HUMAN MACHINES FOR ENGINEERS

TERM PAPER

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ARTIFICIAL VISION: VISUAL PROSTHESIS

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Abstract: Electronic visual prostheses have made significant strides restoring damaged sense of vision for a victim of inherited degenerative diseases such as age related macular degeneration or retinal pigmentosa. Visual prosthesis is conducted by microchip with photodiode implantation in retina, chip placement or transcranial magnetic stimulation of visual cortex or stimulating optical nerves directly. Retinal implants and optical and cortical implants have been evaluated in humans and have achieved remarkable results [1], detection of motion and distinguishing objects from the sets. This paper will highlight past and present progress in this field as well as some technical challenges and possible solutions for further advancements. Moreover, it provides expected techniques to be developed in the near future. In order to achieve a device that can stimulate the visual system in many locations, issues of power consumption and electronic packaging must be resolved.

INTRODUCTION

Blindness is one of the less feared physical challenges though the field of visual prosthesis is still in a developing stage. The advent of new technologies withholds the hope in blind people to retrieve their vision. Blindness is a medical problem that affects more than forty million people throughout the world. Blindness is result of damage to the optical pathway that focuses light on the retina or damage to the visual neurons that sense light and send visual information to the brain. The common retinal degenerative diseases that result in blindness secondary to photoreceptor loss are age related macular degeneration (AMD) and retinitis pigmentosa (RP)[2][3]. AMD results from a slow degeneration of photoreceptor cells of the retina, ending in its cell death. Though only few AMD patients experience total visual loss [4], it leads to conditions like glaucoma, severe stroke or trauma [5]. RP is a collective name for a number of genetic defects that also result in photoreceptor loss [6]. In general, RP strikes the rod photoreceptor cells first, resulting in poor night vision and loss of peripheral vision. Eventually, cone photoreceptor, which mediates color and daytime vision, are lost. Diabetic retinopathy and glaucoma affect the optical nerves [7]. In diabetic retinopathy, retinal blood vessel abnormalities can prevent nourishment from reaching neural cells in the retina. Various techniques both invasive and non invasive have been developed to restore sight in blind. Addingly, it is not just the matter of treatment, how about watching a movie closing your eyes or beholding texts, images or other visuals along with the normal vision i.e. integrating natural vision with the created screen. A man with multiple visions is the type of technology the world is looking forward in this field. At present, invasive implantations are done on patients only to have black and white flashes of light as vision [8].

OUR EYE

Human eye is a complex structure that detects the physical environment by capturing visible electromagnetic spectrum and converts it into suitable information. Having passed cornea, Aqueous Humour, Crystalline lens, Vitreous humour, light reaches sensitive structure of eye, retina which has rods and cones. Rods handle vision in low light while cones handle color vision. Series of complex reactions when light contacts these types of cells forming activated Rhodopsin that creates impulses in the optic nerve. Rhodopsin is a derivative of vitamin A, whose deficiency causes vision problems. Rhodopsin undertakes transformational change when exposed to light and breaks down into intermediate compounds forming metarhodopsin II. Cell membrane of a rod cell has electric charge. More is the amount of light; more Rhodopsin is activated causing reduction in cyclic GMP that increases this electric charge. Eventually, this electric impulse reaches a ganglion cell through bipolar cells and then passes our optic nerve. Nerve fibers reaching optic chasm from the inside half of each retina cross to the other side of the brain, but the nerve fibers from the outside half of the retina stay on the same side of the brain. These fibers finally reaches back of the brain called occipital lobe where our vision is interpreted being known as Visual Cortex, to help to control eye movements, response of iris and pupils, and behavior. Color to our vision is the result of color responsive pigments for red, blue and green in the cones. Each cone cell is equipped with one of the pigments enabling human perceive any color mixing all the three colors. People usually suffer due to the damage of the retinal cells like ganglion cells or conduction path of optic nerve leading to the vision loss.

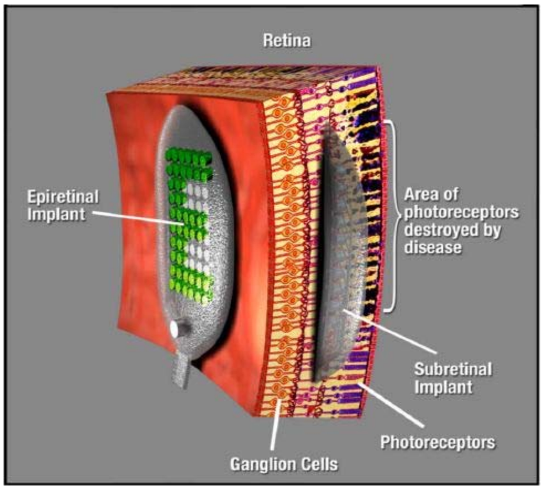
METHODOLOGIES

There are numerous methods developed and pursued to electrically stimulate the damaged vision which can be divided into extra ocular or intraocular devices that are been implanted. Intraocular prosthesis needs the invasive methods to implant devices in visual cortex, retinal or sub retinal surfaces while extra ocular devices are non invasive but less advantageous to have been providing vague alternate vision system.

Retinal Implants

Various clinical trials for retinal implantations in both epiretinal and sub-retinal parts have been performed [8][9]. The main advantage of this implantation is having all the thermal sourcing devices kept away from the retina. Though the electrical stimulation of optic nerve is final destination, there are passive devices that use electromagnetic energy conversion [10] and active devices that give external power [9]. Epiretinal device may be big and complicated powering and transfer of data methods while sub-retinal implants are placed contact with surviving neurons i.e. bipolar cells. The electrical impulses produced by implants activate the membrane potentials of retinal neurons that are in contact thus imitates retinal visual images normally stimulated by retina. Subsequently, remaining Neuro-retinal networks do the visual signal processing.

Passive Retinal Implants make use of integrated circuits to be placed underneath the retina. These microchips have huge number of micro-photodiodes that generates current pulses depending on the amount of incident light on the photodiode. As RP composed of photoreceptor outer and inner segments damaged, inner retina comprising bipolar, horizontal, amacrine and ganglion cells has to be spared [3]. As a result, Semiconductor micro-photodiode array chip or artificial silicon Retina microchip [10], is implanted in the sub-retinal space. This chip provides the platform for light powered electrode tipped micro-photodiodes (MPD) all being independent. The latest developed MPD wafer is 3mm square microelectronic chip having 1500 light sensitive pixels [8]. These wafers have photodiodes that generates electric current and delivered to the neuronal network via micro electrodes. Since, electrode and tissue coupling is capacitive in nature, only transient signals may be used for stimulation. Hence, high capacitance of the interface between electrodes and tissue is mandatory for efficient charge transfer [12]. Non –zero electrode polarization is evaded by the employment of an active current sink in order to draw current to discharge the electrode capacitance. The output voltage of the photo-diodes does not exceed the safe polarization limit i.e. voltage drop across electrode interface



This shows epiretinal and sub retinal approaches [18]

must be limited. Power density should also be as low as possible to prevent tissue damage [12].

In **Active Retinal Implants**, epiretinal approach is being used for the placement of ICs. Our system has an image processing sub system that converts the image captured by a camera into an appropriate stimulus pattern. User has the option of adjusting features like zoom, brightness and contrast. An ordinary make the purpose of an eye while challenge of processing the signals demands image processing techniques like edge-detection, enhancement spatial averaging. Edge-detection algorithm is implemented using high-pass filter masks and gradients while edge enhancement algorithm sharpens the edges in the image frame using spatial domain analysis of direct pixels of image [14]. Computational complexity lies in the digital micro processor that we use that stimulate electrodes on the retina. Power and data need to be provided from the external unit. For a retinal prosthesis, stimulus parameters and diagnostic information has to be transferred [13]. Power telemetry system is used for wireless power transmission for the chip as wired communication to retinal implant causes infection. Power requirement would be 300mW if all the channels active [18]. Power transmitter,

Cascaded resonant tank, diode rectifiers, reverse data telemetry and regulators combine to give voltage levels 2.5V-12V. Cascaded tank receives the wirelessly transmitted wave which is rectified into dc voltage. Regulators are used to give constant dc voltage removing ripples produced by fluctuating coupling coefficients of the power coils [16]. Reverse telemetry is used to send information from implant side to external units acting as a feedback system [17].

Fabrication- Implants are prepared of a doped and ion-implanted silicon substrate disk to produce a PiN junction. A photomask is used to ion-implant shallow P+ doped wells into the front surface of the wafer, separated by channel stops in a pattern of individual micro-photodiodes. An intrinsic layer is formed at the boundary between P+-doped wells and N-type substrate of the wafer and the back of the wafer is then ion-implanted to produce an N+ surface. Silicon nitrate is deposited in the front of the wafer, covering the entire surface except for the opening. A transparent electrode layer of gold, iridium or platinum is deposited on the front well while back is grounded. Current density at each individual micro photodiode subunit can be raised by increasing the photodiode collector to electrode area ratio [11].

Main concerns of retinal implant are power, stimulation efficiency, and lifetime. Efficiency of vision can be improved by increasing number of electrodes. Each electrode of a retinal stimulating array must be capable of supplying an effective stimulus current around 50mA for 1ms [13] that will elicit a phosphene. Also, there should not be any net charge accumulated on the electrode to prevent corrosion and gas formation as it may introduce field intensity in between stimulatable tissue and electrode whose effect depends on the electrode diameter and distance between them [15]. Excess charge density at the electrode can be reduced by recessing the electrode into the carrier, creating an active electrode surface at the bottom of a well, and by flaring the opening of the recess. Electronic packaging must be developed to protect the active components from the corrosive saline environment in the eye. First, electronic modules consisting of ICs, off chip components like capacitors, diodes and inductors are placed inside a capsule filled with an inert gas. Second, thin film is used to coat entire electronic module. Organic materials films like epoxies, silicones and polymers including parylene and inorganic films are used for coating [18].

vOICe

This deals with the technical feasibility of replacing human vision by human hearing through equipment that translates images into sounds. It is a non invasive method to sight. The vOICe vision technology for the totally blind person gives the experience of live camera views through image to sound renderings. The lateral occipital tactile visual area (LOtv) is activated when objects are recognized by vision or touch. LOtv is also activated in sighted and blind humans who recognize objects by extracting shape information from visual to auditory sensory substitution sound scapes [19]. The major equipments made use are two cameras for measuring image depth, micro processor, and ear phone. Micro processor takes care of the job of digital image processing and image to sound mapping. Here, a time multiplexed mapping is performed to distribute an image in time. Two dimensional spatial signal is transformed into a two dimensional map of oscillation amplitude as a function of frequency and time. Image captured is digitally stored and there is a synchronization clock to mark the beginning of new image. The mapping translates each pixel where conversions comprise vertical position into frequency, horizontal position into time after click, and brightness into oscillation amplitude of sinusoidal oscillator operating at frequency range [20].

The sound patterns corresponding to simple shapes are trained to imagine. Hence, learning barrier has to overcome for the sound to image mapping before gradually improved to see complicated image. Human hearing system operates around only about 4-5 kHz as efficiency decreases for higher and lower frequencies. Entire communication has to be accommodated within this bandwidth. This system of Artificial Vision makes use of another sensing system comprising on hearing crosstalk of vOICe and normal sounds. The merits of vOICe are that they are small and portable and it can be even used by born blind people. They can be improvised by increasing processors speed and installing training for device. Device can make use of a Neuro Fuzzy controller to learn from blind case's feedback by asking him to depict the perceived shape /image and make a fine decision. A deaf blind person is liable to have a disadvantage.

Visual Cortex

Localized electrical stimulation of the human visual cortex can excite visual percepts called phosphene in the case of cortical visual prosthesis. The pain crop up in meningeal or scalp if non invasive stimulation, directing more current as required, is performed. Consequently, implantation of floating micro electrodes is placed within the visual cortex with tips of the order of neuron. This Intra Cortical Micro Stimulation (ICMS) has higher density of micro electrodes and lowered power with the decrease in the current per electrode as these are closer to the neurons [21]. This artificial vision system has got a lot of similarities with vOICe system. This model has mainly three parts: graph coding, electrode coding and matching between preprocessed and mental image [22]. In Graph coding, natural image captured from the camera is processed using algorithms like compressing and edge detection. This image is converted into suitable pulse signal to stimulate the mental image and matching sub model is used to make out a reasonable matching between mental image and original image. It makes use of methods like neural networks, fuzzy system to make the system intelligent for which training is done to note from blind volunteer the phophenes or in handwriting way. Training adjusts knowledge base that helps in establishment of one to one corresponding relation between preprocessed image and virtual image formed in the visual cortex providing pattern matching. This uses an invasive method to place the chip having electrodes in the visual cortex. Though it has the advantage of production of phosphene, the surgical procedure for the placement may lead to infection and frequent change of the electrodes [23].

TMS

Artificial vision modeling in the visual cortex can be done by stimulating by the usage of TMS which give less pain for patients being better than Transcranial Electrical Stimulation and chip implantation in the visual cortex. Transcranial Magnetic Stimulation (TMS) is a non invasive tool for studying the human brain. TMS is done by a pulsed magnetic field creating current flow in the brain and exciting specific areas. It can produce even visual phosphene or scotomas [24]. For magnetic stimulation, high current pulse is produced in a coil of wire called magnetic coil that is placed above the scalp and magnetic field is produced with lines of flux passing perpendicularly to the plane of the coil. An electric field is induced perpendicularly to the plane of coil and thus current flows in loops parallel to the plane of the coil. Though precise extent of neuron activation is not known, it varies with the intensity of stimulation. TMS does not activate the neurons directly rather it activates them indirectly through synaptic inputs. Induced currents act the site of activation to the resolution of few millimeters [25]. Thus, this can be well used for providing stimulation of visual cortex placing suitable coils on the scalps and processed captured signals from the intelligent device being sent to coil. There are disadvantages as well such as restricted stimulation limited to mainly surface structures and produce sound and somato sensory stimulation that influence behavior [26].

We have seen various methodologies where research is going on the way to the colorful future for the blind people.

FUTURE TECHNOLOGY

Overcoming of black parts of TMS, it can be made into use for creating newer technologies. Stimulation of visual cortex can be used to generate virtual environment which can present the in front view or 3D view of any place of weight. This makes use of image processing techniques for appropriate 3D conversion from the collection of 2D images captured. This would be a boon for visually challenged cases who have retina damaged or incomplete neural pathway to the brain or both. This system has to make use of multiple cameras around the

This shows multiple vision- normal, texts and visuals

person capturing images incessantly. Images can be processed in a microprocessor of high processor speed that makes computer vision techniques for processing. Processed images are given inputs to the Neuro Fuzzy Logic Control System that helps in making of an intelligent system that gives fine output to the coil. The features of this system are that it takes feedback from the users as a part of training for the device where users are asked to draw the images seen. These inputs modify the system parameters to match the original images with images seen and decisions are taken after the analysis of previous databases. The decision activates TMS system to produce visual phosphenes. This technology can be carried to normal person also. The technology involves the same concept to simulate the virtual environment of any places. But, this requires use of internet scale images that make use of worldwide network. This technology provides the facility to visit to any place in the world virtually sitting at home. Addingly, multiple images integration in the brain to generate visuals along with the normal vision. TMS can be made to use to generate appropriate current to get added with the normal neural current. This technology can be highly beneficial as we would be able to see visuals like texts, images and videos (advanced) along with normal view by using device to be kept on scalp similar to headphones that we keep for the sound effects. This non invasive method just requires TMS mask for the scalp and device for processing. The advancement in the processor speeds and TMS can take this technology to advanced level. TMS has to take care of its accuracy of neural pathway, side effects like pain, and sounds due to sudden coil deformation. Other challenge is that it would be perfect by the long term use being an intelligent system and a fine system for one need not be perfect for all. This pioneering methodology has exciting future and may lead to a much improved quality of life for people.

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