DETECTING EDGES USING AN ANALOG ELECTROOPTIC DEVICE

C. J. Vianna\(^1\) and E. A. de Souza\(^1,2\)

(1) Instituto de Física – Universidade de Brasília, Caixa Postal 04455, Brasília-DF, 70919-970, Brasil.
(2) Universidade Presbiteriana Mackenzie, Rua da Consolação 896, São Paulo-SP, 01302-907, Brasil. E-mail: thoroh@mackenzie.br.

ABSTRACT

We characterized an analog Self-Electrooptic Effect Device with five photodiodes as an edge detector by the use of a step edge image as input. The device extracts edges by finding the zero-crossing points in the second order derivative of the input image.

Key words: Edge detection, SEED, Laplacian, GaAs Device.

1. INTRODUCTION

Edge detection is an important process that attempts to capture the significant properties of objects in the image. Physical edges provide important visual information since they correspond to discontinuities in the physical, photometrical and geometrical properties of scene objects. Since image intensity is often proportional to scene radiance, physical edges are represented in the image by changes in the intensity function. The most common types of image intensity variations are steps, lines and junctions. Steps are by far the most common types of edge encountered in real images and are used to test edge detection algorithms and edge detection devices. During the history of the image processing, a variety of edge detectors have been devised which differ in their purpose (the photometrical and geometrical properties of the edge). The goal of edge detection is to localize variations of the image grey level and to identify the physical phenomena which produced them. Differentiation is the computation of the necessary derivatives to localize these edges. Conceptually, the most commonly proposed schemes for edge detection include three operations: differentiation, smoothing and labeling. Differentiation consists in evaluating the desired derivatives of the image. Smoothing consists of reducing noise in the image and regularizing the numerical differentiation. Labeling involves localizing edges and increasing the signal-to-noise ratio of the edge image by suppressing false edges [1]. The commonly used operators in edge detection are the Laplacian and second-order directional derivative along the gradient direction. The Laplacian operator is linear and rotationally symmetric whereas the second directional derivative is neither linear nor invariant to rotation.

Several devices using CMOS technology have been developed to implement edge detection circuit for image processing and vision chips [2]. In this paper, we used an analog self electro-optic effect device based on GaAs technology consisting of five conventional photodetectors integrated with a pair of quantum well modulators as an edge detector. In this configuration, it works as a Laplacian operator generating analog values (negative, positive and zero) at the output [3].
2. SELF-ELECTROOPTIC EFFECT DEVICE

The Self-Electrooptic Effect Devices (SEED) are a class of optoelectronic devices consisting of p-i-n optical modulator diodes, with quantum wells in the “i” region, combined with optical detection to give rise to devices with several functions [3] associated with an electrical circuit. The analog SEED structure uses heterostructure layers of 90 Å GaAs wells with 35 Å barriers of Al$_{0.3}$Ga$_{0.7}$As grown by molecular beam epitaxy. The physical mechanism exploited by the SEED is the quantum confined Stark effect [4] which is an electroabsorption mechanism observed in quantum wells. Changes in the voltage across the quantum-well layers can cause significant changes in optical absorption; either increase or decrease depending on wavelength. The SEED combines modulation with optical detection. In particular, when pairs of quantum well diodes are used, positive and negative analogue values can be represented linearly through the difference between two output beams at frequencies up to MHz rates [5]. It is simpler to think of this class of analogue differential devices as having a set of conventional photodiodes as the optical signal inputs and a pair of quantum well diodes, driven by net photocurrent from the conventional diodes as output modulators.

![Figure 1 – 5PD-Ana-SEED circuit used to measure the second-order spatial differentiation of images. The difference between the output powers $P_{outA}$ and $P_{outB}$ is linearly proportional to the Laplacian of the input image shining on the 5 photodetectors.](image)

For evaluation of the 2-D Laplacian of an image we used the circuit showed in figure 1 (5PD-Ana-SEED). This spatial layout of photodetectors is a combination of two second order derivative circuits, one in X-direction and the other in Y-direction. Each one of them has three in line photodetectors, properly connected, with the following area distribution (1, 2, 1)[3]. By combining them this way we obtain the circuit shown in figure 1 where the central photodiode has an area four times larger than the adjacent ones. It is important to note that in order to use this layout as a spatial differentiator we are assuming that the size of each one of the photodetectors is much smaller than any important features on the image.

The 5PD-Ana-SEED circuit can be divided into detection and modulation parts. The detection part consists of 5 conventional photodetectors (small ones labeled as 1, and the central one as 4). The central photodetector has an area of approximately 10×10 $\mu$m$^2$ and the others 5×5 $\mu$m$^2$ each. The modulation part consists of a pair of reverse biased quantum-well modulators (labeled as A and B) electrically in series with an area of 7×7 $\mu$m$^2$ each. The whole device has an area of 50×50 $\mu$m$^2$ approximately. The four equal photodetectors labeled as 1 and quantum-well modulator A are electrically in parallel and so are photodetectors labeled as 4 and quantum-well modulator B.
The net photocurrent $I_C$ generated by these five conventional photodetectors is linearly proportional to the difference between the absorbed power in the two quantum wells A and B. It was shown in ref [3] $I_C$ is also linearly proportional to the difference between the control beams ($P_{outB} - P_{outA}$). The photocurrent $I_C$ also “represents” the 2-D Laplacian operation of an image shining on these five conventional photodetectors. Therefore the Laplacian of the image is linearly proportional to the difference between the control beams. Different to what occurs with purely electrical or electronic devices, here we have an optical signal at the output and the difference between the control beams can give us analog values (positive, negative and zero). Besides that, this device can also operate with the traditional electrical readout by the use of the current $I_C$ generated by the set of photodiodes.

3. THE EXPERIMENT

The experimental apparatus used to perform the Laplacian operation is shown in figure 2. A 780 nm laser diode was used to generate the images (grey beam). A single mode optical fiber is used as a spatial filter for the laser diode beam. A polarizer is used after the optical fiber to control the laser polarity. Using vertical polarization the reflected image at the polarizing cube beam splitter (PBS) crosses the quarter wave plate 1 ($\lambda/4_1$) and is reflected by the 50:50 mirror. It crosses again the $\lambda/4$ plate and due to this double pass its polarization is rotated to become horizontally polarized. The beam crosses the PBS, quarter wave plate 2 ($\lambda/4_2$) and is focused by a special lens on the 5PD-Ana-SEED. The device (grown over a Bragg mirror centered at 850 nm) reflects the non absorbed part of the image which has its polarization rotated after crossing again the $\lambda/4_2$ plate. It is therefore reflected by the PBS, sent through a hybrid cube beam splitter (HBS) and completely blocked by an interferometric filter (centered at 850nm).

Figure 2 – The experimental apparatus used to measure the Laplacian of an image. Using a polarizing beam splitter (PBS), two quarter-wave plates ($\lambda/4$) and a 50:50 mirror, it is possible to illuminate simultaneously the 5PD-Ana-SEED with an image (at 780nm) and the power control beams (at 850nm).
The control beams at 850 nm were generated by a laser diode and an anamorphic prism used to reduce the spot ellipticity. The control beam (dark beam) was split in two equal one by a binary phase grating (BPG) at 850 nm. They cross the $\lambda/4$ plate and are focused by a lens onto the two quantum well modulators. The non absorbed part of them is reflected by the Bragg mirror and crosses twice the $\lambda/4$ plate. Their polarization is rotated and therefore they are reflected by the PBS and sent to the detectors 1 and 2.

4. RESULTS

We demonstrated in previous works that the analog SEED with 5 photodetectors was able to measure the Laplacian of an image with a Gaussian intensity profile [6]. To understand how accurate the device is, we measured the Laplacian of images with constant and linear intensity profiles [7], given good results as Laplacian operator characteristics. The Laplacian operator is known also as the zero-crossing detector, which looks for places in the image where the values of the Laplacian pass through zero, i.e. points where the Laplacian changes sign. Computational algorithms and devices are frequently tested using a step edge, where the edge is localized at the zero-crossing point.

Figure 3 shows the measured Laplacian of a sharp step edge (inset on the figure) scanned over the 5PD-Ana-SEED. We observed the zero-crossing (full circles connected by dashed line) at the center of the kernel, as expected. The plateau observed in the measured Laplacian is due the distance between the photodetectors. When the edge is over this space there are no variations in the intensity over the photodetectors and consequently there are no variations in the measured Laplacian. This result shows that the 5PD-Ana-SEED can measure the Laplacian of an image with a step edge intensity profile. We also observed that the width of the response (at the measured Laplacian) was approximately equal to the 50 $\mu$m width of the kernel.
5. CONCLUSIONS

We characterized an analog Self-Electrooptic Effect Device with five photodetectors (5PD-Ana-SEED) as a novel edge detector. It is a smart detector that integrates photodetectors and modulators using GaAs technology. The device is able to simultaneously sense and process images. By shining any image onto a conventional photodiode, regardless of its spatial profile, the photodiode will generate a proportional photocurrent. In our case the 5PD-Ana-SEED output depends on the spatial intensity profile of the input image. The result showed that the device extracted the edge of a step edge image by finding the zero-crossing point in the measured second order derivative.

Due to its linear response this analog device could be used to study and understand vision processing. Some of the early visual processing of human vision are executed in the retina itself and the information is transmitted posteriori to the brain. A very important process of early vision is the local inhibition, that helps us to detect borders and contours of an incident image in the retina: the horizontal cells in the second layer average together the signals from several neighboring sensors in the first layer, and the bipolar cells in the third layer subtract that signal from the original sensor output [8]. This process is similar to obtaining a second order two-dimensional spatial image differentiation.

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7. REFERENCES


