PASSENGER/PEDESTRIAN ANALYSIS BY NEUROMORPHIC VISUAL INFORMATION PROCESSING

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ABSTRACT

The physiological studies since the Hubel and Wiesel's experimentation of cat's visual cortex have confirmed the consensus about the brain's intelligence of visual perception. A new way of enhancing the safety of vehicle is proposed by employing the neuromorphic VLSI or processing for mimicking the robust and natural intelligence of visual recognition, inspired by both the Hubel and Wiesel's experimentation of visual cortex and the neurophysiological model of Hodgkin-Huxley formalism. The feasibility of neuromorphic system is demonstrated successfully for the robust recognition of human objects for the safety either in the car or on the road, evaluating the neuromorphic VLSI implementation based on the controlled CMOS conductance for the bio-plausible performance.

The neuromorphic visual information processing is developed for both applications of the driver/occupant analysis in the car and the human object detection on the road. The neuromorphic vision research was motivated by the status analysis of the human posture and safety apparatus for the innovation of the emergency rescue service dealing the crash accidents, and extended its applications to the safety technology of assisting the vehicle drive by detecting nearby pedestrians or human objects. The overall performance is measured with the success rate over 90%, for both the pedestrian detection and the occupant monitoring, in day or night. The most of human object detections are based on the neuromorphic visual information processing using the still image from the video sensor, because of the limited sight condition.

The appropriate use of orientation feature extraction and neural networks ensures the reliability of proposed neuromorphic visual information processing to perform well under various dynamic conditions, such as in the changing ambient light, in night time, or in wet weather which are inevitable for vehicles on the road. The detection of pedestrian or cyclist performs consistently in wide ranges of environment, evaluated in various times and places of Europe and Asia.

The recognition of driver's eye sight is proved as an added function within the framework of proposed neuromorphic system, to match the varying driver's eye sight for controlling the eye-glassless 3D dashboard display. The same principle is applicable to detect any particular part or pose of human object, and the neuromorphic visual processing system can accommodate the enforced adaptation or learning as it mimics the natural brain.

The neuromorphic coupled with neural networks, suggests it as the new feasible and robust device with the convergence of biological neural system and information technology, or as the cost effective and reliable device of vehicle's safety enhancement by using the CMOS neuromorphic VLSI approach.

INTRODUCTION

There have been developed many works of computer vision for the vehicle safety applications using various tools and methodologies such as the camera-based complex computer vision algorithm or a combination of camera and radar to utilize the distance data in calculation to improve the accuracy and reliability. Although, the computer vision algorithms are effective in their condition of usage, they at most times lack the human vision's robustness for the vehicular applications in dynamic environments. Hence, the neuromorphic visual information is investigated to adopt the robust and flexible performance of the primary visual cortex, inspired by the neuron model of Hodgkin-Huxley formalism and the visual cortex experimentation by Hubel and Wiesel [1].

In this paper, the elements of neuromorphic implementation of visual cortex are introduced with the orientation tuned function of synaptic connections and the spiking neuron, based on the electronically programmable MOSFET conductance[2]. The proposed neuromorphic visual signal processing is investgated for enhancing the vehicle safety by the pedestrian detection or the passenger detection.

NEUROMORPIC VISUAL INFORMATION PROCESSING

The visual signal environment of occupancy detection or pedestrian detection passengers may vary greatly between sensing times and places since the vehicle is in motion. The widely changing environment of the illumination or the background demands the robust human object detection algorithm for the consistent and reliable performance. Much of computer vision algorithms are effective in their specific usage, however they lack the robustness of human vision and for most times will underperform in the varied conditions of illumination.

Primary Visual Cortex

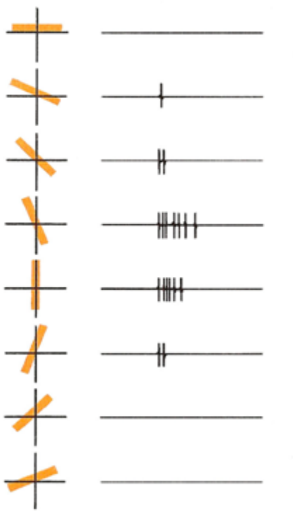

Figure1. Response of the cat's cortex when a rectangular slit of light of different orientations is shown [1].

Although there is not a definite model of visual cortex, Hubel and Wiesel's research on cat's striate cortex confirmed the idea on the functioning of the simple cell. It is from this discovery which motivated various theories of object recognition from characters to complex natural images [3]. The observed orientation based behavior evoked the reflection while the spike-based neuron signal is also an essential feature. These researches on neurophysiology introduced not only the neural networks software algorithm but also the principles of biologically plausible implementation. The neurophysiological model of Hodgkin-Huxley formalism is the most precise spike neuron model requiring complex computing, with the biological plausibility. Two principles of the simple cell and the Hodgkin-Huxley formalism are adopted in the neuromorphic vision together with the linear and controlled CMOS conductance, for the purpose of realizing the robustness of human level and the cost effectiveness of electronic implementation [4].

Neuromorphic Neuron

The neuromorphic neuron of visual cortex can be implemented by simulating the behavior of neuron in the Hubel and Wiesel's experimentation. The spike neural signal is explained by the widely adopted Hodgkin-Huxley formalism in Fig. 2, with the controlled conductance based equivalent model [5]. Hodgkin-Huxley formalism is unlikely used as much in neural networks or VLSI because of uncompromised large demand in computing complexities in its implementation; however the asynchronous spikes are considered as principle element of high level or large scale neural computing system.

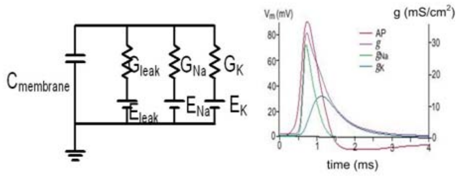

Figure2. (a) An electrical equivalent circuit of a neuron, Hodgkin-Huxley formalism (b) dynamics [5].

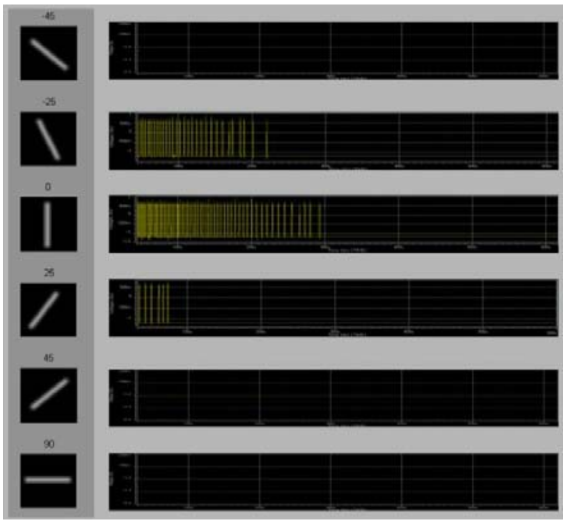

Figure3. Simulated neuron behaviour of visual cortex in Figure 1 by the CMOS neuromorphic neuron based on the model of Figure 2.

The neuromorphic system of neuron and synaptic network was designed for evaluating the feasibility of mimicking the primitive behavior of brain neural system in electronic hardware using the CMOS electronic circuit of [2, 6]. With the neuromorphic neuron formed the various stimuli of six 50 x 50 pixel sized rectangles at different angles are applied as the similar stimulus input to the cat in Hubel and Wiesel's experiment. The simulated result of neuromorphic neuron in Figure 3 shows the consistent outcome as the observation from the Hubel and Wiesel's experiment in Figure 1, where the tuned feature orientations are represented as the spike signal outputs.

NEUROMORPIC VISUAL SYSTEM

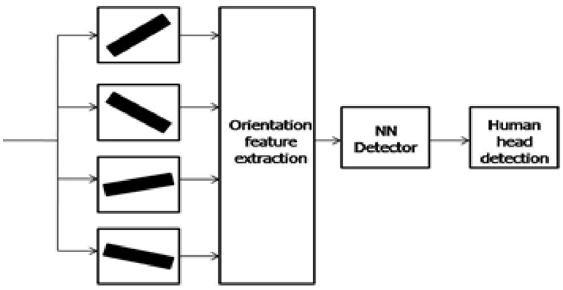

Figure4. Neuromorphic vision for human head figure detection, inspired by visual cortex.

The neuromorphic neuron of simple cell enables the neuromorphic vision system in Figure 4, with the various orientation selective features. The system has three steps in its process which are: 1) orientation feature extraction using neuromorphic neuron, 2) neural network is then applied to the orientation extracted image and finally 3) the human head detection is made to detect the passenger or the pedestrian depending on the system's application.

Pedestrian Detection

One of the major challenges in the pedestrian detection for the enhanced vehicle safety is that the reliability of the detection is strongly affected by illuminace conditions. For example, most pedestrian detection algorithms have significant drop in its detection rate at the night time or indoors compared to the day time or when operating in the bad weather such as rain or snow. The neuromorphic vision system is based on the orientation selectivity of simple cell, instead of the immediate pattern matching or complex figure pattern. The robustness in substantially weak illumination is observed by the successful detection at the indoor parking lot or the night time drive with the head light.

Figure5. Original input image to be processed. Notice the cyclist (red plastic jacket) is uneasy to be recognized by the naked eye.

In addition to the environment of limited illumination, the robustness of neuromorphic visual information processing is demonstrated by the successful cyclist detection in a bad weather and illuminace condition as seen in Figure 5.

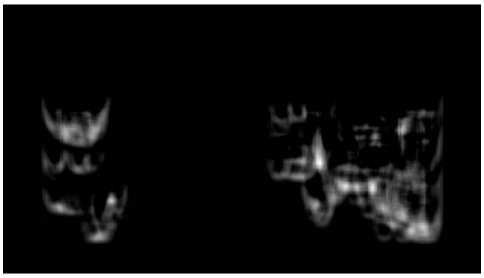

Figure6. Saliency by orientation feature extraction and neural network template of neuromorphic vision system.

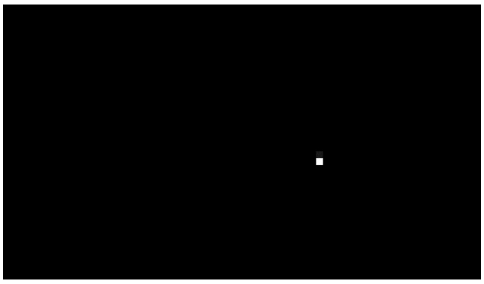

Figure7. Cyclist detection with the post processing applied to the Figure 6.

The saliency after template processing with the orientation features extracted is shown in Figure 6. Due to the extra noise by the snow and limited illumination, the saliency map is shown with extra objects. The characteristics of head detection can separate the large segment in the saliency as it is usually not relevant to human object detection.

The saliency image shows lot of features other than the human object of cyclist. The approaching vehicle's headlight, vehicle itself, and reflected light on the road, wall and objects cause a lot of noisy components appeared as well. However, once the neural network post processing is applied to the image with the individual feature by head-torso template, most of irrelevant signals other than the single detection signal are eliminated in the resulting image in Fig. 7. The resulting detection is shown in Figure 8 where the cyclist is successfully detected. The test video sample was captured in the snow weather, late afternoon of December, in China.

Figure8. Resulting detection of cyclist from original image of Figure 5.

The performance for pedestrian detection for day or night time is both higher than 90% as illustrated in Table 1 and 2. The detection result in Table 1 and 2 is based on the test video sample captured at the same place, different time, in Korea.

Table 1. Detection rate for daytime

Day Time	Frames including human object	Frames without human Object	Total Number of Frames
Number of frames	18	88	106
Positive Detection	15	88	103
Negative Detection	3	0	3

Table 2. Detection rate for night time

Night Time	Frames including human object	Frames without human Object	Total Number of Frames
Number of frames	99	5	104
Positive Detection	89	2	91
Negative Detection	10	3	13

Passenger Detection

The neuromorphic vision system in Figure 4 is applied to the occupancy detection for new emergency service to reduce the fatality of accidents. There is only the little change for the parameter tuning to accommodate the difference of sensor and object type, where the same template of head-toroso and orientation features are maintained.

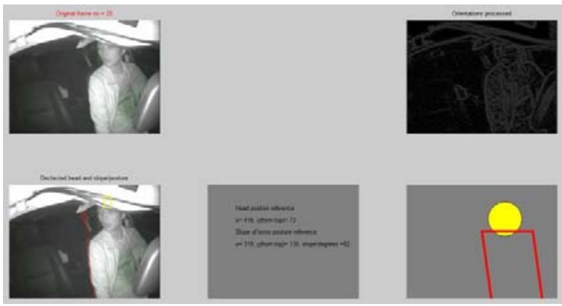

Figure9. Posture detection of passenger. The diagram on the bottom right is represented the posture of the detected passenger.

Similar to the pedestrian detection, same neuromorphic visual system is used to detect the passenger but with minor changes in the processes. For the pedestrian detection, the environment at which the detection must be made is when the vehicle and/or pedestrian is in motion thus there is lot of change in the background such that frame difference cannot be used to reduce noise. However, for passenger detection as shown in Figure 9, the background of passenger is mostly the vehicles stationary passenger cabin with minor variations in the window outlook and so frame difference can be used to minimize noise detected during process.

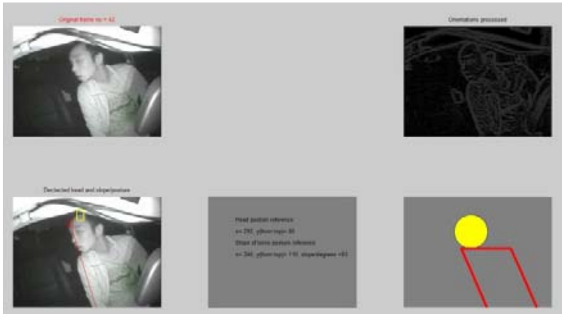

Figure 10. Posture detection of passenger. The passenger is titled further than in Figure 9 and the difference was detected correctly as seen in reconstruction.

To determine the posture of the occupant, the head of the passenger is detected together with the shoulder corner (right arm of driver as in Figure). The straight line is configured to the detected shoulder corner from the edge of driver seat, representing the slope angle of the line. The detected head location and the slope line are used to detect the posture of car occupant as illustrated in Figure 9, 10 and 11. The noisy and unclear image is due to the night time capture by the low cost sensor, while the overall function is reasonable with the consistent head detection.

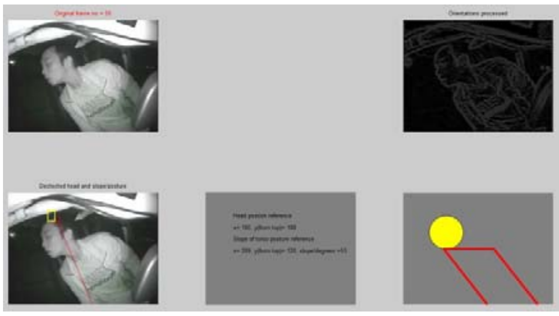

Figure11. Posture detection of passenger. The passenger is titled further than in Figure 9 and 10 and the difference was detected correctly as seen in reconstruction.

Figures 9, 10 and 11 show the posture detection of the passenger. From the detection, the head's x, y position in the image and the angle of its posture is extracted. The extracted information then can be used to visualize the posture of the passenger. This function demonstrates the practical feasibility of sending the information of passenger's posture to the emergency centre without losing the privacy of personal data protection and with the low communication maintenance. The video was captured in night time, in Korea.

Passenger Eye Detection

The demand of the passenger's eye or particular part emerges with the new service or smart devices like 3D dash board without the eye glasses. The monitoring of passenger's facing becomes of interests for the enhanced safety since the information of the face direction or eye status of the passenger is applicable to various advanced service for the attention warning or the smart instrument control.

The fundamental information processing involved in the eye detection is same as for the pedestrian and passenger's posture detection. However, for the robust eye detection, both the nose feature and eye feature are integrated together and the neuromorphic processing is based on the still image after locating the passenger's head. The two stages of processing enhance the image dynamics with localized tuning.

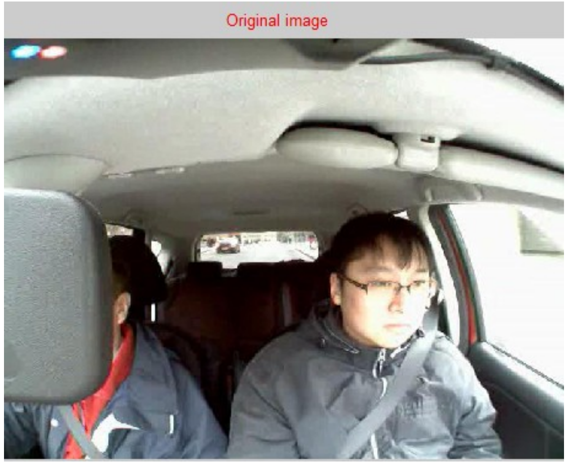

Figure12. Input image

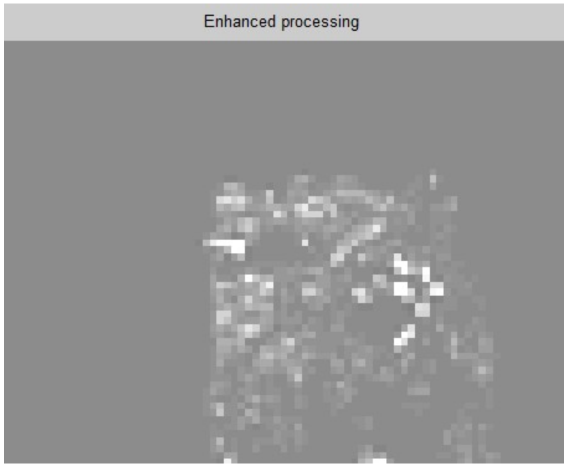

Figure13. Orientation features extracted.

Since the outline of the eye and the nose is distinctively different to that of the head, it is important to detect the head of the passenger to determine the ROI for eye detection. Note that the image used in the detection of the eye and the nose was captured in the different image environment, in the day time, in the UK, even the different vehicle model, but without the change in neuromorphic vision system. The successful detection of the passenger head without calibration or any additional settings to match previous detection shows that the system is robust.

Figure14. Saliency image – resulting image after neural network is applied

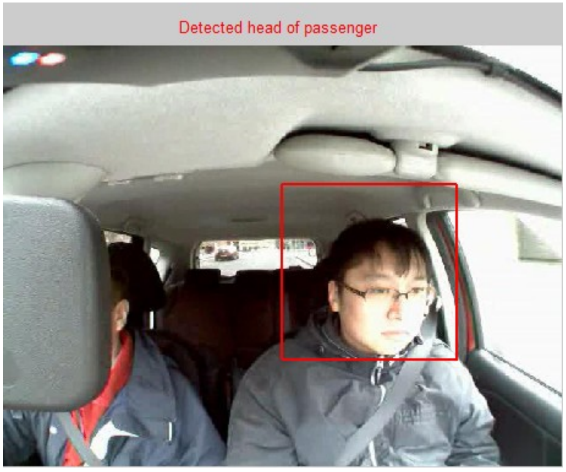

Figure15. Detection of the passenger head to determine ROI for the eye and the nose detection

The orientation features shown in Figure 12 is extracted from the input image, Figure 11. The orientation features were extracted only from the interior of the vehicle, so that the structure of the vehicle and the outside scenery seen through the window is omitted in orientation feature extraction.

Figure 14 is the saliency map after the neural network with human-torso template is applied. From the image it can be seen that the high output levels are concentrated in the center. And the resulting detection in Figure 15 shows the successful detection of the passenger.

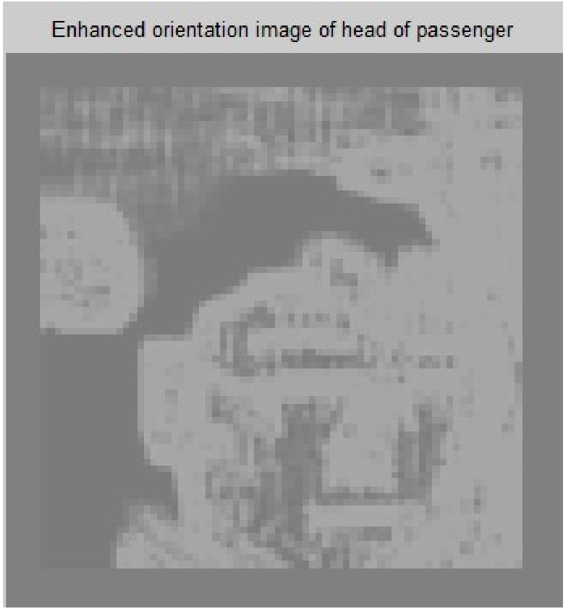

Figure16. Orientation features extracted from the head area.

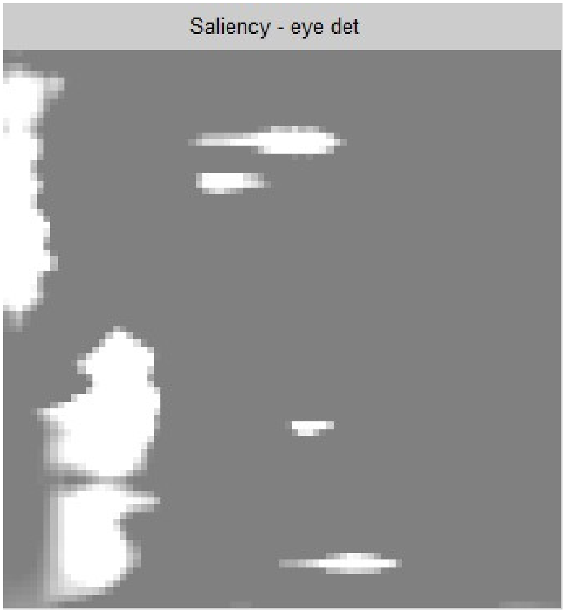

Figure17.Saliency image after neural network with the eye and the nose template is applied

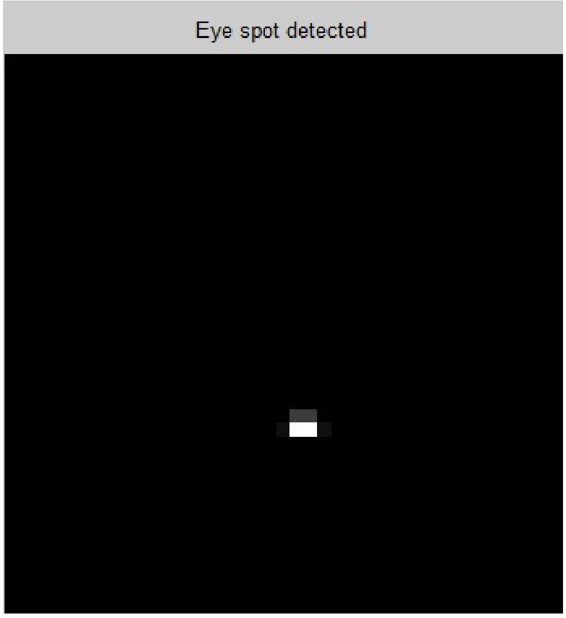

Figure18. Post processing of Figure 16.

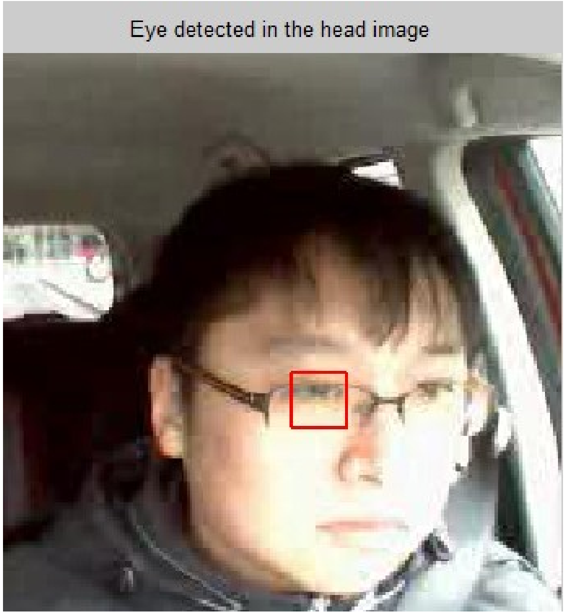

Figure19. Detection of the eye

Once the ROI is selected by detecting the head, the process is repeatedly applied with the same orientation feature extractors and the neural network template of eye detection. The Figure 16 is orientation feature extracted from the ROI but it is different to that of Figure 13 since the orientation feature image is enhanced by the locally tuned parameters. Since the outlines of the eye and the nose in Figure 16 are somewhat clearer than the case of frame difference in Figure 13, it is possible to detect an eye of passenger using the appropriate template.

The Figure 17 is the result after the neural network is applied to the Figure 16. There are strong signals detected on the left side of the image possibly due to the noise from other irrelevant object. However, as the detection is specific to the nose and the eye, the valid assumption of small size and isolation is applicable. The detection result of post processing is shown as a single spot in Figure 18, which is represented as the successful eye detection in Figure 19

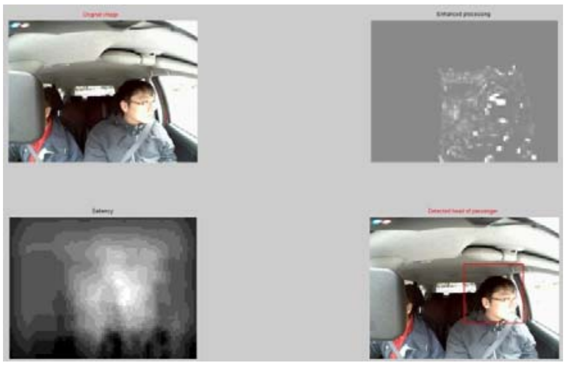

Figure20.Head detection with passenger facing away from the camera

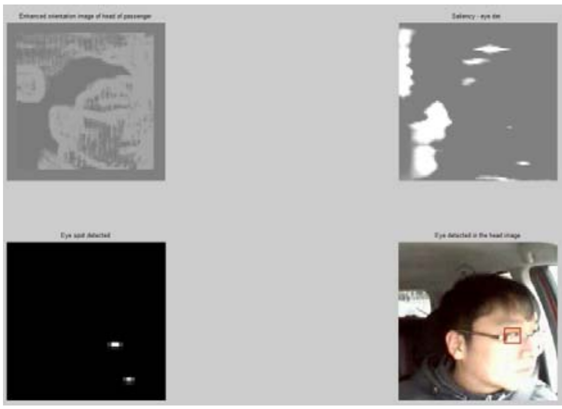

Figure21.Eye detection when the passenger is facing away from the camera.

Figures 20 and 21 show another detection of the eye when the passenger facing away from the camera. The position of the eye detection is different to when the passenger was facing the camera. The difference in these detections can then be also used to determine which direction the passenger faces.

CONCLUSION

In this paper, the pedestrian or passenger detection by neuromorphic vision system is presented with the successful and robust performance in various application environments. The same neuromorphic visual information processing is proven to be applicable to different objects and operation environments, with only the parameter tuning and the addition of necessary template.

The overall performance of the pedestrian detection in both bad weather and illuminace shows that the robustness is sustained without the loss of accuracy as the detection rate was greater than 90%. In addition, the bio-inspired approach involved forming the neuron electronically using CMOS VLSI ASIC technology, which allows for financially advantageous implementation compared to using high-powered chips and computers that the computer vision algorithms requires frequently.

The neuromorphic vision system is demonstrated by using a single camera only compared to other systems which may use stereo-camera or using a IR camera in night-time, which shows promising signs that further use of camera will improve the performance quality even higher.

Acknowledgement

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