

# Neuromorphic Circuits and its Various Applications: A Survey

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**Abstract:** *Neuromorphic circuits are electronic analog circuits that mimic structural and functional behavior of nervous system. These circuits operate in parallel and distributed manner and able to perform various tasks such as pattern recognition, cognitive tasks, sensory integration etc. Neuromorphic circuits can be used for variety of applications such as visual tracking, motion estimation and object detection etc. This paper provides an overview of neuromorphic circuits and done a survey on various fields of its applications*

**Keywords:** Neuromorphic circuits, visual tracking, motion estimation, object detection

## 1. Introduction

Neuromorphic engineering/computing is a promising area that describes the use of very-large-scale integration (VLSI) systems containing electronic analog circuits to mimic neuro-biological architectures present in the nervous system. A key aspect of neuromorphic engineering understands how the morphology of individual circuits, neurons and overall architectures creates desirable computations, affects how information is represented, incorporates learning and development, influences robustness to damage, adapts to local change (plasticity), and facilitates evolutionary change.

Neuromorphic circuits offer a variety of applications. It is mainly used in visual tracking, object detection, motion estimation etc. and these neural systems are excel in pattern recognition, sensory integration, and cognitive tasks. The rest of the paper is organized as follows; section 2 focuses mainly on neuromorphic circuits, motivation behind neuromorphic circuits and its scope. Section 3 deals with various applications of neuromorphic circuits and section 4 deals with conclusions & discussions.

## 2. Neuromorphic Circuits

Neuromorphic chips attempt to model in silicon the massively parallel way the brain processes information as billions of neurons and trillions of synapses respond to sensory inputs such as auditory and visual stimuli. Those neurons also change how they connect with each other in response to changing sounds, images, and the like. This is the learning process. The chips, which incorporate brain-inspired models are called neural networks, do the same.

In [6] the authors developed a Neuromorphic Vestibular System which plays a crucial role in the sense of balance and spatial orientation in mammals. The main motivation and scope of these neuromorphic circuits is that these types of devices and systems offer an attractive low-cost alternative to special-purpose digital signal processors (DSP's) for machine vision tasks. They can be used for either reducing the computational load on the digital system in which they are embedded or, ideally, for carrying out all of the necessary computation without the need for any additional hardware. The biological brain implements massive parallel computations using an architecture that is fundamentally different from that of today's computers and brain circuits operate in an asynchronous, event-driven fashion. Current microprocessors can crunch numbers seamlessly, but they are terrible at tasks that brains do with ease. Another motivation behind designing these chips is to build a platform for running large-scale, real-time simulations to aid neuroscience research.

## 3. Applications

Neuromorphic circuits are nowadays used for a variety of applications and some of the applications are detailed in this section.

### 3.1 Visual Tracking

In [1] the authors present a neuromorphic sensor that consists of a one-dimensional (1-D) array of computational elements that detect and track the position of the feature with highest spatio-temporal contrast in the visual scene. A block diagram of the device's architecture is depicted in Figure. 1.

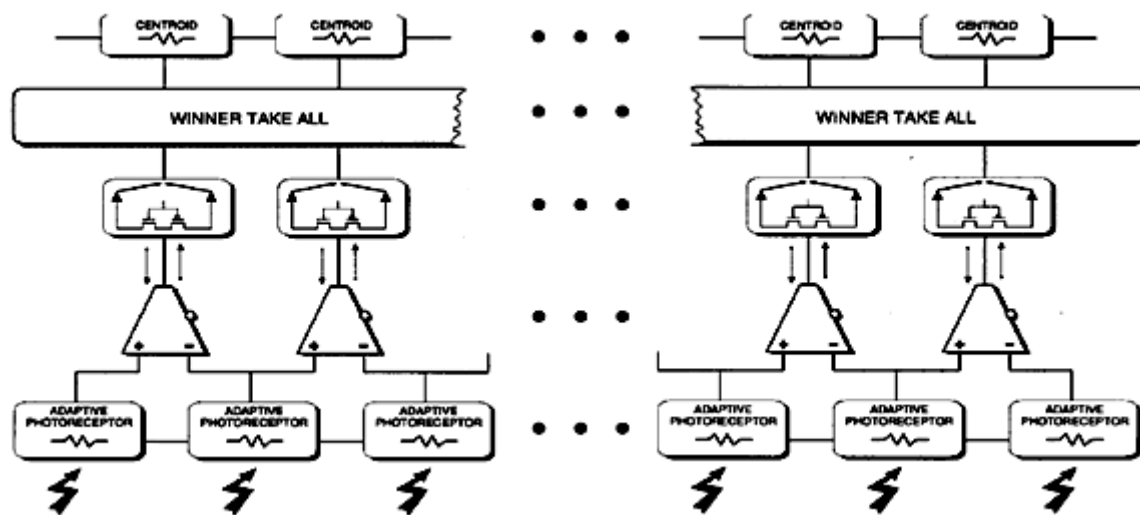


Figure 1: Block diagram of single-chip tracking system

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.

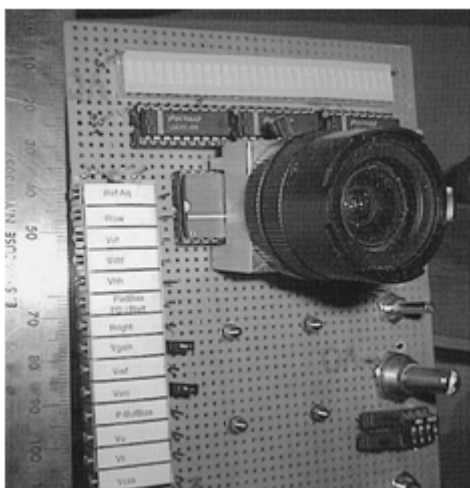


Figure 2: Picture of the stand-alone tracker board

**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.

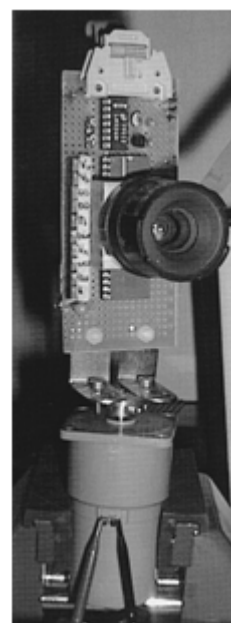


Figure 3: Picture of tracker chip mounted on a dc motor

**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.

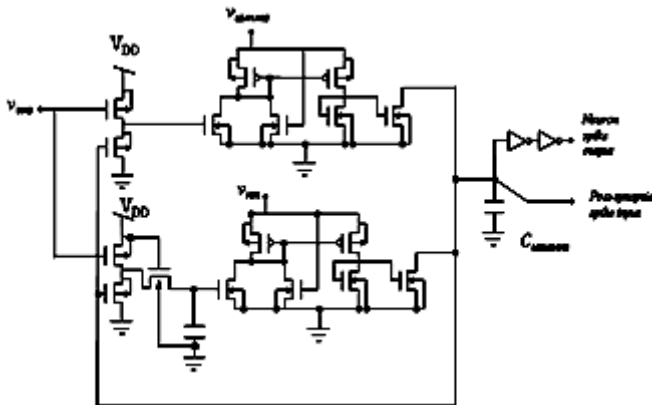


Figure 4: Neuromorphic implementation of a neuron

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

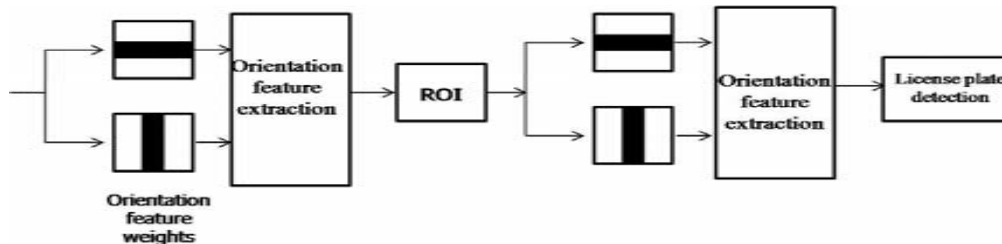


Figure 5: Bio-inspired processing of license plate detection

### 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.

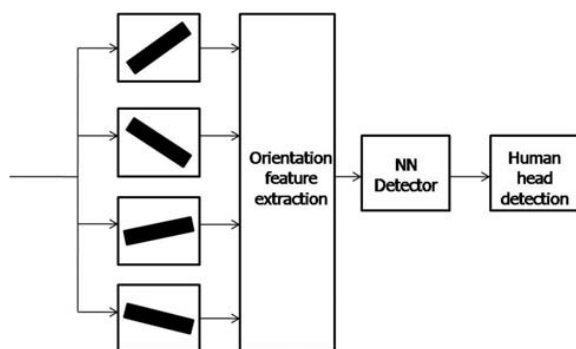


Figure 6: Neuromorphic vision for human head detection

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.

### 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.

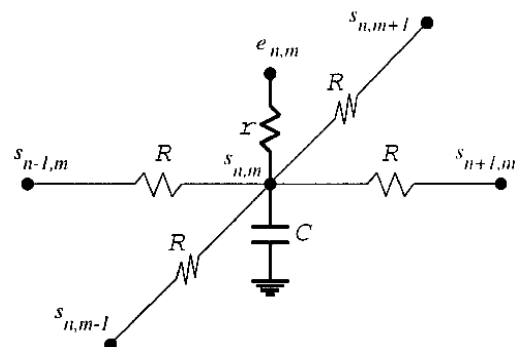


Figure 7: RC network

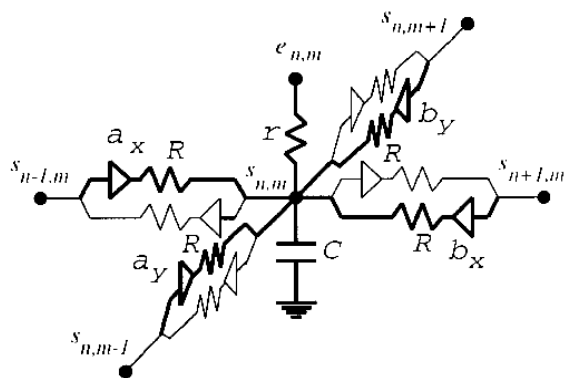


Figure 8: Velocity-tuned analog network

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.

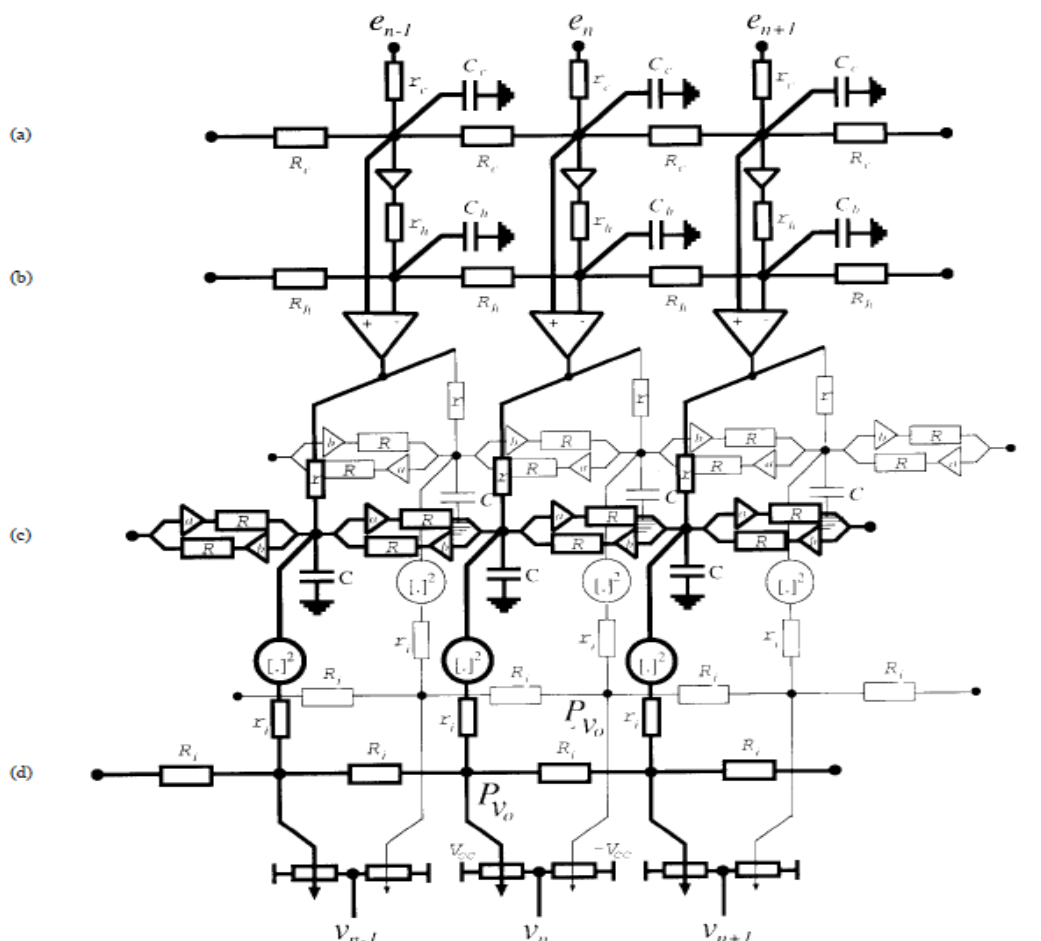


Figure 9: Diagram of the velocity estimation algorithm showing different stages

#### 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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