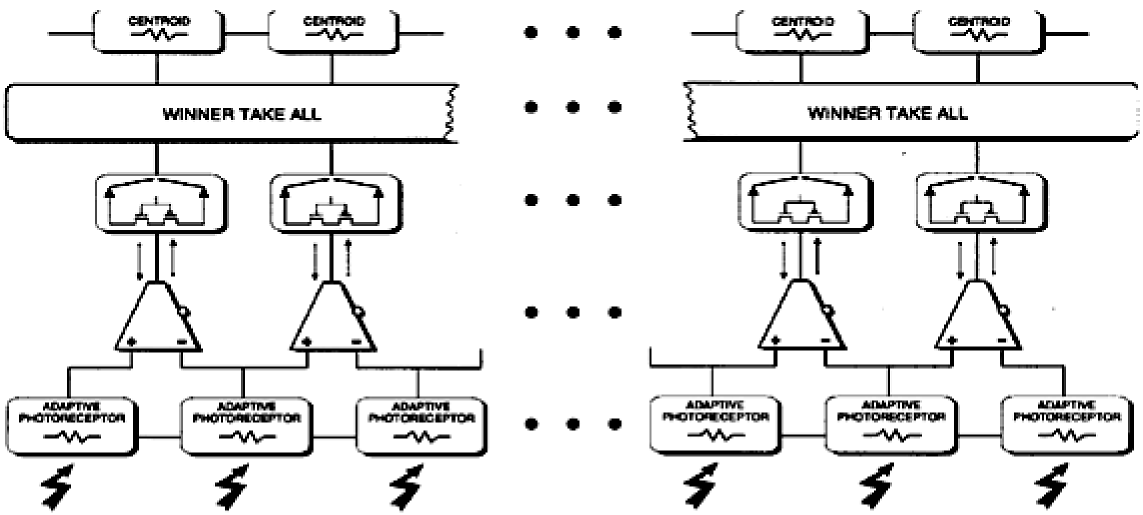

Figure 1: Block diagram of single-chip tracking system

Spatial edges are detected at the first computational stages by adaptive photoreceptors connected to transconductance amplifiers. The edge with the strongest contrast is selected by a WTA network and its position is encoded with a single continuous analog voltage by a position-to-voltage circuit. The various applications of this 1D visual tracking system is listed below

3.1.1 Stand-Alone Visual-Tracking Device

The system is able to detect and report, in real time, the position of realistic types of stimuli moving within its field of view. The picture of the stand-alone tracker board is shown in Figure 2. It consists of 2-um chip and a 4-mm lens mounted on a board with external potentiometers, used to set its bias voltages. The board also has a 1-D LED display with its driver used to have visual feedback on the position of the feature selected by the chip.

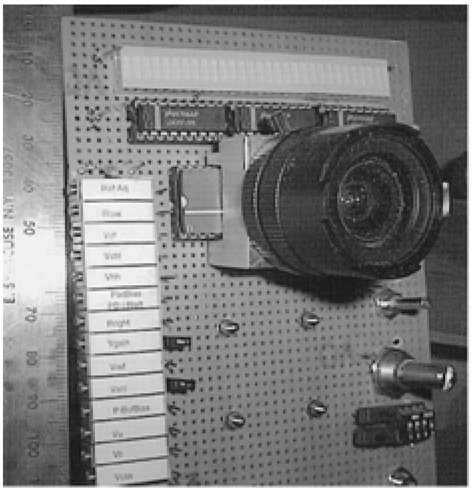

Figure 2: Picture of the stand-alone tracker board

3.1.2 Active Tracking System

It is a fully analog active tracking system by mounting a board with the 1.2- m tracker chip and a 4-mm lens onto a dc motor. Figure 3 Shows Picture of tracker chip mounted on a dc motor. The output of the chip is sent to a dual-rail power amplifier which directly drives the motor.

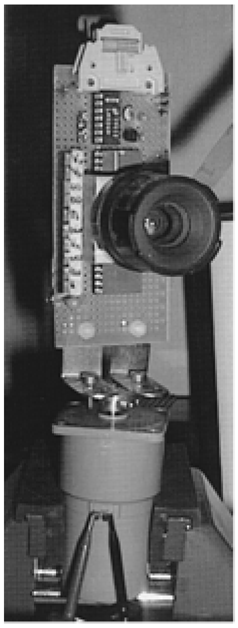

Figure 3: Picture of tracker chip mounted on a dc motor

3.1.3 Roving Robot

Roving Robot is another application of the developed visual tracking system. It can be used for vehicle guidance and autonomous navigation. The tracking sensor is interfaced to a mobile robot and It has an on-board Motorola 68 331 processor, 12 digital I/O ports, and 6 analog inputs, 1 MByte of RAM, and 2–3 hours of autonomous operation from its battery.

3.2 Object Detection

Neuromorphic circuits can be used for real time object detection applications. It is mainly found application in transportation sector for pedestrian detection, number plate detection etc.

3.2.1 Pedestrian Detection

The pedestrian detection and tracking techniques in real-world images have emerged as a solution to protect pedestrians against fatal accident. The vision-based pedestrian detection is very challenging due to the wide range of outdoor lighting condition and pedestrians' appearance. In [3] the authors propose a neuromorphic system that analyzes video image or still image of pedestrians on the road. The system is based on the Hubel and Wiesel's experimentation of cat's visual cortex and the spiking neuron of Hodgkin-Huxley formalism. Figure 4 shows the Neuromorphic implementation of a neuron Hodgkin Huxley formalism.

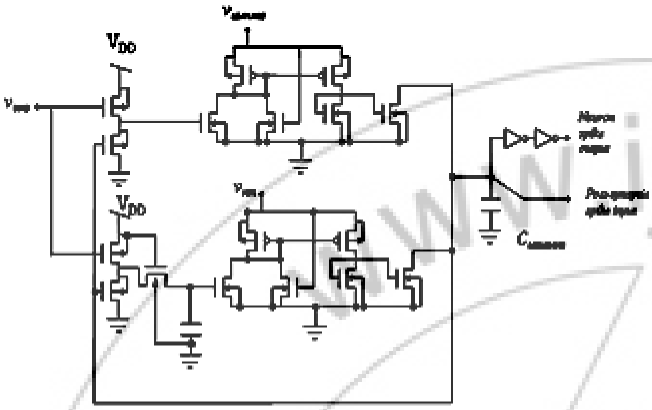

Figure 4: Neuromorphic implementation of a neuron

For detection of pedestrians using bio-inspired approach, firstly orientation features from the input image is extracted. The number of different orientation angles to be extracted will be different depending on the type of the target to be extracted. From the initial orientation feature extracted, it is not easy to easily identify the pedestrian. But since video stream is being used, the difference of orientation feature reduces noise and outline of pedestrian can be more clearly seen. The difference image is then passed through a neural network which uses template of upper torso of human. The action potential of the resulting neural network shows strong signal from the pedestrian and will result in successful detection of the pedestrian.

3.2.2 Vehicle license plate detection

In [2] the authors propose a bio-inspired signal processing mechanism for detecting the license plate from the visual information. The primary functional behavior is applied to locate the license plate of rectangular shape, which is with four right angles. The overall operation of the system is summarized in Figure 5.

The operation principle is to extract the location of four corners of license plate, by removing unwanted information like illumination level, other shapes and etc. At the right angle corners of license plate, there exist both horizontal and vertical components. There are weak horizontal components in the reference mask, which results in the flat and high level of histogram in the supposed plate location. Therefore the region of interest of is determined by the histograms of reference mask.

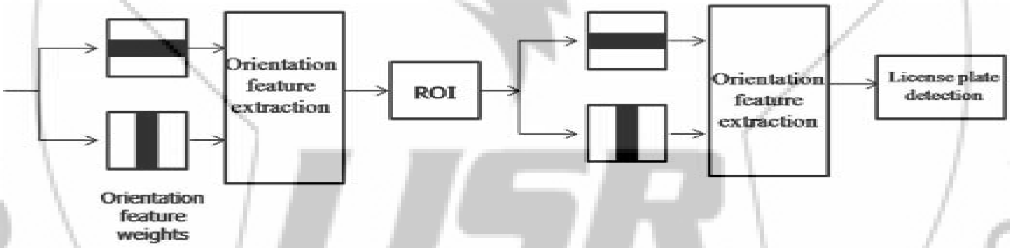

Figure 5: Bio-inspired processing of license plate detection

3.2.3 Human head detection

In [2] the authors propose a neuromorphic visual system for detecting the human. There are two principles employed first, the human object particularly head has high density of orientation components. The other principle is the head linked to torso. Figure 6 shows the neuromorphic vision for human head detection inspired by the visual cortex system.

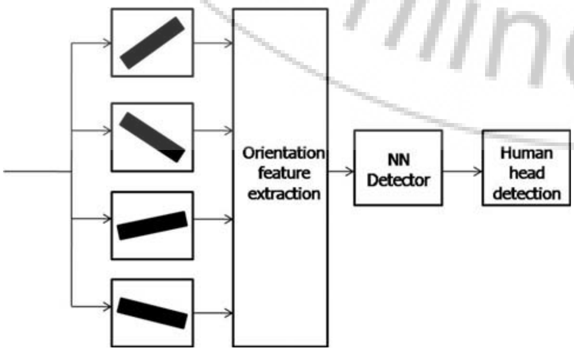

Figure 6: Neuromorphic vision for human head detection

3.3 Motion Estimation

Motion estimation means computation of velocity vectors or optical flow at each pixel. Optical flow estimation is a critical mechanism for autonomous mobile robots as it provides a range of useful information such as ego motion, time to collision, detection of moving objects, three-dimensional (3-D) structure of the environment, etc. Very large scale integration (VLSI) analog circuits can be used as an efficient solution for its real time implementation.

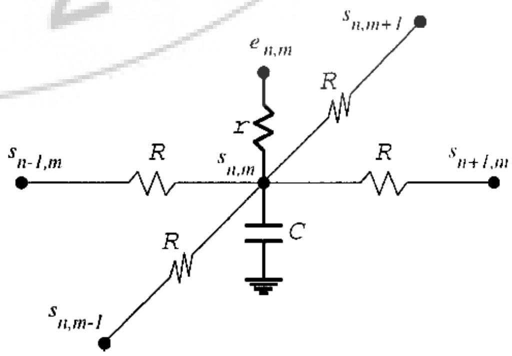

Figure 7: RC network

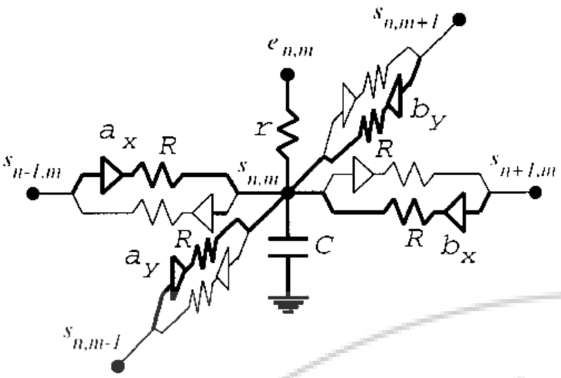

Figure 8: Velocity-tuned analog network

In [4] the authors propose a low complex energy based method using a novel wideband velocity-tuned filter. Figure 7 shows the RC network which act as a low-pass spatiotemporal filter and Figure 8 shows the velocity tuned analog network. The algorithm developed is composed of four stages: In the first stage retinal pre filtering is done in which a retina based analog circuit acting as a spatiotemporal band pass filter is used. For low frequencies this filtering will compensate for the $1/fs^{\alpha}$ spectrum of the images and for high frequencies, the filtering will reduce noise. In the second stage local mean output power estimation for each filter is required to deal with variations of velocity field of the image for local velocity estimation. Local output power estimation at each pixel is given by the voltage at the corresponding node in the resistive network which implements a low pass spatial filter. In the third stage the components of the input velocity vector is estimated by combining the output powers of two loosely tuned VTF's. Estimating two components of velocity in two orthogonal directions will be sufficient to give the input velocity vector.

Some of the limitations of the estimation performed with two filters can be overcome by using a third filter tuned to null velocity and it provides better linearity on the estimation, a simpler treatment of the aperture problem, and eliminate the dependency on the input frequency for sine waves. Figure 9 shows the complete diagram of the velocity estimation algorithm for one spatial dimension from input brightness to velocity estimation.

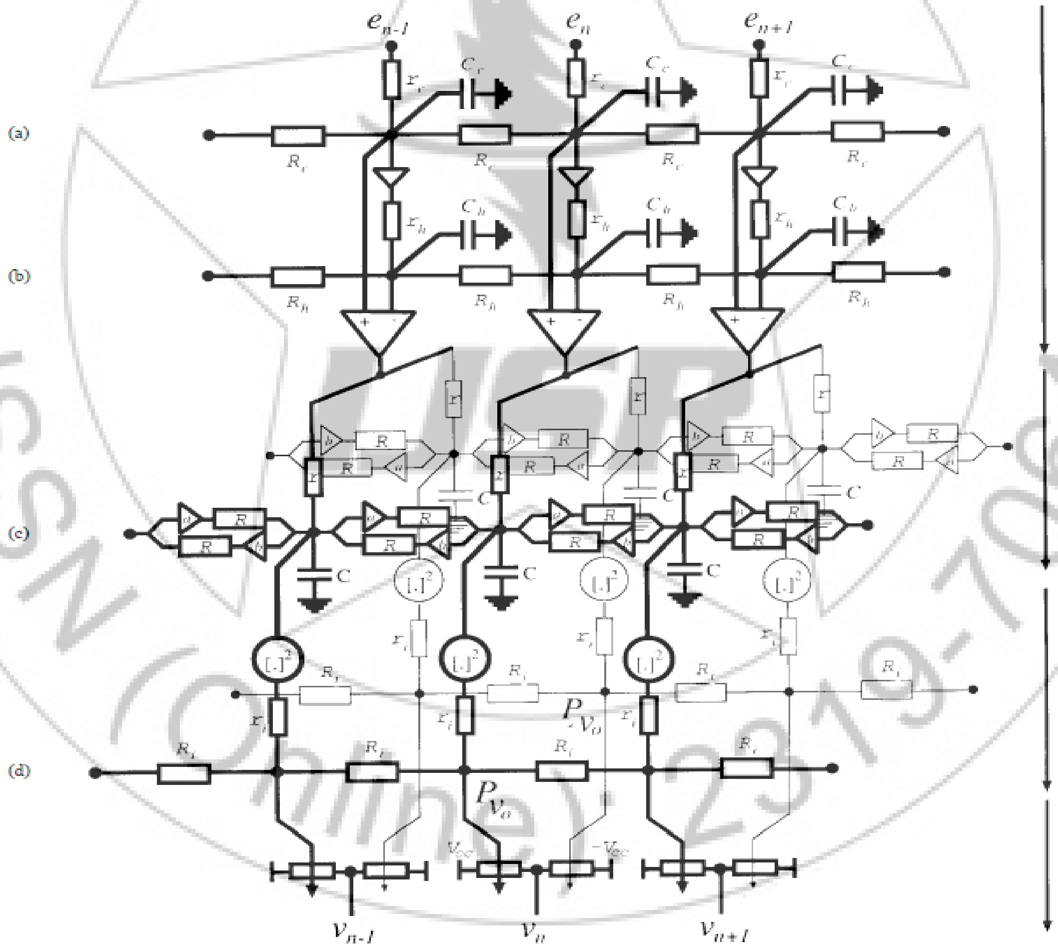

Figure 9: Diagram of the velocity estimation algorithm showing different stages

4. Discussions

Neuromorphic computing is an emerging area and finds a lot of applications in variety of fields. These circuits are gone to replace the present computing devices. Besides the applications surveyed here these circuits can find a lot of other applications such as affective computing, image processing, face recognition etc, so more works are required to fully exploit the advantages of neuromorphic circuits. Also hardware efficient, robust, computationally simple circuit implementation is necessary.

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