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Contrast estimation for the intensity images. A new approach with a dynamic and architectural modelisation of the PLE layer retina

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ABSTRACT

Currently, the knowledges of the mammal visual systems allow the design of new methods for computer vision. These methods try to benefit some properties observed in the visual system. In this paper, our research works use some known mechanisms of the retinian perception. We have designed a artificial retina that implements the first layers dedicated to the primary contrast perception. The contrast detection and its estimation are very important because they are the first steps to a lot of high level treatments in image processing.

We have oriented our study toward biological retina to better understand how works the visual system to perceive image contrasts with different lighting conditions. Our work has been focused on the fonctionnings discovered in the external plexiform layer (PLE). This layer integrates some interesting adaptations that improves its robustness and its efficiency in case of noisy images.

The proposed algorithm is original because it can produce some adaptative effects described in the retina. The adaptations are set locally according to the conditions of lighting. The designed model using an array of filters is able to adjust locally the processing. Moreover the filtering is processing temporally continuously to gain in robustness and efficiency. The suggested architecture allows too an real time use for embedded implementations

based on digital signal processors or wired operators.

1. INTRODUCTION

The retina forms the most internal membrane of the eye. The information is pick up by two kinds of photoreceptors: the rods for the scotopic and achromatic vision that are in great number, and the cones specialized for the photopic and chromatic vision. Rods are preponderant on the whole surface of the retina and more particularly on its periphery. The cones are localized in the center of the retina, in the fovea area.

The retina transforms the light information into a encoded signal by cortical areas. Several distinct neuronal layers are organized to realize a spatiotemporal processings. Between cones and ganglionic cells are organized several kind of cells in two successive functional layers. The first is the external plexiform layer (PLE), and the second is the internal plexiform layer (PLI). More particularly, our works are focused on the functions of the synaptical triad. The cone, bipolar and horizontal cells are forming the PLE layer that brings us to raise contrasts that reveal edges of objects.

At these anatomical classification corresponds enough well a fundamental functional dichotomy between two classes, center ON or OFF, bipolar cells. This antagonism between center and surround is modeled by D. Marr and E. Hildreth [3] and called DOG operator or "Difference Of Gaussians". The PLE layer is basically constituted by (figure 1.a):

- The cones: compose a transduction layer (transformation of the light intensity into an electrochemical potential) and also a regularization layer (sideways spatiotemporal filter).

- Horizontal cells: compose a regularization layer (sideways spatiotemporal filtering).

- The bipolar cells: make difference between respectively the direct cone information and the sideways information provided by the horizontal cells. Consequently,

this layer increases the contrasted visual characteristics and makes up the output of the PLE.

As illustrates the figure 1.b, the horizontal cells acts is the sideways inhibition that provides a reference value, which is compared with the input signal delivered by the cone cells. To subtract a local spatiotemporal average allows an optimal perception in weak or strong lighted visual scenes. The non-linear response of cones described by Michaelis-Menten law [1] allows the dynamics layer to adapt the cone to the local intensity average and moreover to emphasize the temporal smoothing in the weak lighted conditions. In conditions of photopic illumination, this law produces too an pseudologarithmic for static response and allows bipolar cells to estimate, by a difference, the local intensity contrasts with a ratio between I_{center} and $I_{periphery}$. This contrast definition and the minimal thresholds (Just Noticeable Difference) of their perception are given in many reference works of psychocognitive perception [5].

2. OUR APPROACH OF THE PLE LAYER

2.1. Aim of our work

Our objective is to obtain an efficient artificial retina useful for perception in artificial vision. This retina must operate on natural images with a photopic illumination and moreover with a great accuracy. These essential characteristics are found in the fovea zone of the retina dedicated to the diurnal vision so sensitive to chrominance and possessing a strong spatial resolution. Consequently, our model will represent the functioning of a particular zone of the fovea ("midgets" bipolar cells ON or OFF types).

Cones will be supposed achromatic and their distribution (idealized) will be supposed regular and rectangular, these hypotheses will reduce the complexity of the resulting model. Moreover our model will be numerical in view of an real time and embedded implementation.

Our retina is inspired by the B-model presented by W. Beaudot [1]. The PLE layer modeled by W. Beaudot as an analogical electrical device followed by the retina works of Mead [2]. W. Beaudot proposed too a numerical method based on Shen and Castan filtering to illustrate his results [4].

In our works, we propose an original solution using a distributed numerical filtering that will allow thereafter a local adaptation as we can observed inside the retina faced with light variations. To date our model uses a regular sampling of images that is realized with a permanent scene. So we have intended to preserve the notion of time in our image processings but absolutely without input variation between 2 successive images.

2.2. Global description

The figures 2.a describes the principle of our architecture. The processing applied on a single line is showed (sampled each Δx) to simplify the schematic representation. The calculation of the iterative filter is realized periodically each Δt .

The sequence of the input vectors i is sampled periodically (period T with $T = k_T \Delta t$) and loads each cone input $i_{x,k}$.

The visual information crosses a first smoothing layer F_c (cone processings) to give the reply of the cone $c_{x,k}$. The second smoothing layer F_h (horizontal processings) uses the reply of nearby cones to give the reply of the horizontal $h_{x,k}$. The retina result for the bipolar cells is a vector of contrast $b_{x,k}$ obtained by the difference between the cones and horizontal cells responses. Moreover, we apply unit samplings in our equation writings to simplify mathematical formulas (sampling periods are defined by $\Delta_t=1$ and $\Delta_x=1$).

2.3. Description of our model

It was important to reproduce in our architecture the main couplings between cells so as to better approach its adaptation characteristics. The 3 coefficients b_1 , r_1 and a_1 make up the layer F_c :

- The b_1 and r_1 coefficients adjust respectively dynamic and static replies of cones. The couple b_1 and r_1 parameter the direct reply part of the cone excited by the light (cone phototransduction).
- The a_1 coefficient contributes to the coupling between 2 bordering cones. The a_1 coefficient parameter the part of the reply created by the sideways cone synapses.

The layer F_h possesses also 3 coefficients b_2 , r_2 and a_2 :

- The b_2 and r_2 coefficients adjust respectively dynamic and static replies of horizontal cells. The b_2 and r_2 parameter the direct reply of the horizontal cells excited by the cones.
- The a_2 coefficient contributes to the coupling between 2 bordering horizontal cells. The a_2 coefficient parameter the part of reply created by the horizontal cell excited by its neighborhood.

And finally, the difference between 2 layers corresponds to the bipolar cell function that differentiates information transmitted by cone synapses and those of the horizontal cells.

3. FILTER COMPUTING

The filter structure showed in figures 2.a is performed by the recurrent formula hereafter.

$$c_{x,k} = a_1(c_{x-1,k-1} + c_{x+1,k-1}) + b_1 i_{x,k} + r_1 c_{x,k-1}$$

$$h_{x,k} = a_2(h_{x-1,k-1} + h_{x+1,k-1}) + b_2 c_{x,k} + r_2 h_{x,k-1}$$

$$b_{x,k} = c_{x,k} - h_{x,k}$$

$$\text{with } a, b \in \square \quad \text{and} \quad r_{1/2} = e^{-1/k} 1/2 \quad | \Delta_t=1 \text{ et } \Delta_x=1$$

k_1 and k_2 represent respectively the constant times of cone photoreceptors and horizontal cells.

3.1. Behavioral studies

The response of the bipolar cells is given by the B-retina modelisation as the difference of 2 layers respectively F_c and F_h . The fourier transform F of the resulting filter can be expressed by the following equation:

$$F[\omega_x, z] = F_c[\omega_x, z] (1 - F_h[\omega_x, z]) \quad \text{with } z = e^{p \Delta t}$$

The transfer function of each layer is expressed for the time scale by the z-transform and for the spatial scale by a discrete Fourier transform.

The transfer function of the 2 layers is given below:

$$F_{c/h}[\omega_x, z] = \frac{S[\omega_x, z]}{E[\omega_x, z]} = \frac{b_{1/2} \cdot z^{-1}}{1 - 2a_{1/2} \cdot \cos(\omega_x) \cdot z^{-1} - r_{1/2} \cdot z^{-1}}$$

By replacing in the above formula of F, we obtain:

$$F[\omega_x, z] = b_1 \cdot \frac{(z - (z_2 + b_2))}{(z - z_1)(z - z_2)}$$

$$\text{with } z_{1/2} = 2a_{1/2} \cos(\omega_x) + r_{1/2}$$

This function is composed of 2 unstable poles z_1 and z_2 and an zero value equal to $z_2 + b_2$. The coefficient b_1 is the upstream proportional gain of the retina.

3.2. Settings

The transfer function must be stable in the course of time for some images $i_{x,k}$. The stability for a reply is obtained with the respect of the inequation hereafter:

$$\forall \omega_x \text{ we have } |2a_{1/2} \cos(\omega_x) + r_{1/2}| \leq 1 \Rightarrow |\pm 2a_{1/2} + r_{1/2}| \leq 1$$

The condition to verify to obtain a stable and a none oscillant reply is given hereafter:

$$0 \leq (\pm 2a_{1/2} + r_{1/2}) \leq 1$$

And finally, to obtain a null reply at one time when the sequence of entry image i is a temporal and spatial constant (image without contrast and not evolving in the course of the time), one has to have ($F_h[0,1]=0$):

$$1 - (z_2 + b_2) = 0$$

$$\text{Let } z_2 + b_2 = 2a_2 \cos(\omega_x) + r_2 + b_2 = 1 \text{ for } \omega_x = 0$$

$$\text{therefore } 2a_2 + b_2 + r_2 = 1$$

In static functioning, the filter thus obtained is adjustable in a band-pass or high-pass filter. The figure 4 gives the appearance in module of the spectrum of the filter. The retina according to its adjustments changes properties in function of the time. The filter response behaves in a first time as a low-pass frequency filter (cellular capacity cones) to evolve to the band-pass or well high-pass frequency filter. Thus, during the appearance of a detail in the scene i , the retina analyzes its details by a progressive filtering as 'coarse to fine'

3.3. Balance of the network

For this filter structure, the calculate are necessarily iterative. When initial conditions are modified and held, the system puts a some times ($T_E = K_E \Delta T$) to reach again a new balance ($r_{1/2} = 0$). So to obtain a balance response, K_E iterations guarantee the static balance at least and is function of the 2 used coefficients $a_{1/2}$. The iteration number that undertakes to obtain the static balance solution is minimized by the value K_E (figure 4). It is to note that some image sequences, sampled well beneath the Shannon limits will require a weaker iteration number and certainly controllable by calculation.

4. RESULTS

The algorithm describes previously is applied on 2D. The retina replies to a stimulus by a retinian field ON/OFF

that gives the activities of "midgets" bipolars of the layer PLE (figure 1.b). This response is similar to the reply of the DOG operator [3]. The ability to set with our architecture the retinian fields shape is given by the figures 4 and 5. According to a_1 and a_2 , we can modulate:

- The size of the peripheral field constituting the zone of inhibited cells OFF (diameter > 30 pixels).
- Or the size of the central type field constituting the zone of excited cells ON (diameter < 6 pixels).

The adjustment of the center ON is on the other hand more limited. The bipolar cell by the differentiation of these 2 areas estimates therefore the local contrast [5].

5. CONCLUSION AND PERSPECTIVES

We have presented a structure of filter that modelizes the PLE layer of the retina. This distributed architecture permits local adaptations and a well-suit implementation. The first obtained results allow us to envisage some modifications that we will bring us interesting properties. We have realized tests with the aiming to simulate local effects observed according to the light intensity and detailed below:

- The size modulation of retinian fields.
- The use of Michaelis-Menten law in the layer Fc.

The size modulation of retinian fields allows detecting local contrasts with a accuracy varying according to the intensity average. In dark zones, the signal noise ratio is weak, also the retina has tendency to spread out the retinian fields to better evaluate the contrasts.

The use of the cone transduction brings to us 2 advantages. On the one hand it adapts the reply of the cone to the intensity light by a dynamic compression and thanks to its logarithmic shape, it discriminates efficiently the reflectance by the differentiation of the bipolar cells. On the other hand it reduces the noise in weakly lighted zones by the enhancement of temporal smoothing.

Results obtained by this architecture modelizes only nearby connections of the PLE. The retinian fields created specialize the retina in the high frequency ranges. The pointed center ON of retinian fields reveals this fact. The estimation with the periphery OFF of the intensity average far around the center reduces efficiently noisy effects. In our case, to enhance size of the retinian fields is possible but it would increase too the computing time entailed by a slower convergence of the filter between 2 updates of the image input.

6. REFERENCES

- [1] W.H.A. Beaudot - "Le traitement neuronal de l'information dans la rétine des vertébrés", Thèse de doctorat de l'Institut National Polytechnique de Grenoble, France, 1994
- [2] C.A. Mead and M.A. Mahowald - "A silicon model of early visual processing", Neural Networks, n°1, pp. 91-97, 1988.
- [3] D. Marr and E. Hildreth - "Theory of edge detection", Proc. R. Soc. Lond., B 207, pp.187-217, 1980.
- [4] J. Shen. and S. Castan - "Un nouvel algorithme de détection de contours". AFCET INRIA, 5ème congrès, 1985.
- [5] W.F. Shreiber - "Fundamentals of Electronic Imaging Systems". Information Sciences, Third Edition - Springer Verlag, 1999.

7. ANNEXES

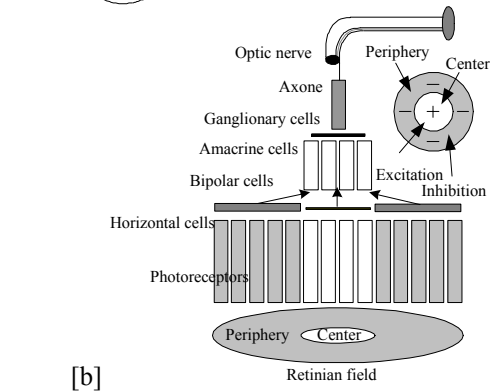
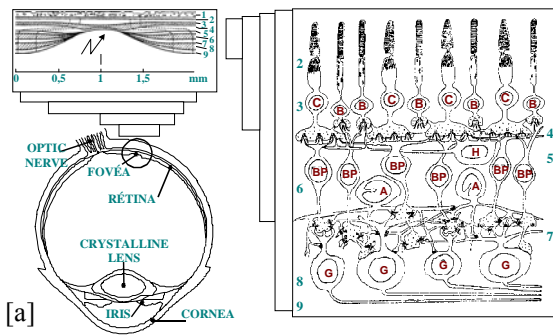


Figure 1: The eye and the retina - Perception et compression of the visual information

[a] Cells that cover the retina surface are the cone and rod photoreceptors (C and R). The PLE region of the retina are composed by the horizontal and bipolar cells (respectively noticed H and B). The PLI region is made up by amacrine and ganglionic cells (respectively noticed A et G).

[b] Diagram of the visual information path through the retinian layers and the cells networks.

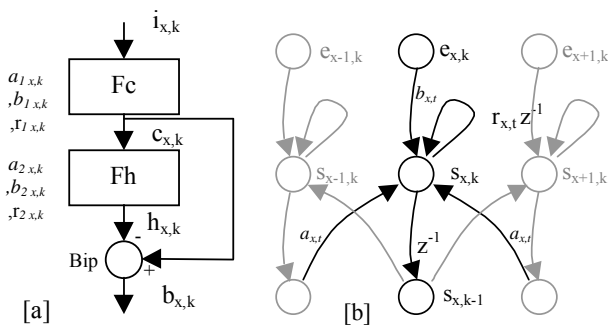


Figure 2: [a] Diagram of the retina - [b] Representation of the filter architecture chosen for Fc and Fh blocks. They are implemented by a distributed filtering architecture and drawn by a graph. The parameters a,b and r are periodically controlled at each computational iteration.

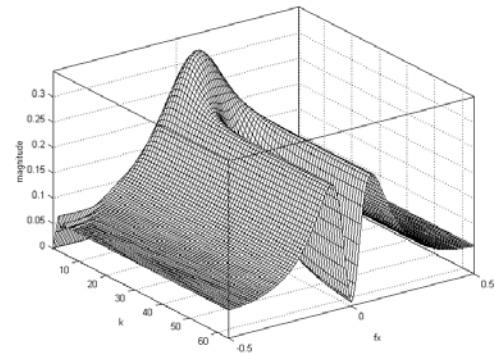


Figure 3: Spatial Fourier transform F across the time - Fourier transform behavior obtained during the iterative computing ($a_1=a_2=0.4$, $b_1=b_2=0.1$ et $r_1=r_2=0.1$).

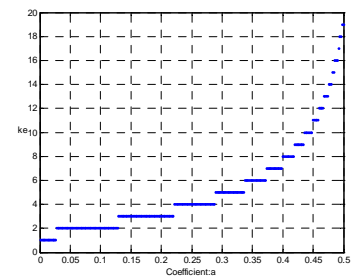


Figure 4: Convergence to the balance - Maximal iteration number k_E necessary to reach a balance static response ($r=0$) of an only layer sets with a low frequency gain equal to 0. The response is obtained with a 95% ratio and is function of the value a.

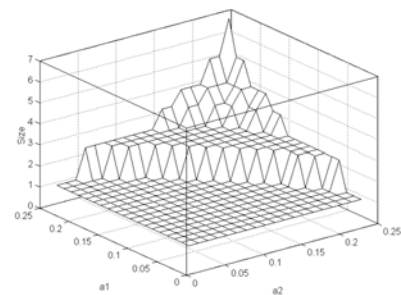


Figure 5: Retinian field behavior - Size of the center ON given in function of a_1 et a_2 values (balance ratio equal to 99 %).

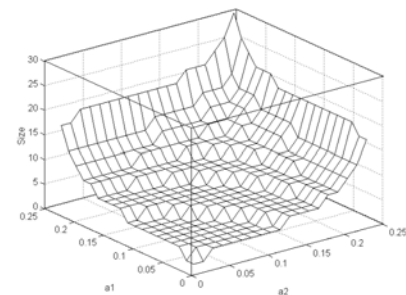


Figure 6: Retinian field behavior - Size of the periphery OFF given in function of a_1 et a_2 values (balance ratio equal to 99 %).