

REAL-TIME PEDESTRIAN & DRIVER ANALYSIS BY NEUROMORPHIC VISUAL INFORMATION PROCESSING

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ABSTRACT

Objective

The safety enhancement of road users has begun to gain more attention, in particular the innovation and application of ADAS. The accurate and timely detection of the risk of accident has become an active area of research, with the focus on the drivers and other vulnerable road users.

The neuromorphic visual information processing method, inspired by Hubel and Wiesel's experiments on mammalian visual cortex, is proposed as a possible solution to these tasks. The proposed method replicates the performance of visual cortex in practical computing settings. By applying the orientation feature extraction and subsequently applying the neural network ensured robustness and accuracy.

Method

The proposed system has been evaluated on pedestrians/cyclists detection and driver monitoring, with a particular focus on emotion/stress detection. The tests have been carried out with video data sets of various conditions, with the experimentation and data set generation at public roads in every day settings.

The neuromorphic visual monitoring of drivers for the attentive or emotional status has been also evaluated, as approximately 15% of road accidents have been caused by the dangerous driving in 'anger and or/frustration'. The driver monitoring system by detecting the emotional state from the limited facial image of driver would make the measures of early warning against possible dangerous or inattentive driving. The neuromorphic system was evaluated to determine the warning signal based on the emotional state detection, based on the key feature extracted from the face images. The test was based on the facial database (JAFFE) of six basic emotional states.

Results and Conclusion

The performances of neuromorphic visual information system were measured to the success rate 99% of pedestrian/cyclist detection, and the successful recognition 91% of facial emotional states. The real-time

performance was evaluated with the neuromorphic ASIC, fabricated by the automotive CMOS technology. The processing speed of neuromorphic ASIC alone was tested for the speed of 30 frames per second, without the latency or external memory.

KEYWORDS

Pedestrian Detection, Cyclist Detection, Driver Status Monitoring, Advanced Driver Assistance Systems (ADAS), Image Processing, Neuromorphic Vision

INTRODUCTION & BACKGROUND

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 (Hubel & Wiesel 1959, I Han 2006). The proposed neuromorphic visual signal processing is investigated for enhancing the vehicle safety by the pedestrian detection or the passenger detection as well as monitoring the driver status .

Vulnerable Road Users (VRU)

Alongside pedestrians, cyclists and motorcyclists make up the category of road users regarded as vulnerable. These individuals are most exposed to the dangers of serious injury or fatality from a road accident. Furthermore, according to the CARE (Community database on Accidents on the Roads in Europe), as there is a 1-in-4 chance of having to be admitted to the hospital in case of a road accident, the risk doubles for pedestrian. Statistics on cyclists also show similar trend. While the overall number of fatality is in a steady decline, the cyclists' ratio of road fatalities is now growing, with the percentage making up more than 21% in certain European countries.

These higher risks are also coupled with the fact that a pedestrian casualty of road accident would have the longest length of stay (10+ days) in hospital compared to any other groups, signifying the vulnerability of the pedestrians in road accident situations. In fact, 63% of non-fatal road casualties were from VRU, emphasising the need for improving safety for this group.

Advanced Driver Assistance System (ADAS)

An increasing proportion of cars include ADAS to maximize the safety of road users (drivers, passengers, and pedestrians). European New Car Assessment Program (Euro-NCAP) initiatives support this trend by attributing a higher safety rating to cars that incorporate ADAS. Currently the NCAP ranking metrics focus on increased ADAS system performance. It is expected that after 2016, NCAP will introduce additional metrics that focus mainly on extending system functionality through the addition of pedestrian detection and automatic emergency braking, as well as lengthening operational up-time by requiring continued system functioning at night and during adverse weather conditions. This is logical as almost 60% of all road accidents happen in poor lighting conditions.

Driver Monitoring/Emotion on Concentration and Driving

One of the issues of prime importance to traffic and transport psychologists is the possible effect that a particular emotional state would have on concentration in driving situations. Relationship between anger and the subsequent aggressive behaviour manifested in 'road rage' have been investigated in depth. And recently, more researches have been carried out on effect of other emotional states such as fear, anxiety, and surprise on driver's performance. Emotion affecting driving behaviour is widespread, with studies sometimes finding almost 90% of the questioned admitting to engage in behaviour motivated by their emotion. These behaviours ranged from sounding the horns to indicate annoyance, to chasing down other drivers as a display of hostility, and they were quite often regarded as a reckless or risky driving. This accentuates a need for monitoring the driver, and forewarning of any change in emotional status as a measure to improve road safety.

NEUROMORPIC VISUAL INFORMATION PROCESSING

The proposed method of neuromorphic visual information processing has its basis on how we, humans process visual information. As the light enters the eye, it stimulates the sensors at the back of the retina, which in turn triggers a complex chemical reaction that results in electrical signals being sent to the brain through optical nerves. These signals travel through the optical nerve, and eventually reach the visual cortex at the back of the brain to be analysed. While visual cortex itself is still far from being fully understood, extensive studies of the mammalian brain including the 1960s research from Hubel and Wiesel have gave us basic understanding of how the visual cortex functions, as well as picture the physiology of the low-level human/mammalian visual systems (Fig. A1) (Hubel & Wiesel 1969).

Primary Visual Cortex

Hubel and Wiesel's research on cat's striate cortex have established the concept of the simple cell within the visual cortex. The simple cell responds to the orientated edges, and each types of cell responded specifically to the different inputs. Observations showed orientation based behavior evoked the reflection while the spike-based neuron signal is also an essential feature. Several theories and algorithms in image processing, object recognition and computer vision have been developed from this experiment and its findings (Risenhuber & Poggio 1999).

Neuromorphic Neuron and Visual Information Processing

The proposed neuromorphic visual information processing replicates the orientation selectivity of the simple cell. 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, based on the neurophysiological model of controlled conductance (Hauser 2000). 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 neuromorphic circuit (I Han 2006, WS Han & I Han 2010, WS Han & I Han 2014). 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 is demonstrated to be consistent to the outcomes from the Hubel and Wiesel's experiment, as shown in Fig. A1, where the tuned feature orientations are represented as the spike signal outputs (WS Han & I Han 2014).

The neuromorphic neuron of simple cell enables the neuromorphic vision system in Fig. A2, 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 driver or the pedestrian depending on the system's application.

The proposed neuromorphic orientation feature extraction has the advantage of robust abstract image generation, under the limited situation like fuzzy human object image in the veil or in the dark/bad weather. The neuromorphic vision is based on the orientation feature processing using the scalar filter, where the filter shape is rotated with the designated orientation selectivity. Contrary to the complex computation of Gabor filter for the similar purposes, the neuromorphic visual signal processing has the feasibility of effective implementation for automotive applications because of its simpler integer computation.

Detection of Vulnerable Road Users

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 illuminance 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.

The test result has been summarized in Table. 1, and Fig. 3 demonstrates the process of detecting various types of VRUs. The data set is the captured video by on-board camera of passenger vehicle, on the turning road with slop at KAIST campus.

In addition to the pedestrian detection at various environments, the robustness of neuromorphic visual information processing is demonstrated by the successful cyclist detection in the crossing road as seen in Fig. A3. The data set for cyclist detection has been captured video by on-board DVR (a car blackbox with the lens of wide FOV) of moving passenger vehicle, on the cross road at KAIST campus.

The illumination for the pedestrian detection at night time is limited by the head light of passenger vehicle, with the low beam direction in the urban area. The earliest appearance of pedestrian is the lower part of body in this case, rather than the upper body of head and torso. The orientation feature at the scene of night time accident displays a clearly defined region of interest. The template of neural network detector is designed for detecting the lower body, as it is apparently required in this particular case. The saliency map is evaluated with the lower body template and, the result illustrates the condition required for lower body detector in the night time.

Driver Monitoring System

The proposed neuromorphic vision system is also applied inside the vehicle for the purpose of driver monitoring. For this purpose, only a minimal modification to the parameter is necessary to accommodate the difference of environment. The sensor used was identical, and the same template of head-torso and orientation features was reused. 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. The driver detection is in the quasi-stationary background condition, as the background of driver is mostly the vehicles stationary passenger cabin with minor variations in the window outlook. Hence, the frame difference of orientation features can be used to minimize noise detected during process.

To determine the head (equivalently face) of the driver, the template of head and torso is applied after evaluating the difference of orientation features extracted between the current frame and the previous frame. The processed orientation features in subsequent images yielded the clearer feature detection of head and particular object like driver's eye (W. J. Han & I. Han, 2013)

Emotion Detection for Attentiveness Monitoring

For the purpose of inattentiveness detection, we investigated on detecting emotive states from the abstract facial expression, based on neuromorphic processing as shown in in Fig. A4. This is due to the fact that the anger is the principal emotional state most linked to automobile accidents.

In order to detect emotional states, we have established three regions of interest (ROI) which would be obtained and processed. These regions are eye brows, cheeks and mouth. While the regions can be further divided into left and right eye brows and cheeks, since the expression would be similar within both sides of the face in most situations, we have processed each pair of them as one ROI.

The success rate for detecting happy emotion is 98%. This translates to one input being incorrectly classified from the 43 test images (from 5 individuals of JAFFE data set) used to evaluate the proposed framework. The one instance of detection failure occurred primarily due to the large displacement of face in the test image comparing to the reference point of neutral image.

The neural network of multi-layer perceptron (MLP) is applied for the autonomous or trainable detection of emotion state, instead of detection algorithm based on the statistical threshold value for evaluating orientation features.

The overall successful recognition of 91.4% is achieved, and has been presented in the confusion matrix of MLP classification of facial emotional states using JAFFE data set.

Blind Spot Cyclist Detection

The cyclist detection in the blind spot emerges as a serious issue as the population of cyclists grows rapidly due to its eco-friendly nature. It is particularly demanded for the commercial vehicles, as the tall and long

commercial vehicle is subject to the relatively limited sight of view. The neuromorphic processing is applied to the cyclist detection in the blind spot area of commercial vehicle. The captured video in Fig. A6 is for the test data, which was recorded from the upper deck of double decker bus (the public transportation in London). The orientation features extracted, which is illustrated in the second image of Fig. A6, has been evaluated by the same neuromorphic pedestrian detection system we have proposed in this paper. The nature of blind spot cyclist detection demands further enhancement as it is based on the view from the higher sensor location. The additional detector template is introduced to enhance the cyclist detection with the expected appearance in the blind spot analysis. The additional template of frontal part of cycle is designed and applied together in parallel with the existing human detector.

Bottom image of Fig. A5 show the successful cyclist detection in the shadow and blind spot area, simulated by the captured video from the double deck bus.

REAL-TIME NEUROMORPHIC INFORMATION PROCESSING

The neuromorphic visual information processing is based on the multiple orientation filters mimicking the simple cell neuron of visual cortex, which are similar to the convolutional neural networks. The real-time operation requires the simple computational elements but parallel operation.

The processing speed of neuromorphic ASIC developed by the industry collaborator is the 30 frames per second for the orientation processing up to the HD video quality, without the latency or the external memory. The neuromorphic ASIC was fabricated in automotive CMOS 0.18 μ m technology, and it performed the same orientation selective processing as simulated in the software.

CONCLUSION

In this paper, the pedestrian/cyclist detection or driver monitoring by neuromorphic visual information processing is presented with the successful and robust performance in various application environments. The neuromorphic system demonstrated its versatile application to different objects and operation environments, with only the parameter tuning and the addition of necessary templates.

The overall performance of the pedestrian/cyclist detection in both under the nominal and the limited illumination shows that the robustness is sustained without the loss of accuracy as the 99% of successful detection rate. The neuromorphic vision processing demonstrated the 91% recognition rate of emotion detection for driver state monitoring.

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 stand-alone neuromorphic ASIC demonstrated the speed performance of 30 frames per second and its practical advantage of working without any memory or complex programming,

The neuromorphic vision system is demonstrated by using a single camera, which suggests the further improvement in performance quality by employing the stereo camera or IR camera in harsh environment or more precise operation

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APPENDICES

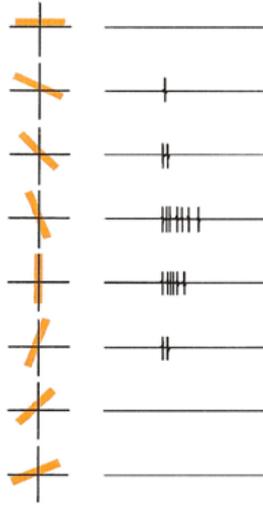


Figure A1. Response of the cat's cortex when a rectangular slit of light of different orientations is shown

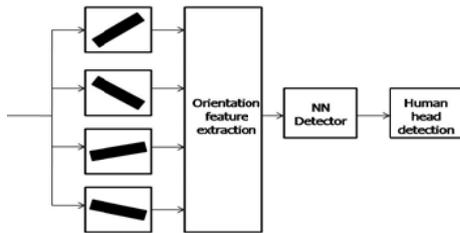


Figure A2. Neuromorphic vision for human head figure detection, inspired by visual cortex.

Test Data Set	Total Frames	Success Rate Frames [%]	Undetected Failure Rate Frames [%]	Positive Failure Rate Frames [%]
1	60	58 [96.6%]	0	2 [3.3%]
2	36	36 [100%]	0	0
3	150	150 [100%]	0	0
4	162	160 [98.8%]	2 [1.2%]	0
Total	408	404 [99%]	2 [0.5%]	2 [0.5%]

Table 1. Test Result Summary for VRU detection.

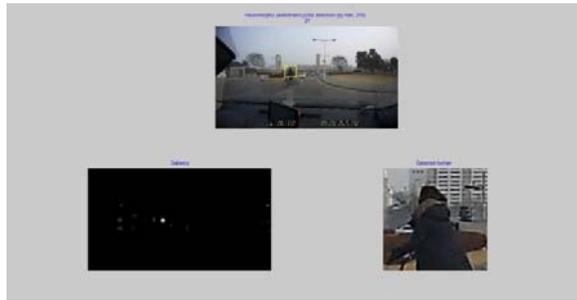


Figure A3: Cyclist detection (bottom), (anti-clockwise from top left) input image with the box of detected cyclist, saliency map by neural network detector, and detected cyclist, crossing the road.

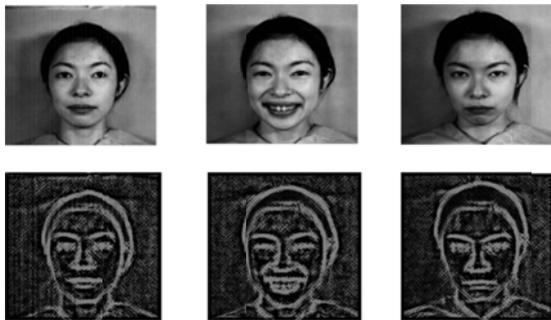


Figure A4. Example of orientation processed images for subject “NA” (JAFPE) in various expressions: (top) original images - neutral, happy and angry, from left to right (bottom) orientation processed images –neutral, happy, and angry, from left to right. Notice the movements of mouth and cheeks in ‘happy’ image and lack of it in ‘angry’.

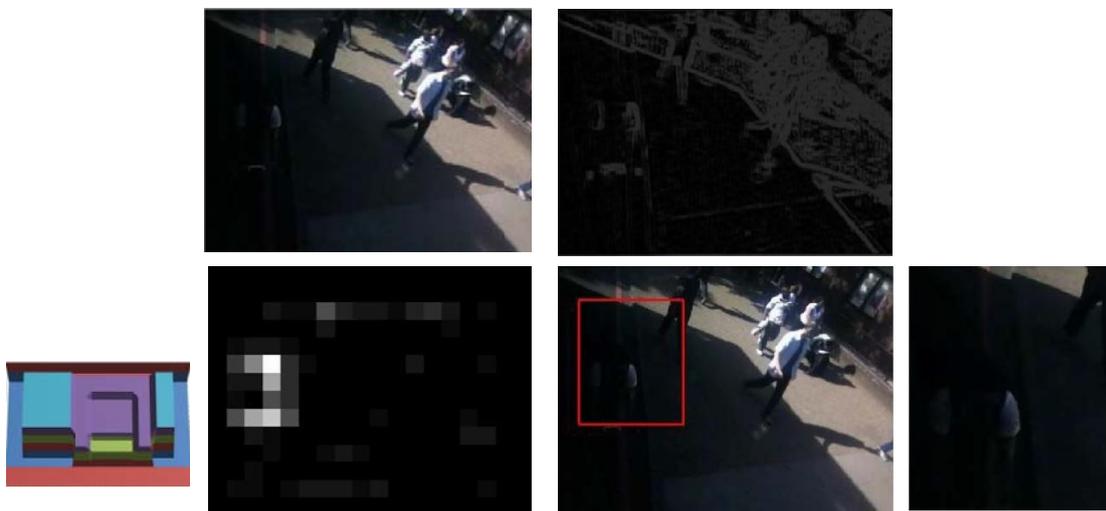


Figure A5. (top-left) Video image captured by a smartphone, on the upper deck of London bus in the U.K. (top-right) Neuromorphic orientation features of the image in Figure 18. (bottom-left) Blind spot cyclist template enhancement (left) additional template configuration - the frontal part of cycle (right) saliency map processed by the parallel detectors applied. (bottom-right). Resulting blind spot cyclist detection of Figure 18 (left) the detected cyclist in the red box, (right) the detail image inside the red box.