The Influence of the Surface Topography of Distributed Sensor Networks on Perception

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Abstract - *This work investigates the effects of surface topography of the distributed sensor networks on perception through the differences in sensor readings. Compound eyes are found in some insects and crustaceans. Lateral inhibition is a biological signal processing which can increase contrast, enhancing perception. It is known that eye convexity helps increase field of view (FOV). A series of experiments were carried out to understand the effect of surface topography on local contrast gradient. Two sets of sensor networks of 5 x 5 were constructed. In the first network the board holding the sensors was a flat circuit board, whereas the second one was given a radius of curvature of roughly 30 cm. All readings were recorded in a dark chamber. Sensor networks were illuminated by a light source whose coordinates could be adjusted. Results are tabulated. It is seen that eye convexity in compound eyes improves perception, as well as FOV.*

Keywords: Lateral Inhibition, Distributed Sensor Networks, Contrast Enhancement, Convexity, Compound Eyes, Contrast Enhancement

1 Introduction

Haldan Keffer Hartline have studied the underlying principles of compound eyes for over thirty years by analyzing horseshoe crab (Limulus polyphemus) that has compound eyes. Hartline has shown that the photoreceptor cells in each ommatidium are connected in such a way that these cells drive down the output of the neighboring cells when stimulated. This leads to an increase in contrast and sensitivity in peripheral processing [1].

The literature search has found that almost no work exists about compound eyes with regards to topography and perception sensitivity. In fact the authors have failed to find one. One of the partially related research is about poly-visualization. Multi-lens visualization device used in medicine was designed by Joseph Rosen and David Abookasis. Their study has focused on the imitation of the visual processing of flies. Researchers combined individual photographs after scanning an object, and obtained a representative good picture. Images were averaged and dispersed beams were eliminated. This means strays at image were eliminated. This technique has been a solution for the problem on present devices [2]. But this study is about image improvement instead of increasing sensitivity in multiple sensing.

Another worth mentioning may be found in Istanbul Technical University. Ozcelik was inspired by the compound eyes of the insects in his thesis of subpixel information gathering and resolution improvement. The spinoff was a high-resolution low-cost camera in the similar working principles of a fly obtaining a single image from a multitude of images [3].

Last study models compound eyes and contrast enhancement. Workers there try to find a cost-effective sensory information processing setup for an engineering application. Coskun et al. [6] show that a low-cost but sensitive distributed sensor network is feasible. Nevertheless, there is also no link between surface topography and sensitivity increase in perception, given that everything else is the same.

2 Compound Eyes and Lateral Inhibiton

Ommatidium is a single simple eye unit of a wider ommatidia in a faceted compound eye. The number of ommatidium varies. There are roughly 4000 ommatidia in stablefly (Musca domestica). This number comes down to 300 at glowworms. It may reach 5000 for chafers, 9000 for Dytiscus, and up to 28 000 ommatidia for certain species [4].

Every ommatidium in a compound eye has a specific optic system. Every ommatidium has the basic anatomy form of a simple eye. There are retina and retina cells, rhabdomeres, masking pigments and axons, Figure 1.

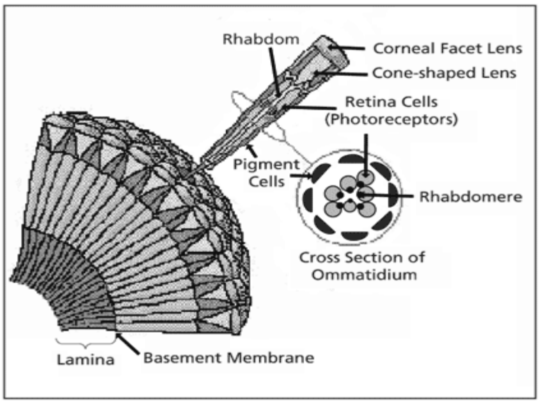


Figure 1. Form of Ommatidium [7]

Perceptions at compound eyes are somewhat different from simple eyes. Each ommatidium transmits the reverse images cast on retina to the brain. Number of images transmitted to the brain, is equal to the number of ommatidia. The brain stiches one image with the other. This composed new image is thought to be a mosaic-like image compared to what we see. This in turn likely to mean that the eventual composition is a high-resolution and high-contrast picture.

Contrast in mosaic-like vision is higher than the image formed by a simple eye. The main reason of this contrast difference is basicly Lateral Inhibition. Lateral inhibition (L.I.) is the dominant feature of biological distributed sensory networks where each individual receptor drives down each of its neighbors in proportion to its own excitation. The strengths of these connections are fixed rather than modifiable and are generally arranged as excitatory among nearby receptors and inhibitory among farther receptors. In other words, when any given receptor responds, the excitatory connections tend to increase its response while inhibitory connections try to decrease it [4, 5, 6].

The frequencies of discharge of each of two ommatidia were measured, for various intensities of illumination, when each was illuminated alone and when both were illuminated together. The below expressions show the amount of inhibition exerted upon ommatidium A by ommatidium B, as a function of the degree of activity of B, and shows the converse effect upon B of the activity of A [1, 5].

$$r_A = e_A - \beta_{AB} * (r_B - r_B^0) \quad (1)$$

$$r_B = e_B - \beta_{BA} * (r_A - r_A^0) \quad (2)$$

- r_A and r_B values are reactions of A and B ommatidiums after lateral inhibition,

- e_A and e_B are reactions of A and B ommatidiums without lateral inhibition,

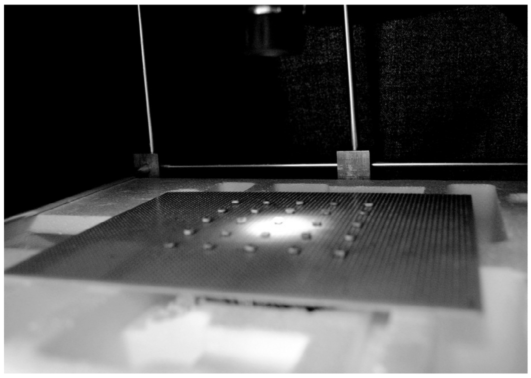
- β_{AB} is inhibition coefficient of B ommatidium for A ommatidium,

- β_{BA} is inhibition coefficient of A ommatidium for B ommatidium,

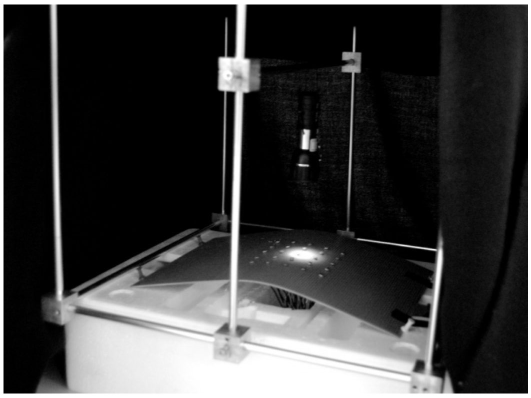
- r_A^0 and r_B^0 are threshold frequency of A and B ommatidiums

3 Experiments on Surface Topography

At this study, photoresistors (LDR) were used to represent ommatidia in compound eyes. The test rig is composed of an aluminum frame, a light source whose height and position could be adjusted. Down below, there is a flat board to allow LDRs. The whole rig was then covered by a thick black cover in a darkened lab environment. In each setup, a total of 25 sensors were used. Light source was tuned in position so that sensor number 13 receives a maximum amount of light, and neighboring sensors give off a close reading, Figure 12 a. In Fig 12 b, the same test rig is used except that the board that all the sensors were mounted upon is convex with a rough radius of curvature of 0.3 meters. Sensor outputs were measured by a Keithley 2700 multimeter with multiplexers.



(a)



(b)

Figure 2 a, b. Compound Eye on Flat(a) and Convex(b) Surface

All the experiments were performed at two height levels for the light source, 196 and 100 mm. The convexity in the board was formed when the board was allowed to soak moisture and then shaped under a heat gun.

It is worth mentioning that if the Table 1 is inspected carefully, even though symmetrical, not all the neighbors received the same amount of light. This may be due to the fact that the light source may be slightly off the vertical, or the sensor normals do not coincide with the surface normals. To have a meaningful comparison, lower right quarter of the Table 1 was assumed to be measured from all the remaining three quarters, leading to Table 2. Table 1 gives resistance values (KOhm). Table 2 shows symmetrized version of Table 1. Table 3 gives the reciprocals of the resistance values, 1/R which is used at signal processing. Table 4, on the other hand, reflects these above-mentioned reciprocals after LI was applied with (α = 0,15 and β = 0,05). Including Table 4, the distance of the light source has been 196 mm and it is kept right above the 13th sensor. Then, to compare the convex and flat compound eye systems, the light source has been adjusted to 100 mm from the surface, and tabulated on the Table 5.

Table 1. Actual LDR Resistance Values, K Ohm

1. Sensor R = 11,831	2. Sensor R = 3,792	3. Sensor R = 3,518	4. Sensor R = 5,561	5. Sensor R = 10,196
6. Sensor R = 4,909	7.Sensor R = 1,439	8.Sensor R = 1,18	9. Sensor R = 1,921	10. Sensor R = 6,564
11. Sensor R = 2,93	12.Sensor R = 1,334	13.Sensor R = 0,991	14. Sensor R = 1,479	15. Sensor R = 5,805
16. Sensor R = 6,131	17.Sensor R = 1,988	18.Sensor R = 1,46	19. Sensor R = 2,379	20. Sensor R = 5,961
21. Sensor R = 8,63	22.Sensor R = 4,556	23.Sensor R = 4,13	24. Sensor R = 5,76	25. Sensor R = 12,616

Table 2. Symmetrized Resistance Values, K Ohm

1.Sensor R = 12,616	2.Sensor R = 5,961	3.Sensor R = 5,805	4.Sensor R = 5,961	5. Sensor R = 12,616
6.Sensor R = 5,961	7.Sensor R = 2,379	8.Sensor R = 1,479	9.Sensor R = 2,379	10. Sensor R = 5,961
11. Sensor R = 5,805	12.Sensor R = 1,479	13.Sensor R = 0,991	14.Sensor R = 1,479	15. Sensor R = 5,805
16. Sensor R = 5,961	17.Sensor R = 2,379	18.Sensor R = 1,479	19.Sensor R = 2,379	20.Sensor R = 5,961
21.Sensor R = 12,616	22.Sensor R = 5,961	23.Sensor R = 5,805	24.Sensor R = 5,961	25. Sensor R = 12,616

Table 3. 1/R Values

1.Sensor $\omega_1 \cong 0,079$	2.Sensor $\omega_2 \cong 0,167$	3.Sensor $\omega_3 \cong 0,172$	4.Sensor $\omega_4 \cong 0,167$	5. Sensor $\omega_5 \cong 0,079$
6.Sensor $\omega_6 \cong 0,167$	7.Sensor $\omega_7 \cong 0,420$	8.Sensor $\omega_8 \cong 0,676$	9.Sensor $\omega_9 \cong 0,420$	10. Sensor $\omega_{10} \cong 0,167$
11. Sensor $\omega_{11} \cong 0,172$	12.Sensor $\omega_{12} \cong 0,676$	13.Sensor $\omega_{13} \cong 1,009$	14.Sensor $\omega_{14} \cong 0,676$	15. Sensor $\omega_{15} \cong 0,172$
16. Sensor $\omega_{16} \cong 0,167$	17.Sensor $\omega_{17} \cong 0,420$	18.Sensor $\omega_{18} \cong 0,676$	19.Sensor $\omega_{19} \cong 0,420$	20.Sensor $\omega_{20} \cong 0,167$
21.Sensor $\omega_{21} \cong 0,079$	22.Sensor $\omega_{22} \cong 0,167$	23.Sensor $\omega_{23} \cong 0,172$	24.Sensor $\omega_{24} \cong 0,167$	25. Sensor $\omega_{25} \cong 0,079$

Table 4. 1/R Values Subjected To LI

1. Sensor $\gamma_1 \cong 0,05315$	2. Sensor $\gamma_2 \cong 0,11635$	3.Sensor $\gamma_3 \cong 0,1053$	4. Sensor $\gamma_4 \cong 0,11635$	5. Sensor $\gamma_5 \cong 0,05315$
6. Sensor $\gamma_6 \cong 0,11635$	7. Sensor $\gamma_7 \cong 0,3271$	8. Sensor $\gamma_8 \cong 0,59205$	9. Sensor $\gamma_9 \cong 0,3271$	10. Sensor $\gamma_{10} \cong 0,11635$
11. Sensor $\gamma_{11} \cong 0,1053$	12. Sensor $\gamma_{12} \cong 0,59205$	13. Sensor $\gamma_{13} \cong 0,94115$	14. Sensor $\gamma_{14} \cong 0,59205$	15. Sensor $\gamma_{15} \cong 0,1053$
16. Sensor $\gamma_{16} \cong 0,11635$	17. Sensor $\gamma_{17} \cong 0,3271$	18. Sensor $\gamma_{18} \cong 0,59205$	19. Sensor $\gamma_{19} \cong 0,3271$	20. Sensor $\gamma_{20} \cong 0,11635$
21. Sensor $\gamma_{21} \cong 0,05315$	22. Sensor $\gamma_{22} \cong 0,11635$	23. Sensor $\gamma_{23} \cong 0,1053$	24. Sensor $\gamma_{24} \cong 0,11635$	25. Sensor $\gamma_{25} \cong 0,05315$

4 Experiment Results

The first four tables reflect the trials for flat circuit board with sensors. So as to understand the influence of the surface curvature on the sensory perception, light source was pulled down to 100 mm distance from the nearest sensor, located at the center (number 13). These results may be seen on Table 5. The first column on Table 5 gives the ratio of certain resistance values. When no signal processing is made, raw independent readings show that the ratio of the 2nd sensor to the 3rd one is 1.67. This means, the 2nd sensor has 67 % more resistance than the 3rd one. The second and the third columns reveal ratio of resistance values at flat and curved surfaces. The last two columns display the cases of lateral inhibiton applied on flat and curved systems. Table 5 helps gather some important information. This information can be stated as follows:

When light is shed on the board centrally, light intensity naturally dies out toward the distant sensors. Even when there is no signal processing, this weakening of light from the center generates a natural contrast difference.

Table 5. Comparison Table

Contrast Between	Crude Data (Flat)	Crude Data (Curved)	Flat Data (After Lateral Inhibiton)	Curved Data (After Lateral Inhibiton)
R2 / R3	1.67	2.06	5.33	21.5
R7 / R8	3.20	3.18	10.52	8.75
R12 / R13	3.06	4.83	4.03	7.27

Second and third columns are the proof that curvature has a very positive effect on the contrast augmentation. If the ratio of R7/R8 is considered to be roughly the same, there is a 50% rise at R12/R13 value. With lateral inhibition, contrast is seen to wax even more for both flat and curved systems, but notably more so for the curved one. In our opinion, the discrepancy in R7/R8 ratios in all the four columns is due to misalignment of sensor 7 during surface mounting and soldering. Sensor 7 must slightly be off from the surface normal towards the light source in couple of degrees.

5 Conclusions

As seen from the experiments, contrast is being enhanced when a sensor network and lateral inhibition signal processing are adopted. It is also observed that when the radius of curvature of the board where the sensors were mounted gets smaller, the difference in consecutive sensor outputs increases. This is another way of saying that convex eyes not only allow a wider field of view but also augment the total light difference between light and dark areas in perception. Even though not reported here, another obvious advantage of a curved system is the capability of better localization of sources (light, for example), on the grounds that it simply makes the contrast gradient sharper. Curved facetted compound eyes thus must be quite an advantage in nature to both hunter and the prey alike. Hence, a good engineering application with a sensor net so as to have a sharper perception may involve a curved sensor board architecture, as well as an implementation of LI.

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6 References

1. Hartline., H.K., Wagner, H.G., 1956, Ratcliff, Floyd, Inhibition in the Eye of Limulus, Journal of General Physiology, 39:5 pp 651-673
2. Joseph Rosen and David Abookasis, “Seeing through biological tissues using the fly eye principle”, http://www.ee.bgu.ac.il/%7Erosen/fly_eye.pdf
3. Özçelik,E., Temmuz 2006 , Ardışık görüntüler ile piksel altı bilgi çıkarımı ve çözünürlük iyileştirme, Yüksek Lisans Tezi, İTÜ, İstanbul
4. Demirsoy, A., Yaşamın Temel Kuralları, Meteksan Yayınları, Ankara, Cilt 2 Kısım 219923 pp 158-169
5. Coskun, A. (2006), ‘Contrast Enhancement by Lateral Inhibition in a Sensory Network’, M.Sc. Thesis, Izmir Institute of Technology, Mechanical Engineering Department.
6. Coskun, A., Sevil, H.E., Ozdemir, S., “Cost Effective Localization in Distributed Sensory Networks”, Engineering Applications of Artificial Intelligence, Vol 24, issue 2, pp 232-237, 2011.
7. http://www.isa.org/InTechTemplate.cfm?Section=Features3&template=/TaggedPage/DetailDisplay.cfm&ContentID=53255