proposed bio-inspired system 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 membership function is introduced to improve the early vision and the improvement is demonstrated for robust applications, based on the recognition of human head figures.

Keywords—neuromorphic; neural networks; CMOS; vision, visual cortex, simple cell, Hodgkin-Huxley formalism, membership function

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, at most times, they 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 enhanced performance by introduction of membership function.

The feasibility of bio-inspired visual signal processing is evaluated showing robustness for gray scale image and single color component image. Potential application for such system is explored in human detection in wide range of environment; passenger occupancy detection, pedestrian detection and human detection in the conference presentation. The latter environment was explored with a view to further extend it into gesture detection.

II. PRIMARY VISUAL CORTIX 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 on 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 mimick, while there is another experimentation of complex cell based on moving stimulus by Hubel and Wiesel.

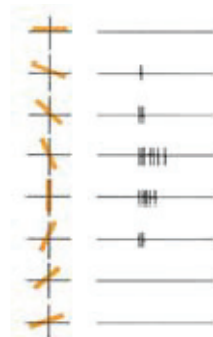


Figure 1. Response of the cat's cortex to shining a rectangular slit of light in various orientations [1].

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].

III. BIO-INSPIRED VISUAL INFORMATION PROCESSING AND APPLICATION TO OBJECT DETECTION

Hodgkin-Huxley (H-H) formalism is a widely adopted idea of neuron's biophysical characterisation and dynamics. The electrical equivalent circuit model of Fig. 2a is known as the empirical model of H-H formalism, which describes quantitatively the dynamics of the voltage-dependent conductance. Although the particular advantages of H-H formalism were not exhibited in neural network's 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.

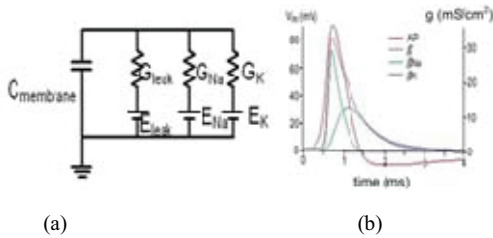


Figure 2. (a) The electrical equivalent circuit of a neuron, Hodgkin-Huxley formalism (b) dynamics of asynchronous spike and refractory period vs. the membrane potential [3].

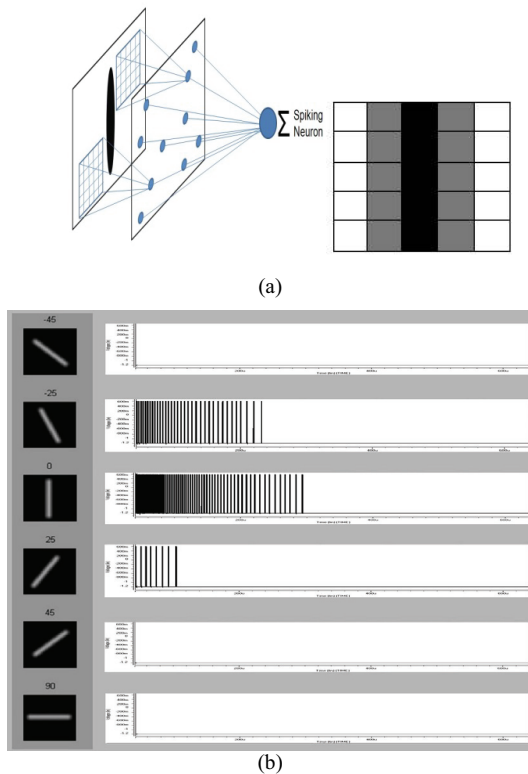


Figure 3. (a) The artificial primary visual cortex model with orientation selective synaptic weights to mimic the simple cell of visual cortex (b) the simulated spike burst of VLSI visual cortex to the stimulus in various orientations.

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 mimic 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].

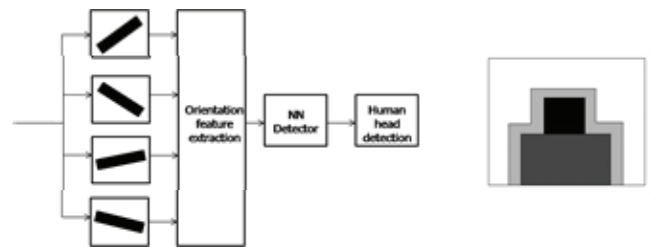


Figure 4. Neuromorphic vision for human detection, inspired by the visual cortex, and based on the neural network detector of head-torso shape.

Fig 5 shows the successful detection of the two passengers in the car. 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. 5, 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 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 shows heavy density in the head area which yields the high lightened head area. And lastly, neural net detection were made resulting the yellow boxes of human heads detected, 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. 5, two strongest signals were taken.

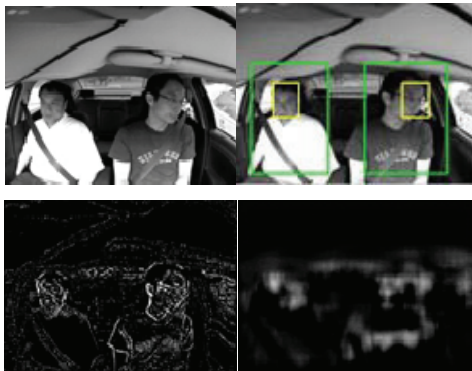


Figure 5. (from top left in anti-clockwise direction) Input image with resolution of 640×480 , bio-inspired processing of current and previous image, torso template-based neural network detector of Fig. 4 and detection result where yellow box denotes the passenger head detected from the bio-inspired visual processing and green box denotes the detected passenger

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 due to the change in both the illumination and background when only gray image is used. Thus to improve robustness, color component of image was added during processing to improve the robustness reflecting on the fact that animals utilizes different color components to human when processing. In Fig. 6, red color component was taken to process to improve the robustness. 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. 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.

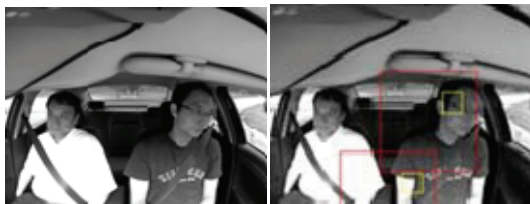


Figure 6. (from top left in anti-clockwise direction) The gray input image converted from the colour image, the image of red-color component extracted from the colour image, improved detection of passenger based on the combination of the gray image and the red-color component image and imperfect detection of passenger based on the gray image converted from the colour image.

The bio-inspired processing is applied to pedestrian detection where the test image set was captured from a moving bus in London from a commercially available camera. Same approach was used for pedestrian detection such that the orientation features from the input image is extracted first and then neural network with human shape template was used to detect the human. For pedestrian detection application, especially for a vehicle, may require the detection of a pedestrian who is having certain amount of motion, e.g. running. Also there is more interest in a pedestrian moving across the field of vision as there is more likelihood of collision. Considering these points, frame differences were taken so that the detected pedestrians are those with more than certain motion as seen in Fig. 7. In Fig. 7, other pedestrians are seen other than the detected pedestrian but they were not detected since their motions were low.

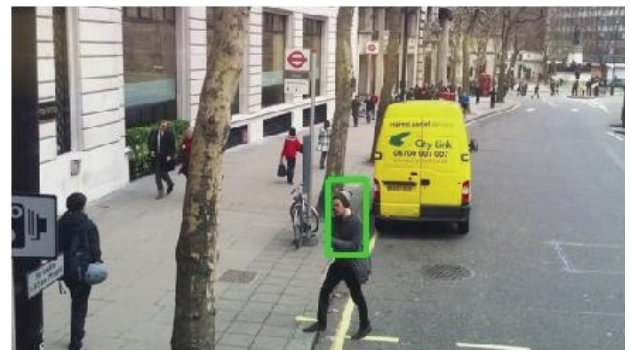


Figure 7. Pedestrian detection result where two previous frames were used in the process.

IV. FUZZY MEMBERSHIP FUNCTION TO ENHANCE DETECTION

There are some tasks demanding further processing, because of dynamic environmental changes or the limitation of template features for complex object. The detection of a presenter in the dark conference room is challenging, as there are not only the dynamic changes of illumination but also the confusing patterns from the displayed presentation. The recognition process in the neuromorphic vision is based on the winner neuron representing the regional summation after the template processing, however the exact winner location can be disturbed by multiple locations close to the maximum value (i.e. the winner). The membership function of Fig. 8 is

introduced to improve the cases of confusing illumination or complex situation of Fig. 9. The illustrated membership function is derived for 12 x 22 reference locations is based on the heuristic evaluation. The average of 12 x 22 elements from the local summation of saliency map is derived to accommodate the changes in the illumination or patterns, while the membership function of Fig. 11 is determined by four points of (average)x8, (average)x10, (average)x11, (average)x12. The action potential value is applied to the membership function, and the multiple candidate locations can be determined with revised value rather than a winner location of the maximum action potential. Several locations are suggested as the location of human head object with the processing of fuzzy membership function.

In Fig. 10, the application of fuzzy processing illustrates the improve detection of a presenter (head) than the case without the fuzzy processing, though the primitive fuzzy membership function is applied.

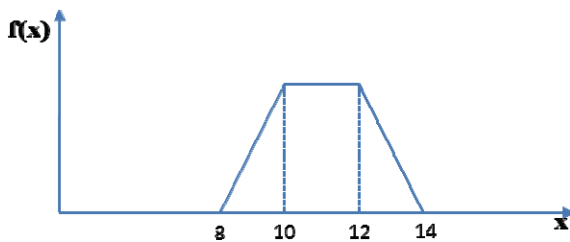


Figure 8. Membership function introduced to the neuromorphic vision

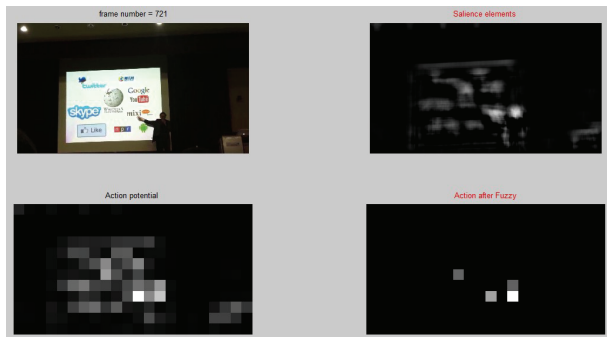


Figure 9. Effect of applying fuzzy function.

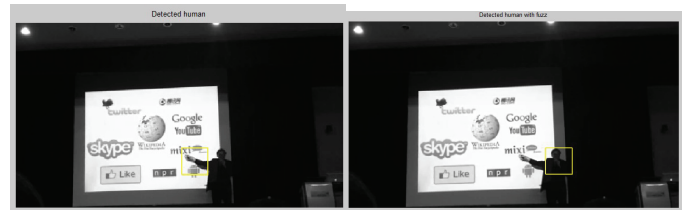


Figure 10. Enhanced human detection procedure with membership function is shown on the right and on the left shows the detection result without applying the membership function.

V. CONCLUSION

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

The object detection in the moving vehicle or the conference room shows the successful human detection under the changing environment of illumination. The bio-inspired computing of human detection in the moving vehicle or the dark conference room demonstrated the robust vision, and the feasibility of neuromorphic vision is exhibited for various applications in the limited operation environment.

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REFERENCES

- [1] D.H. Hubel and T.N. Wiesel, "Receptive fields of single neurons in the cat's striate," J. Physiol. 148, pp. 574-591, 1959.
- [2] M. Riesenhuber and T. Poggio, "Hierarchical models of object recognition in cortex," Nature Neuroscience, pp. 1019-1025, 1999.
- [3] M. Hausser, "The Hodgkin-Huxley theory of action potential," Nature Neuroscience Supplement 3, pp. 1165, 2000.
- [4] I. S. Han, "Mixed-signal neuron-synapse implementation for large scale neural networks," J. Neurocomputing, pp. 1860-1867, 2006.
- [5] W.J. Han and I.S. Han, "Bio-inspired visual signal processing based on neuromorphic circuit," Proc. 10th WSEAS International Conference on Instrumentation, Measurement, Circuit and Systems, pp. 131-136, 2010.