

Chapter 75

Replicating the Role of the Human Retina for a Cortical Visual Neuroprosthesis

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ABSTRACT

Neuroengineering is an emerging research field combining the latest findings from neuroscience with developments in a variety of engineering disciplines to create artificial devices, mainly for therapeutical purposes. In this chapter, an application of this field to the development of a visual neuroprosthesis for the blind is described. Electrical stimulation of the visual cortex in blind subjects elicits the perception of visual sensations called phosphenes, a finding that encourages the development of future electronic visual prostheses. However, direct stimulation of the visual cortex would miss a significant degree of image processing that is carried out by the retina. The authors describe a biologically-inspired retina-like processor designed to drive the implanted stimulator using visual inputs from one or two cameras. This includes dynamic response modeling with minimal latency. The outputs of the retina-like processor are comparable to those recorded in biological retinas that are exposed to the same stimuli and allow estimation of the original scene.

INTRODUCTION

Nature is a source of inspiration for a variety of engineering fields, such as aerospace engineering, robotics, civil engineering, architecture, optics, etc. From nature, we can obtain a series of ef-

ficient, functional, and tested designs. In some cases, these bio-inspired designs are far superior to conventional engineering models, offering better solutions that improve current designs or even become the first approach to problems remaining unsolved.

Biomedical engineering is one of the research fields that has looked to biology for solutions.

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In particular, this discipline has built models for addressing a number of questions that have long been posed by the scientific community. A novel research field named neuroengineering (Sanguineti, Giugliano, Grattarola, & Morasso, 2001) has emerged from the intersection of nature and engineering and is aimed at creating artificial systems able to interact with the central or peripheral nervous systems. A connection between an electronic device and some point of the nervous system could be established by means of invasive (intra- or extracellular electrodes) or non-invasive (surface electrodes) interfaces. This method communication can be used to create therapeutic solutions in which a lost or damaged function in a patient is at least partially restored. Examples of these neuroengineering systems include cochlear implants for the deaf, deep brain stimulation for individuals with Parkinson's disease, brain-computer interfaces for communication and control in paralyzed patients.

Computer vision research has used bio-inspired models to explore issues such as optical flow, object segmentation, etc. The study of natural vision can also take advantage of engineering models to explain how visual processing is carried out at different levels along the visual processing stream. These bio-inspired models can serve not only as a simulator for understanding functional vision, but also as means for understanding and developing solutions for visual impairments. Visual neuroprostheses are aimed at restoring vision in the blind by means of sending the proper neural-like signals to the remaining functional elements of the visual pathway. Building an electronic stimulator able to translate images into neural spike trains requires an interdisciplinary approach involving neuroscientists, neurophysiologists, as well as computer and electrical engineers.

For decades, different research groups throughout the world have pursued the creation of visual neuroprostheses. Although there are some differences in their approaches, they all follow a common principle. The systems proposed take as basis the

electrical stimulation of neurons carrying visual information to the cortical areas of the brain in the occipital lobe. It has long been known that electrically stimulating the visual cortex (or neurons arriving at this area) elicits the perception of visual in the form of bright spots, similar to stars in the darkness, known as phosphenes (Löwenstein & Borchart, 1918). Based on that principle, some attempts have been made to provide controlled stimulation of different parts of the visual cortex, in the hope of helping blind individuals perceive shape as a form of rudimentary artificial vision (Brindley & Lewin, 1968), (Dobelle, Mladejovsky, & Girvin, 1974).

VISUAL NEUROPROSTHETICS

Currently, there are three major approaches for restoring sight to the blind by electrical neurostimulation. The major difference between these approaches lies in the location at which the neural interface for electrical stimulation is implanted, as represented in Figure 1.

Thus, we can distinguish retinal implants, optic nerve implants and cortical implants. The first type of neuroprosthesis uses the retina as an entry point for electrical neurostimulation. Depending on the side of the retina receiving the implant, these are named as epi-retinal prostheses (Eckmiller, 1997; Rizzo, Wyatt, Loewenstein, Kelly, & Shire, 2003), (Delbeke, Oozeer, & Veraart, 2003) or sub-retinal prostheses (Chow et al., 2001; Zrenner et al., 2001). Optic nerve implants (Delbeke et al., 2003; Veraart, Wanet-Defalque, Gerard, Vanlierde, & Delbeke, 2003), (Delbeke et al., 2003) use cuff electrodes embracing the nerve bundle travelling from the eye to the visual cortex. The combined activation of several of these electrodes elicits the stimulation of some of the fibers in the optic nerve, creating visual sensations in the patient. In the case of cortical implants, electrodes might be placed on the surface of the visual cortex (Dobelle, 2000)

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