PIGMENTED RAT-BASED VISION FOR ARTIFICIAL INTELLIGENCE APPLICATIONS

Francisco J. Cisneros de los Rios , Isabel Martín Moreno-Cid , Abel Sanchez-Jimenez , Juan Castellanos, Fivos Panetsos

Abstract: *One of the most important objectives of artificial vision is the development of bioinspired and biomimetic robot vision as well as the development of bionic eyes for the blind. Depending on the specific application different eye models can be used but the most ambitious is the development of a human-like eye. However, human eye is extremely complex and if we even design such a visual device the amount of information to process should be computationally intractable. Normally low-resolution image quality and low visual acuity would be sufficient for our purposes, so simpler biological models could represent excellent computational alternatives. In the present communication we propose to use the visual system of the rat and we justify our proposal by proving that this model fits perfectly the requirements of our applications.*

Introduction

In the last decades artificial vision has been integrated in our life, mainly in industrial applications like quality control, fault detection or robot guidance. More ambitious objectives include bio-inspired and biomimetic robot development and bionic eyes for the blind (Panetsos F., et al., 2009). Different eye models can be used depending on the desired application, spanning from insect eyes to the human retina that represent the highest goal in artificial vision (B. Dietrich 2007 y R Hendriks 2008).

Insect eyes are compound eyes usually consisting of thousands of tiny lens-capped optical units, the ommatidia. Ommatidia are formed by a lens, a crystalline cone and the rhabdom channel that contains the photoreceptors (Fig.1, left). The light is conveyed to the photoreceptors through the lens and the rhabdom channel. Photoreceptors are connected to the optical nerve cells to which transmit information. In insect eyes ommatidia are orientated in slightly different directions and generate slightly overlapping images. This way the compound eye creates a low-resolution mosaic image but with excellent performances in movement detection. Artificial insect vision reproduces this eye design (Fig.1, left) (K-H Jeong 2006); dibujar del ojo del insecto y el ojo artificial) [http://axxon.com.ar/mus/Insectos.htm]

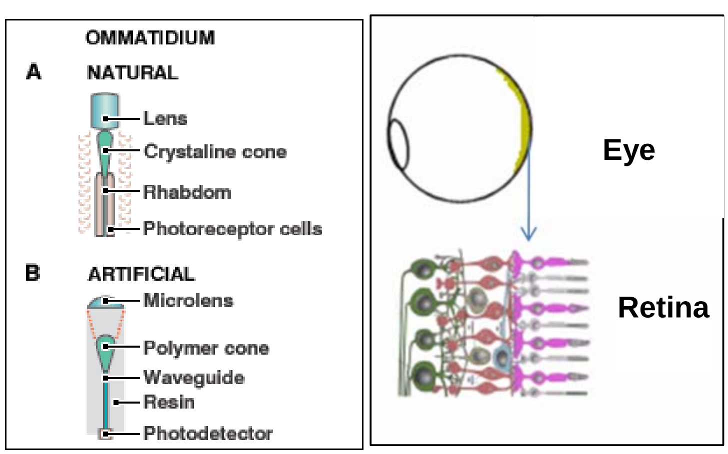


Figure 1. Left, insect vision: natural (A) and artificial (B). Right, mammal vision: natural

Mammal retina is the eyeball's inner lining onto which images of the outside world are projected by the light that enters the eye (Fig.1, right). Images formed at the retina consist of continuous multidimensional stimuli formed by spatiotemporal and intensity patterns of different wavelengths of light. A sheet of photoreceptors transforms these images into another multidimensional pattern made by spatiotemporal and intensity pattern of electrical signals. Photoreceptors are connected to the ganglion cells to which they transmit their electrical activity. Signals from the ganglion cells are transmitted to the thalamus and then to the cortex, where visual perception takes place (P. Kara 2002).

An artificial retina connected to the higher stations of the visual pathway should generate artificial visual percepts (sensations of spots of light) similar to the natural ones (G. A. Horridge 2006). Similarly, an artificial retina used by a bioinspired robot should provide eye-like images to the robot's brain. However, human eye is extremely complex and if we even design such a visual device, the amount of information to process should be computationally intractable. Fortunately, the eyes of most mammals, including humans, are very similar their main differences found in the distribution of the photoreceptors (H. Perry 1981). So simpler mammal eyes could be proposed as experimental paradigms for mammal-like artificial vision. In particular, the similarities in the effects of visual deprivation on visual acuity between rats and other mammals confirm that rats are a good model system for our purposes (Prusky et al. 2002).

Biomimetic robot vision does not normally need high acuity and visual neuroprostheses will be implanted to blind subjects through some hundred or at maximum thousand of microelectrodes. In both cases, a low-resolution image quality or low visual acuity would be sufficient for our purposes. The visual system of the rat fits perfectly our requirements and it could be used as a model for our study.

Visual acuity for robotics and neuroprosthetics

Visual acuity is measured in cycles per degree (cpd), a measurement of the number of lines that can be seen as distinct within a degree of the visual field. It reaches 30.0 cpd in humans, 1.0-1.2 cpd in pigmented rats and 0.3-0.5 in albino rats (Hughes, 1979; Prusky et al. 2002). The maximal spatial resolution of dark-and light-adapted retinal ganglion cells recorded from optic tract of hooded rat is, however, only about 1.2 cycles/degree or about 25 min of visual angle (A. Hughes 1979). Ganglion cells are relatively evenly distributed across the rat retina, the density varying from 3,000 in the central area to 600 cells/mm2 in the periphery (5:1, (G. Paxinos, 2004).The denser the ganglion cells the higher the acuity at that point of the retina, it reaches 6,774 cells/mm2 in rats and 38,000 cells/mm2 in humans (Curcio and Allen 1990). A theoretical estimation of rat's maximum acuity indicates 1.5 cpd consistent with experimental data (Heffner and Heffner 1992). In Table 1 are showm the physical characteristics of the three eyes.

Table 1. Comparison of visual properties of the human and rat eye

	Humans	Pigmented rat	Albino rat
Best visual acuity	20/20	20/600	20/1200
Resolution	~ 30 cpd	~ 1.0 cpd	~ 0.5 cpd
Maximum density of photoreceptors (fovea)	10.000 cells/mm2	3,000 cells/mm2	3,000 cells/mm2
Depht vision	2.3 m - ∞	0.07 m - ∞	0.07 m - ∞
Maximum monocular visual field (normal vision)	60º	max 60º	max 60º
Minimum monocular visual field (low vision)	>20º	>20º	>20º

To establish the visual acuity several high-contrast tests with letters of different sizes (optotypes) are presented to the observer at a fixed distance. The smallest letter the observer is able to detect or recognize (depending on the task assigned to the subject) is taken as threshold (Baily, 1976). In Fig. 2, in the first line we can observe the perception of two optotypes by humans and the two rats where it is clear that pigmented rats vision could substitute the human one with good performances. The first character of this optotype is 9.0 cm at 110 cm from the rat. The next character 4,5 cm placed at the same distance. If we translate Prusky's cpd measurements into vision chart measurements we obtain about 20/600 for the pigmented rat and 20/1200 for the albino rat. In the middle line a more intuitive example corroborates the suitability of the pigmented rats model while in the bottom a real scene is shown as perceived by the three eyes. Pigmented rat is able to distinguish the same objects as a human observer while an albino rat cannot.

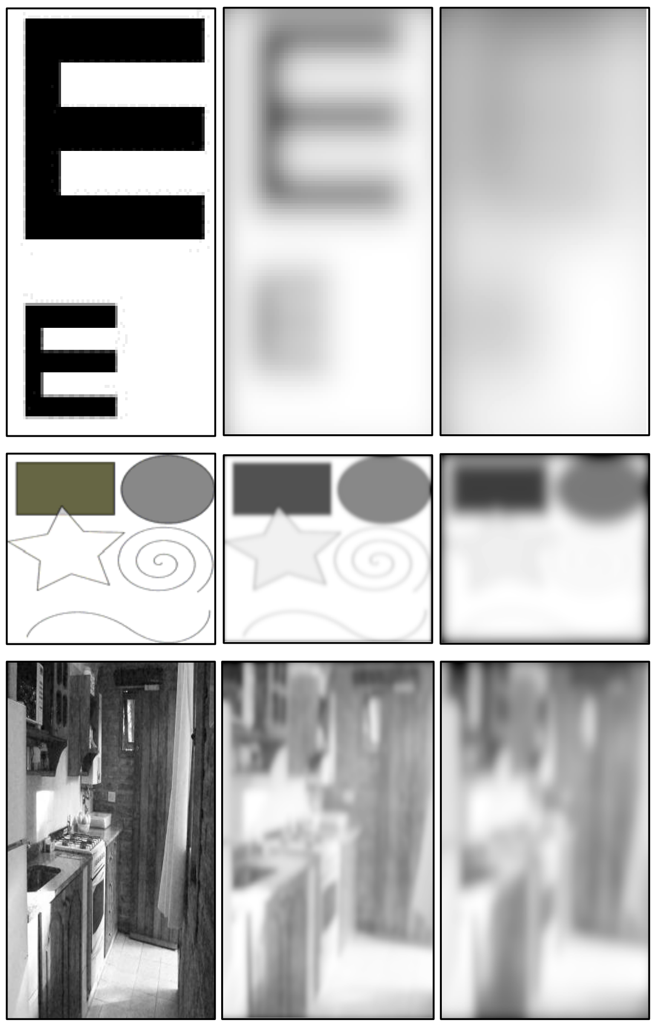


Figure 2. Top: A seeing optotype e as perceived by a human (left), a pigmented rat with visual acuity of 1.2 cpd (center) and an albino rat with visual acuity 0.5 cpd (right). Middle: Different drawings as perceived by humans and the two types of rats prove the suitability of the pigmented rat model for artificial vision applications. Bottom: Areal scene as perceived by the three eyes.

Given their visual resolution, pigmented rats should be able to distinguish a 9.0 x 9.0 cm optotype at a distance of 1.1 m and an albino rat the same optotype at 4.5 cm. The minimun resolution to define an optotype is 5 x 5 pixels. Taking into account the loss of information when we reduce the size of an image and the different visual angles, the following dimensions of an artificial retina should be necessary (Fig. 3). In Fig. 4 we present the vision capabilities of the rats at XXº in two real environments, one close and the other open.

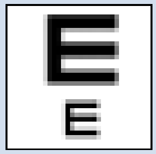
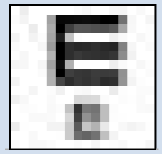
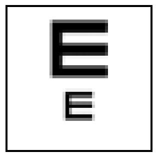
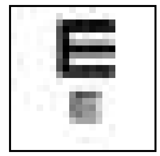
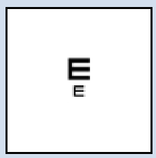
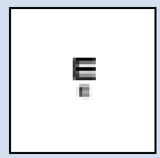
Degrees	Pigmented rat (1.2 cpd)	Albino rat (0.5 cpd)
20	32 x 32 px 	16 x 16 px 
30	44 x 44 px 	22 x 22 px 
60	88 x 88 px 	44 x 44 px 

Figure 3. Different optotypes as perceived by the two types of rats using different vision angles.

Figure 4. A close (left) and an open environment (right) as perceived by the two types of rats using XXº angle.

Conclusions

Any visual neuroprosthetic design have to consider the less amount of information to inject to the Central Nervous System, specially for the number of implanted electrodes. "Ad hoc" information processing and coding strategies will reduce the dimension of the thalamic input. On the other hand, an important research objective of artificial vision for robotics is to reduce the amount of information that is obtained by the visual system and needs very time and memory consuming processing. According to our study, relatively good performances can be achieved by artificial systems using visual acuity characteristics as low as those of the pigmented rats. Our proposal has the additional advantage that rats can behave well with their visual system although their optical apparatus is bad, the neuronal organization of the retina is very rough and their visual acuity is low. Therefore with our model we could use obtain good performances in either biomimetic robotics or visual neuroprostheses using a rat-mimetic visual system.

References

[A. Hughes 1979] Hughes A, Wässle H.An estimate of image quality in the rat eye.Hughes A, Wässle H. Invest Ophthalmol Vis Sci. 1979 Aug;18(8):878-81

[B. Dietrich] B. Dietrich. On the vision of insects Current Biology.17, 329–335, February 20, 2007

[C.A.Curcio, 1990] C.A. Curcio , K.A. Allen. Topography of ganglion cells in human retina. J Comp Neurol. 1990 Oct 1; 300(1):5-25

[G. A. Horridge 2006] El ojo compuesto de los insectos. *Science* 28 April 2006: Vol. 312. no. 5773, pp. 557 - 561 DOI: 10.1126/science.1123053

[G. Prusky, 2002] G.T. Prusky, K.T. Harker, R. M. Douglas, I. Whishaw. Variation in visual acuity within pigmented, and between pigmented and albino rat strains, Behav Brain Res. 2002 Nov 15;136(2):339-48

[F. Panetsos, 2009] F. Panetsos, E.Diaz-de Cerio, A.Sanchez-Jimenez, C.Herrera-Rincon. Thalamic visual neuroprostheses: Comparison of visual percepts generated by natural stimulation of the eye and electrical stimulation of the thalamus. NER2009

[H. Perry 1981] Spatial contrast sensitivity of cells in the lateral geniculate nucleus of the rat. J. Physiol. (1981), 315, 69-79 69

[G. Paxinos, 2004] G. Paxinos. The Rat Nervous System, Cap.32 Visual System, 3th edition 2004. Elsevier.

[K-H Jeong 2006] Ki-Hun Jeong, Jaeyoun Kim, Luke P. Lee Biologically Inspired Artificial Compound Eyes. *Science* 28 April 2006: Vol. 312. no. 5773, pp. 557 - 561 DOI: 10.1126/science.1123053

[P. Kara 2002] Prakash Kara, John S. Pezaris, Sergey Yurgenson, and R. Clay Reid. The spatial receptive field of thalamic inputs to single cortical simple cells revealed by the interaction of visual and electrical stimulation. October, 2002, Harvard Medical School, Boston, MA,

[R Hendriks 2008] Retinal Implants, Still in Their Infancy, Provide a New Vision of the Future. Richard Hendriks. March 2008 Bionic Eyes. Medical Device Marketplace Review

[R.S. Heffner, 1990] RS, Heffner, H.E. Heffner. Visual factors in sound localization in mammals. J Comp Neurol. 1992 Mar 15;317(3):219-32.PMID: 1577997 [PubMed - indexed for MEDLINE.

Authors' Information

Francisco J. Cisneros de los Rios *– Natural Computing Group. Universidad Politécnica de Madrid, Boadilla del Monte, 28660 Madrid, Spain: e-mail: kikocisneros@gmail.com*

Isabel Martín Moreno-Cid *– Neurocomputing and Neurorobotics Research Group, Universidad Complutense de Madrid, 28037 Madrid, Spain. School of Optics, Universidad Complutense de Madrid, 28037 Madrid, Spain: email: fivos.panetsos@opt.ucm.es*

Abel Sanchez-Jimenez *– Neurocomputing and Neurorobotics Research Group, Universidad Complutense de Madrid, 28037 Madrid, Spain. School of Optics, Universidad Complutense de Madrid, 28037 Madrid, Spain: email: fivos.panetsos@opt.ucm.es*

Juan Castellanos *– Natural Computing Group. Universidad Politécnica de Madrid, Boadilla del Monte, 28660 Madrid, Spain: e-mail: jcastellanos@fi.upm.es*

Fivos Panetsos *– Neurocomputing and Neurorobotics Research Group, Universidad Complutense de Madrid, 28037 Madrid, Spain. School of Optics, Universidad Complutense de Madrid, 28037 Madrid, Spain: email: fivos.panetsos@opt.ucm.es*