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Artificial Vision - Visual Prosthesis

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Abstract- A visual prosthesis is a device that captures visual images, convert light energy into electrical pulses, and deliver electrical pulses to the retina which helps blinds to restore vision artificially and uses an optogenetic approach that involves the reverse engineering of the retained visionary pathway on the visual system to become photosensitive with pumps and channels that are light-activated. It requires the combination of many types of engineering and biological expertise.

Keywords- Vision; Prosthesis; Blind; Eye

1. INTRODUCTION

The visual system of human beings is quite advanced as it contains powerful lenses, self-cleaning abilities, automatic focus, tracking abilities, image stabilization, and photosensitive adjustment as it can operate in different light intensities [8]. This makes the eyes among the most vital sensory organs for humans. Vision allows the perception of the world, recognition of shapes, colors, and movement with nearly a half of the cerebral cortex utilized for visual processing [8]. Losing one's ability to see is a severe handicap for an individual's entire life, and this would require the individual to relearn the causal tasks and become increasingly reliant on the senses of touch and sound [8]. However, there is significant effort that has been put in place to develop a device or devices that could restore site by performing similar functions as the eye – visual prosthesis [7]. Due to the recent technological advancements in developing tools and devices that act as an interface to the nervous system, a lot of research has been done to promote the understanding of the nervous system of human beings or interfacing the nervous system for prosthetic purposes (Maghami et al., 2014[7]). These tools used for the restoration of human vision after loss are known as visual prosthesis.

2. VISUAL PROSTHESIS

A visual prosthesis is a device that stimulates the components of the visual pathway electrically to produce visual sensations known as phosphenes [8]. It can restore vision to blind patients artificially and uses an optogenetic approach that involves the reverse engineering of the retained visionary pathway on the visual system to become photosensitive with pumps and channels that are light-activated. The illumination of the optoelectronics encoding visual scenes returns the sense of sight [7]. Microsystems that are implantable are designed and developed for either stimulating the nervous system or record neural activities directly with a high spatial resolution [7]. These are known as neural prostheses.

The visual pathway begins from the photoreceptors and extends into the retina to the brain's visual cortex. To obtain a visual prosthesis, the information recorded in the outside world can be delivered to the natural visual system at any point of the visual pathway provided that the other parts from the point of delivery are fully functional [1]. Therefore, there is a wide range of approaches that can be undertaken to restore vision and these are categorized into retinal, optic nerve, and cortical stimulation with each of them having their strengths and weaknesses [1]. On the part of ingenuity, the greatest interest is placed on the retinal approaches as they provide the maximum benefit from the image processing that is performed in the natural visual system. Therefore, it reduces the image processing expected from the prosthesis [7]. The stimulation of the optic nerve is making an attempt to deliver information regarding an image to the natural system at the first place after the retina and possible where there is an atrophied retina.

3. INTERACTION OF THE EYE AND THE OPHTHALMIC NERVE WITH THE ELECTRONIC SIGNALS/ DEVICE

Artificial vision is the restoration of sight through electrical stimulations of the visual system at either the level of the retina, optic nerve, lateral geniculate body, or the occipital cortex [9]. The development of visual prosthesis began with the prosthesis of the occipital cortex, however, today, retinal prosthesis has significantly advanced [9]. Presently, numerous efforts are directed towards the development of an optimal approach for visual restoration through a system of an implantable retinal microelectrode array. Considering the retinal system, the retinal prostheses function through the stimulation of the internal neurons of the retina that survive degeneration [9]. In these prosthetic devices, visual information is collected by a light detector and transformed into controlled patterns of electrical impulses. These impulses are transmitted to the surviving parts of the retinal neurons by an array of electrodes.

A retinal electronic prosthetic device replaces the dead or nonfunctional photoreceptors of the eye. It translates external visual information and other photic images into electrical signals in the eyes' retina these can then be perceived by the brain as visual images [2]. It involves the mounting of a small camera behind the eyeglasses of a patient and this camera captures an image and wirelessly sends the image into a microprocessor that converts the image into an electronic signal [2]. The electric signal them moves to a special receiver and transmitted to the prosthetic microelectrode implanted in the retina. This implant then transmits the received signal to the surviving retinal cells that are them preliminarily processed, and the signal sent down to the optic nerve for final processing in the brain [2]. Here the signal is synthesized into a visual image and the blind individual can then view the image just like a person with normal functioning eyes.

4. WORKING PRINCIPLE OF THE ARTIFICIAL DEVICE

The basic idea about visual prosthetics is creating an imaging device which through some artificial methods injects signals that have been appropriately processed into the visual stream. The devices are meant to perform their functions in a similar manner to the normal image processing abilities of the retina (Pezaris & Eskandar, 2009[10]). Therefore, unlike bionic devices, visual prosthetic devices focus on photons onto a light sensitive surface for image creation, extraction of the image's salient features, and transmission of the features to the brain (Pezaris et al., 2009[10]). In these devices, each electrode contact is intended to generate a single phosphene and if they are small and tightly focused, they are considered to be pixels separated by unstimulated backgrounds (Pezaris et al., 2009[10]. Mapping the visual scene to these pixels develops a prosthetic image from the adjustment of the pixels' brightness according to the brightness of the original image.

Considering the retinal implants as the example, the underlying principle is replacing the functions of the rod and cone photoreceptors with outer retinal degeneration. This is achieved by stimulating the retina's secondary neurons that is the bipolar and/or ganglion cells [3].

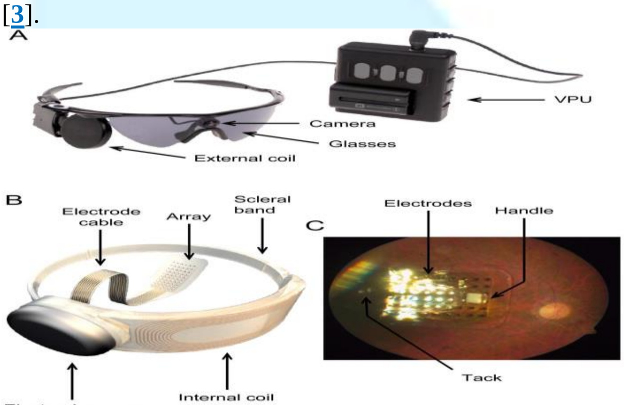

Figure 1: Argus II Retinal Prosthesis System
Source: (Ghodasra et al., 2016).

Stimulation is provided by an array of small electrodes. A good example of a retinal prosthetic device is the Argus II Retinal Prosthesis System [4]. It is a surgically implantable device and designed to provide artificial sight to patients suffering from outer degenerative diseases. It comprises of an external unit for processing videos whose function is to translate visual information from an eyeglass that is mounted on a video camera into electric signals [4]. The portion that is implanted comprises of a receiver coil that transmits stimulus that is electrical in nature through a cable that is polymerized to an array of 60 electrodes that is implanted on the retina's surface [4]. The remaining retinal neurons are electrically stimulated to evoke action potential that travel via the optic nerve to the brain and elicit the visual precepts.

5. EXTENDING THESE IDEAS TOWARDS A FULLY FUNCTIONAL RECORDING AND TRANSMITTING DEVICE

Initiatives such as that highlighted above have been established to develop innovative neural technologies for advancing spatial and temporal resolution of neural recording and stimulation towards the dynamic mapping of brain functioning [5]. As among the most accessible parts of the brain, the retina is highly characterized and mapped in its different types of cells and their connections [5]. Despite the significant progress made in the mapping of retinal activity, retinal prostheses for blindness treatment are still at an early stage of technological development and, therefore, advancements can be to the existing technology of retinal prosthesis.

Retinal prosthesis simply replaces the degenerated photoreceptor cells function of photo transduction through the application of electrical stimulation to the surviving tissues to induce visual sensation and restore site [5]. Patients that have inherited degenerative retinal diseases loss rod receptors in the eyes and hence suffer from poor vision and peripheral loss of vision and Age-related Macular Degeneration (AMD) affects the fovea's dense concentration of cones which is the optical focus of the retina [5]. The receptors cannot be repaired by any form of treatment and surgery and may result in full blindness.

Fortunately, even in cases of severe photoreceptor loss, the visual information pathway from the retinal neurons, bipolar cells, and retinal ganglion cells (RGCs) to the neurons for visual processing within the visual cortex remain undamaged [5]. To bring back the vision, the surviving neurons can be activated using electrical simulations with prosthetics such as the Argus II Retinal Prosthesis System described above [5] The have up to date been the most viable and promising prospects for visual restoration among patients with degenerative diseases and AMD [5]. The others that can utilize photothermal and ultrasonic simulation are considered alternative.

However, despite the use of these devices, over 75% of the patients that received the implants reported not to attain visual acuity that was measurable and the Argus II devices has been found not to go above the threshold of legal blindness that is 20/200 [5]. In addition, the devices are bulky as they have many components that the individual has to carry around so as to see and it involves the use of an external camera for scanning an area. This requires the person to move around the head [5]. In addition, the implant has a limited number of electrodes resulting in rudimentary shapes only and have limited battery life hence limited time for seeing.

However, this design can be improved and further extended to alleviate the shortcomings of the Argus II system. New prosthesis are being developed and these depend on upcoming technologies. These are, for instance, the use of silicon nanowires that sense light and stimulate the retina electrically at the same time [6]. They provide a greater resolution than that achieved by the Argus II system and which is closer to the natural retina photoreceptors. This prosthesis does not need an external vision sensor to capture images and transform them into alternating signals to stimulate the retinal neurons [6]. They mimic the structure and functioning of cones and rods of the retina responsible for sensing light and hence stimulate the retinal cells directly [6]. They are bundled in a grid of electrodes that are activated directly by light and they are powered by one wireless electrical signal. This direct and localized translation of light into electrical simulations makes the design much simpler and scalable for retinal prosthesis [6]. Finally, the power delivered to the nanowires from a single wireless electrical signal gives the electrodes that are activated by light a high level of photosensitivity while controlling the timing of the stimulation just like in a normal eye.

6. DESIGN, MANUFACTURING, AND IMPLEMENTING CONSTRAINTS

While the new technology may be effective, there are several constraints that are experienced and these are related to design, manufacturing, and implementation. In regards to design, the designing of the nanowires is complicated and designing single nanowires is often difficult. In addition, the nanowire technology is complicated as it is required to suit the retina of each individual and this will prove challenging in designing the nanowire prosthesis. Furthermore, common in any prosthetic is impact of the material on the body and this may pose a challenge especially during the implementation of the technology. Moreover, implementation requires the approval by specific health bodies, for instance, the Food and Drug Administration (FDA) in America. The approval process takes much time and may, therefore, act as a constrain. Since this is a novel method for treating blindness, there are no well-developed manufacturing infrastructure or the manufacture can only be done by a few companies. This generates a manufacturing problem as infrastructure has to be developed. Finally, implementing will also require consumer education and given it complexity, it may pose a challenge to understand.

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