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Prospects of Implantable Micro-System Technology and Experience in the Artificial Vision System

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1. Introduction

The field of integrating a dysfunctional biological subsystem with microelectronic systems is fastly emerging. Implantable or wearable microelectronics enable monitoring of physiological conditions and can even perform lost biological functions. Some success has been obtained, including the cochlear prosthesis, and implantable stimulators to alleviate pain and reduce the unwanted tremor associated with diseases such as Parkinsons. Implantable/wearable microelectronics could also augment the existing human senses such as hear, see, feel, smell, and taste beyond the current abilities of human body. This ability would be useful for individuals in hostile environments, such as soldiers and firefighters, or for doctors performing microsurgery. In order to capture this apparent wealth of opportunity, many barriers for the core implantable technology development must be overcome. Implantable microelectronics share common requirements such as telemetry, hermetic packaging, bio-compatibility, electrode interface. Thus the intra-ocular prosthesis project can be used to demonstrate the research issues and perspective of the implantable technology.

The Hopkins - NCSU intra-ocular prosthesis project was conceived a decade ago and is a multi-disciplinary effort toward an implantable prosthetic device. The rehabilitative device is designed to replace the functionality of defective photoreceptors in patients suffering from Retinal Pigmentosa (RP) and Age-Related Macular Degeneration (AMD). Due to the size of the intra-ocular cavity (2.25cm in diameter), very delicate, but fragile, tissue-paper like thickness of the retina (100-300um), and the fact that the eye is mobile, a retina implant poses difficult medical and engineering challenges. All of these factors and constraints must be taken into consideration in the engineering research of efficient power/energy mechanism, bio-compatibility, hermetic sealing, reliable device attachment, the interface of living tissue and material, electrode material and design, device miniaturization, signal bandwidth/transmission. The teamwork of medical doctors and engineers has maintained much steady progress in physiology, clinical, and engineering since then.

2. Implantable Microelectronics

Chronically implanted devices employing a micro-biosensor and actuator can be diagnostic and therapeutic. For example, a smart device could respond to changes in metabolic rates and adapt to the patients current physiological status, automatically release the proper dosage of a therapeutic medication. The keys toward an efficient and successful implantable microelectronics are the miniaturization with extremely low power dissipation as well as bio-compatibility. While implant durability is one concern, bio-compatibility is a major problem due to the body's ability to reject implanted materials as foreign objects. The packaging problem of electronics components and electrode array can be eased if both are fabricated on the common substrate. An implantable device with some degree of smartness and mobility requires an integration of wireless and information technology. Thus implantable electronics provides a significant challenge in material, device fabrication, and design technology.

Implantable microelectronics share common requirements, it is possible to realize systems for several applications with the same basic architecture. Various applications involve changing the type of sensors or actuators (chemical, electrical, optical) and may require special micromachined interfaces including microelectrodes, microfluidic channels, and membranes for chemical sensing. The core implantable technology include bio-compatible material, interface of device and living tissue, miniaturized passive and active devices, hermetic sealing/packaging, energizing mechanism, heat and EM propagation modeling in living systems, wireless link of distributed sensors and actuators, signal processing, etc. Clearly the advances of micro- and nano-fabrication would greatly benefit the development of the core implantable technology. Thus, with the ultra low power CMOS microelectronics, advances in micro-fabrication and MEMS technology, these implantable technology will eventually enable the realization of an integrated system for stimulation and data collection of electrical and/or biochemical activity over long time scales in freely moving subjects.

3. Intra-Ocular Prosthesis

Blindness robs millions of individuals of the keen sense of vision, leaving them in perpetual darkness. Several groups around the world are evaluating the feasibility of creating visual perception by electrical stimulation of the remaining retinal neurons in patients blinded by photoreceptor loss [1-3]. Artificial vision as provided by the prosthetic system of a multiple-unit artificial retina chipset (MARC) implanted within the eye holds a promise to restore useful vision to a large subset of patients who are blind from retinal disorders. The system would have an external camera (mounted in a glasses frame) to acquire an image and convert it into an electrical signal. This signal would be wirelessly transmitted to an implanted chip, which would electrically stimulate the non-degenerated cells of the retina. The pattern of electrical stimulation would be controlled to produce the perception of an image. Hence, the sense of vision could be partially restored with such an implantable electronic device. Figure 1 illustrates the concept of a prosthetic device.

Patients blind from RP and AMD, two prevalent retinal disorders, could regain vision with MARC is developed. AMD is the leading cause of blindness in individuals 60 years or older, with 200,000 eyes left legally blind each year. RP has an incidence of 1 in 4,000 and in the US alone afflicts 100,000 people. Currently, no treatment exists for either RP or AMD. We have shown that in these diseases despite near total loss of the photoreceptors, the remaining retinal neurons remain intact. Prosthetic device provides a way to jump-start these remaining awaiting neurons and thus create the sensation of vision.

3.1 Experiments

In 15 blind human volunteers tested, we have shown that the remaining neurons in a non-seeing eye can be activated by an electrical signal, resulting in the perception of light. The human tests were performed in an operating room, where, under local anesthesia, different custom-built stimulating microelectrode arrays were placed into the eye of a blind subject and positioned near the retina. Then patterns of electrical signals, generated by an external computer, were applied to the retina via the electrode arrays. The subjects were asked to describe the resultant perceptions. Once we were able to get patients to see one discrete spot of light localized to the retinal area being stimulated, the next question was could we create an image by eliciting the perception of multiple spots of light (i.e., akin to how a dot-matrix printer creates images)? Could the brain make sense of more than one artificial signal at a time or would the spots of light merge into an incoherent blur? Using a 25-electrode array, we stimulated at first rows and columns of electrodes and then patterns of electrodes outlining a large letter or simple geometric shapes such as a rectangle. In all our experiments it took several minutes before the patient could confidently identify the artificially created spot of light. Once they recognized the first dot of light they made quick progress. As expected, the 25-electrode array provided poor resolution, however, it was sufficient for all the patients tested to date to see forms such as a large letter and simple geometric shape.

3.2 Progress Results

Our human tests have also demonstrated that the artificial vision created by controlled electrical stimulation of the retina has color although as of yet we do not have a firm understanding on how to reliably elicit seeing one color over another. We could also set the stimulation frequency at a sufficiently high rate so that the perceptions would not flicker but instead appear continuous. Our results from tests in blind human volunteers demonstrate that form vision is possible using controlled pattern electrical stimulation of the retina. In order to determine the degree of visual acuity that is possible with such an approach, an implantable MARC is currently being developed so that the patient can become accustomed to processing a new type of visual input.

Concomitant with the human tests, we have been engineering a MARC, a completely implantable system capable of creating hundreds of individual spots of light. Through a large number of electrodes, the retinal stimulation pulse has to excite the neurons but not damage them. To date, we have developed a chip that is 4x4 mm and can stimulate 100 electrodes with a safe and effective charge. Other system components are also under development. Electrode materials are being tested to assess their ability to withstand corrosion within the eye.

Of equivalent importance to the engineering development of the device is the biological testing that will show that a retinal implant is well tolerated in the eye. Procedure of attaching a device to the delicate, paper-thin retina must be developed. We have investigated the usage of alloy tacks, magnet, and bio-glue. Experiments in progress will examine the effects of electrical stimulation on the retina.

4. Conclusion

The artificial retinal prosthesis is a complex project, bridging the fields of optics, material, microelectronics, retinal surgery, electro-physiology, and psychophysics. Our team consists of medical doctors, scientists, and engineers each of who brings a unique and necessary experience that will enable the development of the retinal prosthesis system. The initial human tests and engineering developments have generated a great deal of excitement not only in the scientific community but also in the mainstream media. While the implantation of a retinal prosthesis would be a significant achievement, it would mark only the start of more research. Expected advances in microelectronics will allow more sophisticated implants. Image processing algorithms will enhance the electronically created perception. The experiments should lend insight into the actual functioning of the human retina. The feedback gained by these studies should provide a vehicle for further understanding of the retinal/vision/perception process. The implications of this research may extend beyond this immediate project, as contributions are made to the overall field of chronically implanted prosthetic devices, telemetric monitoring and control, and hermetic packaging

References

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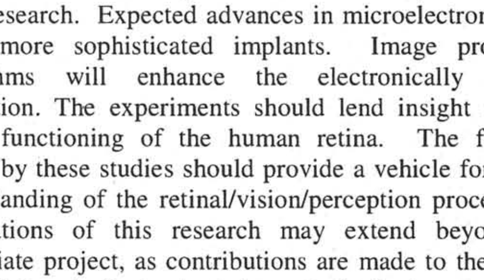

Figure 1: A Conceptual Retinal Prosthesis