AMORPHOUS SILICON FOUR QUADRANT ORIENTATION DETECTOR (FOQUOD) FOR APPLICATION TO NEURAL NETWORK IMAGE SENSORS

Wen-Jyh Sah and Si-Chen Lee

Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan, Republic of China

ABSTRACT

It is learned from biological perception of external image that the most important features of an object are the position and orientation of a contrast edge. In this paper, we present an a-Si:H orientation detector which can extract both the position and orientation of an edge passing through it. It is sensitive to half plane, thin line and even a gradient contrast with preferential orientation, and the output signal is independent of the illumination level and the position of the edge in the device area.

INTRODUCTION

Improving the processing speed is a major issue in pattern recognition. It is learned from biological evidence that the brain uses hierarchical structure and massive parallelism in each processing step to do efficient feature extraction, and we know the most important features are the position and orientation of a contrast edge [1]. As a result, to build a fast recognition machine, the parallel processing architecture and edge extraction capability must be included. Recently some achievements had been done according to this trend. Both the Si retina implemented by analog VLSI [2] and a-Si:H edge detector [3] can extract the edge position of an image. The key feature of these systems is to build a simple computation function (such as local average or subtraction) for each pixel such that the routine computation is done in parallel. In this paper, we present the measured performance of a new a-Si:H FOur QUadrant Orientation Detector (FOQUOD) which can extract both the position and exact orientation of a contrast edge in a single device configuration and the output is independent of the edge position and illumination intensity.

DEVICE STRUCTURE

Fig.1 shows the top geometry of the orientation detector which is composed of two cross-positioned two-half edge detectors, let's call them X and Y cells. The output of the edge detector is the difference of the photoresponse between the two pin diodes, and this is taken to be the projection along the X and Y axis. The orientation information can be obtained from the ratio of the two projections, i.e., $tan\theta$. As shown in Fig. 2 when an edge appears in the detector area, the illuminated part of the detector (bright side of the edge) can be sectioned into several regions. The output of X cell is b+c-a while that of Y cell is d+e, it can be shown that e/(b-a) and d/c are both equal to $tan\theta$, so the output of the detector, i.e., (d+e)/(b+c-a) is also $tan\theta$.

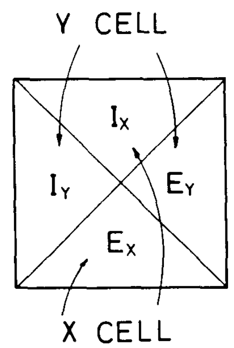

Figure 1: The top geometry of the orientation detector. It is composed of two cross-positioned pair edge detectors, i.e., X and Y cells. Each edge detector contains two triangular shaped pin diodes, i.e., the excitatory cell ($E_{X,Y}$) and the inhibitory cell ($I_{X,Y}$).

11.7.1

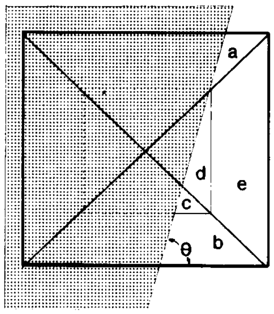

Figure 2: A half-plane edge with a slope of $tan\theta$ passes the orientation detector, the illuminated part of the detector can be sectioned into five regions whose area are a, b, c, d, and e. The ratio of the outputs from the two edge detectors, i.e., (d+e)/(b+c-a) is equal to $tan\theta$.

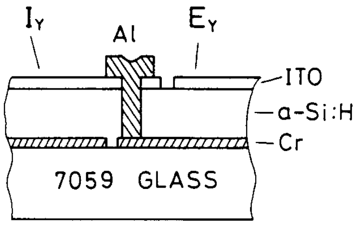

Figure 3: Cross section of a FOQUOD including the contact via hole for excitatory and inhibitory cell connection.

EXPERIMENT

Fig. 3 shows the cross section of FOQUOD including a via hole. The orientation detector is fabricated on Corning 7059 glass. the bottom contact is 2000 Å thick thermally evaporated Cr. After patterning the Cr layer, a-Si:H n, i, p, layers are deposited in a single run using capacitively coupled rf glow discharge decomposition of silane and hydrogen mixture. The thicknesses of the n, i, p, layers are 200, 4500, and 120 Å, respectively. Then a low temperature ITO film of 1000 Å thickness is thermally evaporated on the a-Si:H p layer to form the top contact. The through hole is formed by etching away a-Si:H and ITO film in appropriate place, then a thick Al film is thermally evaporated on the through-hole to connect the top contact of excitatory cell to the bottom contact of inhibitory cell, and vice versa. The dimension of the detector is $4mm \times 4mm$.

RESULTS AND DISCUSSION

Accuracy

Fig. 4 shows the measured orientation, θ_m, with respect to the actual orientation θ_a of a half-plane edge passing through the center of the detector under different illumination intensities. Owing to the four-fold symmetry of the device, it suffices to measure the device performance in the 0 to 90 degree range. The measured θ_m are very close to θ_a, and the error is within 3 degrees over the whole 90 degree range.

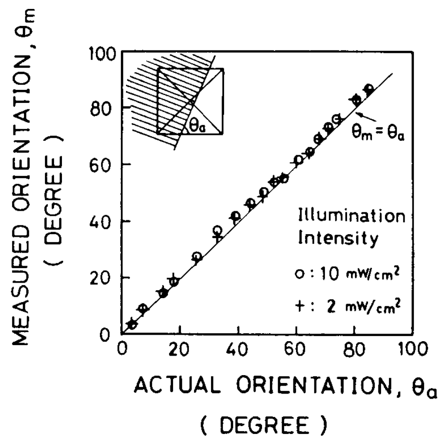

Figure 4: Measured orientation, θ_m as a function of actual orientation, θ_a of a half plane edge under two different illumination intensity, 10 and 2 mW/cm^2. It shows no intensity dependence and very good detection accuracy.

Intensity effect

Due to the division operation to obtain $tan\theta$, the influence of the illumination intensity on the signal level is completely eliminated. As shown in Fig. 4, the θ_m is measured under two different illumination intensities, i.e., 10 and 2 mW/cm^2. The data really shows no dependence of illumination intensity.

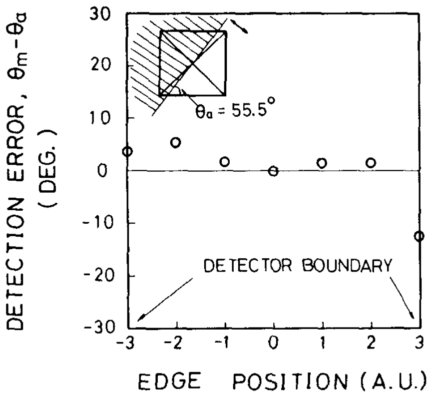

Figure 5: Detection error, $\theta_m - \theta_a$ as a function of edge position relative to the orientation detector for a half plane edge. The error remains very small except when the edge is on the very border of the device (position -3 and +3).

Position effect

The output of FOQUOD is independent of the edge position within the detector area due to its special geometry and the nature of the edge detector to extract only the difference between the excitatory and inhibitory signals such that the output change of each pin diode due to parallel shift of the edge is completely eliminated. Fig. 5 shows the detection error $\theta_m - \theta_a$ of an half-plane edge as it makes a parallel displacement within the device area. The error remains very small except when the edge is on the very border of the device (position 3 and -3), this is due to the isolation gap between the edge detectors in the real device. This gap has no photoresponse, therefore, when it becomes a significant part of the illuminated area, error results. Thus it's important to minimize the gap width in real device application in order to minimize the detection error due to parallel displacement of an edge with respect to the detector.

Line edge

Besides the half plane edge, FOQUOD is also sensitive to a line edge (a light or dark bar). The line edge can be considered as the combination of two parallel half plane edges with opposite contrast placed a distance apart equal to the line width. As the detector output is independent of the edge position, superposition principle ensures the line edge sensitivity. Fig. 6 shows the measured response for a dark line whose width is about 20 % of the detector dimension under two different illumination intensity. It shows no distinct deterioration as compared with the half plane edge, though the error is somewhat larger. This is due to the smaller active area under the line as compared with the half plane, while the gap area is the same for the two cases.

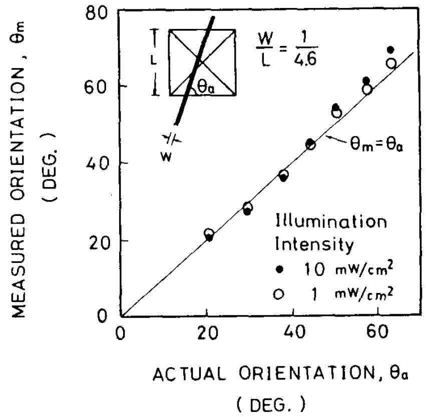

Figure 6: Measured orientation, θ_m as a function of actual orientation, θ_a of a thin line under two different illumination intensity, 10 and 1 mW/cm^2. The ratio between line width W and device dimension L is 1/4.6. It shows no intensity dependence and very good detection precision.

Gradient light

Due to the superposition principle, a gradient contrast with preferential orientation can be considered as the combination of a group of parallel half plane edges with different brightness and thus can be extracted by FOQUOD. In order to show this capability, we measure the performance of the device for a half plane edge placed at different height from the device surface. As the edge height increases, the contrast fades. As shown in Fig. 7, the detector output, however, is independent of the edge height.

CONCLUSION

In conclusion, a novel a-Si:H orientation detector is successfully fabricated. In addition to the edge position, it is also able to extract the exact orientation of a contrast edge or a gradient contrast with preferential orientation. The output is independent of the illumination intensity and relative position of the edge in the detector area.

REFERENCES

[1] S. W. Kuffler, J. G. Nicholls, and A. R. Martin, *From Neuron To Brain*, 2nd ed., Sinauer, Sunderland, MA, 1984, Chap. 2, pp. 19-23.

[2] Carver Mead, *"Analog VLSI and Neural Systems"*, Addison Wesley, Reading, MA, 1989, Chap. 15, pp. 257-278.

[3] W. J. Sah, S. C. Lee, H. K. Tsai, and J. H. Chen,"Amorphous silicon edge detector for application to neural network image sensors", *Appl. Phys. Lett.*, Vol. 56, pp. 2539-2541, June 1990.

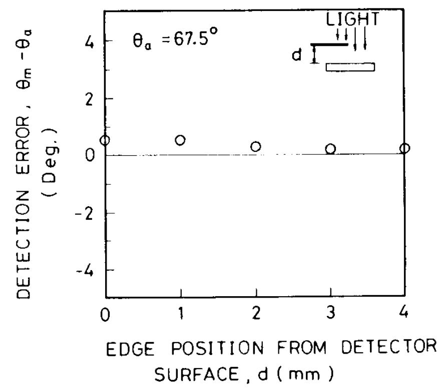

Figure 7: Detection error, $\theta_m - \theta_a$ as a function of the height, d of a half plane edge from the detector surface. This measurement can simulate the condition of detecting a gradient contrast with a preferential orientation. It shows that FOQUOD is sensitive to the gradient contrast as well as a sharp edge.