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Retinal Prostheses: Basic Introduction, Current Technology Investigate and Future Outlooks

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Abstract:

This passage would briefly introduce the Retinal Implant technology from three aspects: System, structure and signal processing of the Retinal implantation, reviewing on several existing specific example in the market, also comparing and contrasting them and making possible suggestions of future developing pathways.

Keywords: Brain Machine Interface; Medical Protheses; Artificial Sight; Disability Recovery.

CCS Concept:
Computer systems organization
Medium Relevance
Embedded and cyber-physical systems
Sensors and actuators
Sensor networks

1. Introduction

Eyes or the ability to see things comes together with most of the people in the world as they were born, but some people lost their sight before they are born or in accidents or diseases. According to a statistic result published by John Elflein, in 2020, 43.28 million people are blind in the whole world [1]. The loss of vision would cause severe physical or mental problem, causing patients losing their independence, including lacking ability of dodging potential sharp objects, unable to find the path or sense where objects are. What's worse it will also lead to depression and anxiety which will largely invrease the risk of suicide. Actually the blindness is relate to the risk of mortality [2]. Due to this reason, blindness should be solved through technological approaches. One of the recent technologies that gave solution to congenital retinal dystrophies which is a disease-causing blindness, is Retinal Implant, which through the using of retinal prostheses, simulating the regular functioning retina, stimulate optic nerves to reach the goal of recovering from blindness [2].

In the medical field, Retinal implants is a technique used to treat retinal diseases. Photoreceptor cells in the retina convert light into nerve signals that are then transmitted to the brain. Some retinal diseases can cause damage to the light-sensitive cells in the retina, such as retinitis pigmentosa, blockage of retinal blood vessels, and so on, resulting in blindness or vision loss.The purpose of retinal implants is to help restore some degree of vision to patients who have lost their sight due to these retinal diseases. Tiny electronic chips, or arrays of electrodes, are implanted into a patient's damaged retina to help mimic the function of light-sensitive cells.

2. Background Information

Retinal implant is a technology where a retinal prostheses is implanted in the eyeball, replacing the original retina and perform its function of giving electric signals to the optic nerves, hence creating image in patients' brain. The prostheses has to fulfill a few criteria: 1) Providing effective electrical simulation 2) Creating high resolution view 3) activate specific retinal cells to prevent disruption of image 4) Allow diversity of patients [3].

The way how the prostheses works is as the image that the prostheses system aquired would be interpreted and changed into digital signals to the implanted chip. The chip then gives out electric signals to the optic nerve, performing the funtion of the retina.

As technological issues are being solved, it is the best for for treating blindness, the percentage of acceptance rate of retinal implants is not satisfying.Because of the limitation of technology, retinal implant still needs asistance devices in order to gain information and analyzasion of the picture gained and transfer to electric stimulation. Besides from inconvienience, sky-high cost of the device also seems untouchable for most of the patients [4].

The first type of retinal implant that can be approved was the second sight's Argus II Retinal Prosthesis System in 2013 [5]. In the later 10 years, various types of retinal implant technology and approaches has been designed and created, such as sophisticated flexible US-induced retinal stimulating piezo-array (F-URSP) [6], high-density MoS_2-graphene curved image sensor array [2]. Alpha-IMS retinal implant, the latest MPDA based chip implant and more [7].

3. Systems of Retinal implant

The most common system uses the Camera as a information collector, then through a image processor, wirelessly transmit to the chip and the chip then emitt the electric signal to stimulate the optic nerve. however another system that was introduced to the public recently is based of a photo-sensitive chip that directly convert light signal into optic nerve stimulation [8].

Photovoltaic retinal prostheses system, for example the Argus II, has a goggle that has a camera on it that the patient would have to wear in order to obtain information. Also a microelectrode array is implanted which cannot convert light signals directly into electric signals hence needs a image processer that converts light signals into electric impulse, sending the impulse to a periocular implantation which finally transferred the signals to the microelectrode array, creating stimulation to optic nerve, creating an image in the patient's brain [8].(figure 1)

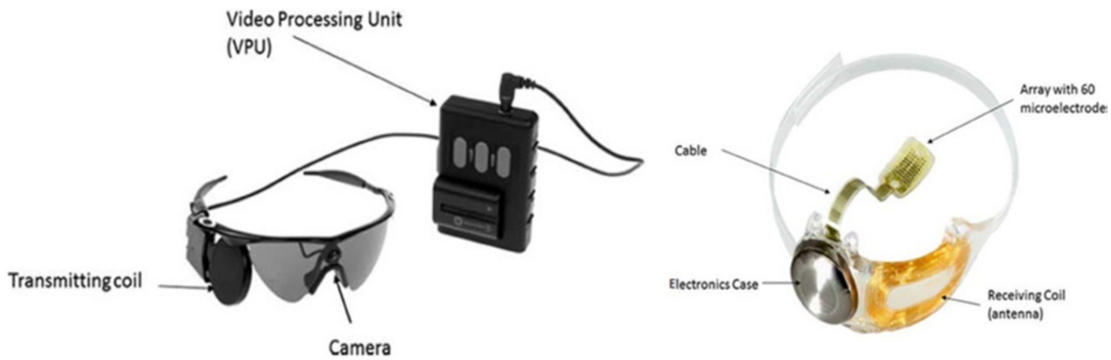

Figure 1. structure of Argus II system

Microphotodiode array (MPDA) based proteses system is a recent technology that was proposed and tested. Through the MPDA chip, light signals could directly be transferred into electric signals which could stimulate the optic nerve [3]. In some cases, the portable power connected to the chip would act as amplifier for light or electric signals to achieve the goal. The chip, connected to a cable was planted to the eyeball. The cable came out under the ear which could be connected to a portable battery as Fig 2. graph shown [7].

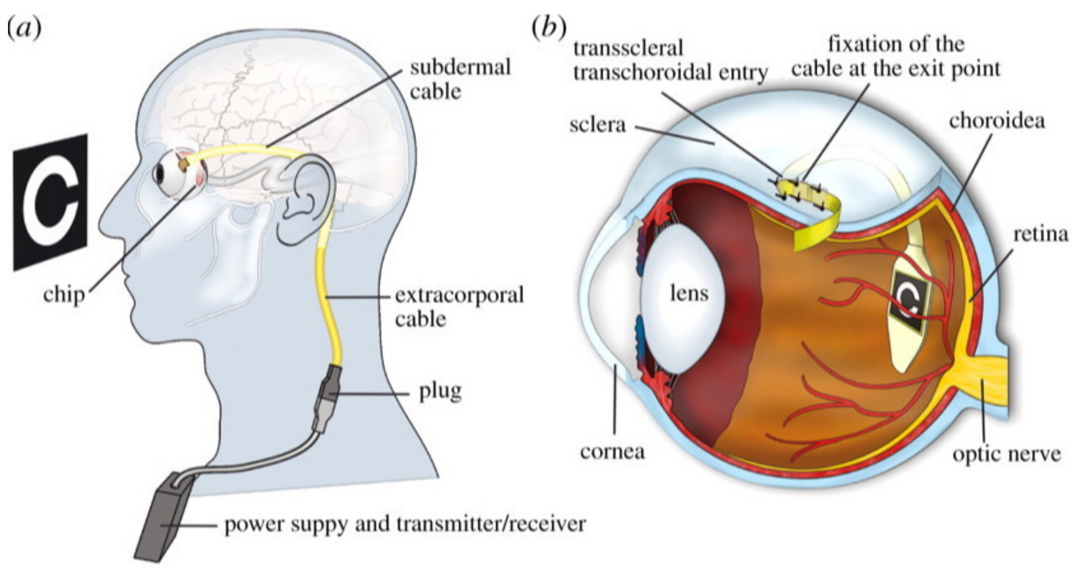

Figure 2 Structure of MPDA system [7]

The MPDA system shows its advantage against the Photovoltaic system by: 1) The system is independent. The protheses would function normally without outer image obtainer, reducing the probablily of losing or breakig gear. [10] 2) The system has less cable implantation, reducing the complexity of implantation surgery, hence reducing the probability of surgurey damage to the eye.

4. Structure of retinal implant

If the outside camera work as the lens to "photograph" and "see",the mircrochip perform the job as the brain. The camera can be divided into two main part: one for imitating the sensing the eye and one for imitating the ability of changing direction of sight line of eye muscle (eye tracking) [11]. For example, the F-URSP [6] that was invented in recent years, is a retinal impalnt which is a sophisticated flexible retinal stimulating piezo-array that shapes like a pair of glasses. The microcamera for videography is located at that position where a usual glasses would connect two lenses. By processing the image record by the camera, the image was transformed into signal and then transferred to the brain those things are in work of the inner machine or microchips.

The inner chip of F-URSP retinal prostheses can also be divided into two parts, which are two circular layer with diameter of 12mm and 7mm. As figure(x) had shown, the bigger layer it was put in the lens of eyes with piezo-array matching layer on the top, with a square having dimension of $8.5\times8.5mm^2$. The piezo-array layer is made by lead magnesium niobate-lead titanate (PMN-PT) single crystal considering its high electromechanical coupling coefficient, high piezoelectric coefficient and low dielectric loss properties. And a passive resin matrix was also putten into it by cutting and filling. to improve the performance of the device. The diamond blade cut the PMN-PT crystals into small PMN-PT rods and the epoxy was dropped and filled into the gap. PMN-PT rods are put on glass substrate closely and small piece of piezo-element is put on the rod. They are squared 1mm×1mm shaped and are separated 0.5mm apart which create the Piezo-array of the chip. When the piezo-array layer gain the ultrasonic beamlines which contains the information of recorded videos in camera, it starts vibrating and generated electric charges.

The small layer lays on the retina of the eye with small stimulating electrodes. Those two layers are connected by a 25mm-long and 4mm-wide flexible PCB. The PCB can be bent and contact the upper layer of eye ball with a semi circle structure. The alternative current produce by the vibrating piezo-array matching layer was transferred into direct current signal and transfer to the stimulating electrodes through the flexible PCB, stimulating neural cells in the retina. And then the action potentials was conducted to the central visual pathway to produce phosphenes and artificial visual percepts [6].(figure 3)

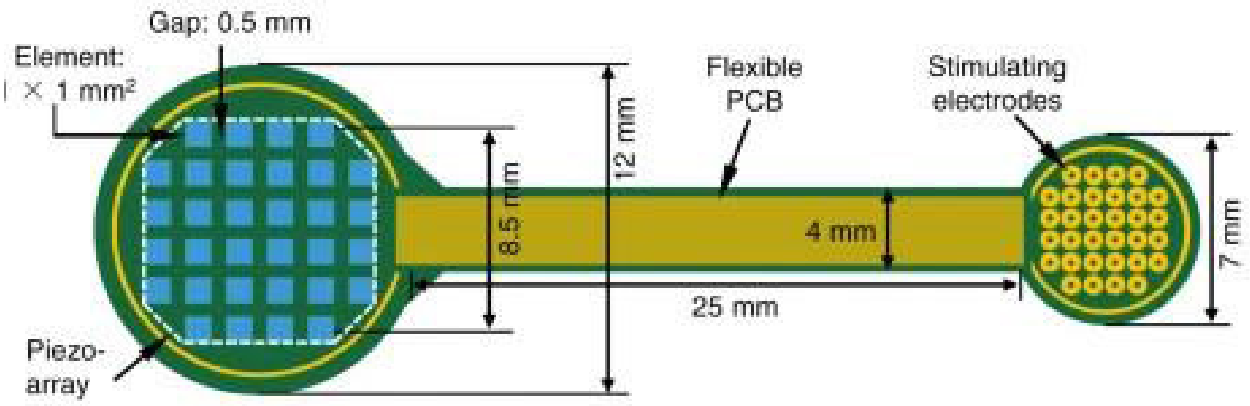

Figure 3 structure of F-SRSP array[6]

Other than the F-URSP, PMN-PT also plays a role in the market. For the PMN-PT, the outer camera slightly differs from the F-URSP, but the inner chip has nothing alike. The PMN-PT not only is material for the arrays of high-density MoS2-graphene, where it also could be the material to create a sensing array. The array has radiating shape constructed by MoS2-graphene heterostructure and other nanomembranes like Al2O3 dielectric, tianium and gold mental gate, Si3N4 substrate. The T-shaped mental gates are put on the graphene interconnection. Under the light, the MoS2 gate will produce photocurrent which is proportinal to the strengh of light. As a result of this, the because of the difference of light strength of objects the different part of the gate will produce different photocurrent. This photocurrent will produce different stimulating to people's brain that help people watch things. This type of array has unique advantages of high-density array design, small optical aberration, and simplified optics [2].

(figure 4)

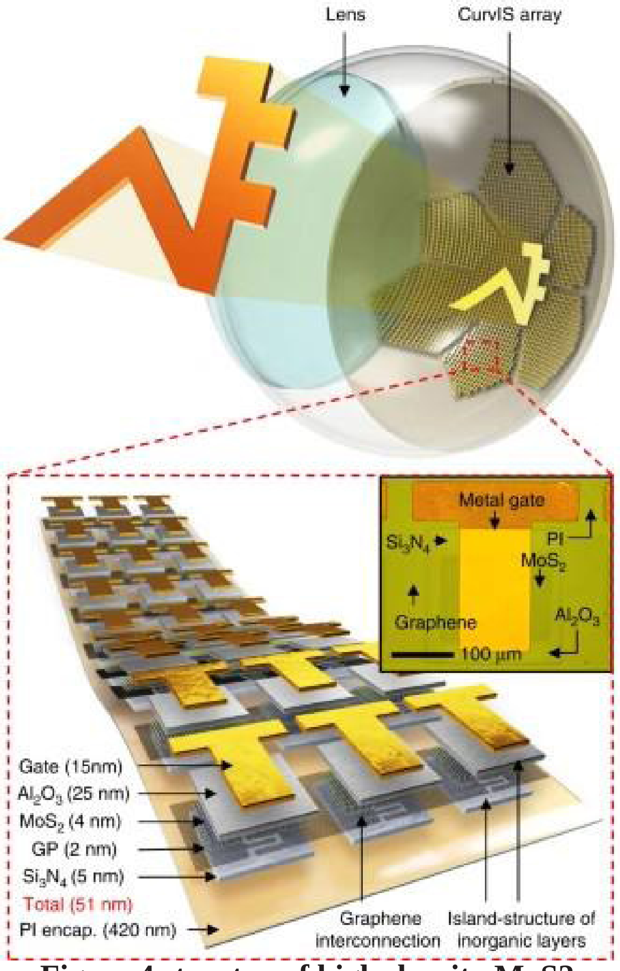

Figure 4 structue of high-density MoS2-graphene sensor array [2]

5. Signal processing in retinal implantation

Typically, retinal implants are equipped with a vision processor or wearable camera to capture visual information from the outside world and convert it into an electrical signal, which is then transmitted wirelessly to the implant. The implant converts the electrical signals into nerve impulses that stimulate nerve cells. The production of visual perception transmits neural conflict through the optic nerve to the visual cortex and then to the brain. But such visual perception can only help patients perceive changes in external light, or simple Outlines of objects, which are often blurred. The mechanism of signal processing is very complex, including image acquisition, image analysis, feature processing, information coding, wireless transmission and so on. Coding and decoding, which translates electrode stimulation into code that the brain can understand, is also a prominent challenge.

The technology used for signal processing in retinal implants involves many fields. In order to transmit the electrical pulses collected by the micro-electrode arrays or micro-photodiode arrays implanted in the retina accurately to the visual cortex of the brain, the following signal processing technology is commonly used in retinal implants:

The first is visual signal acquisition and pre-processing, usually using the technology of Internal light-sensitive photodiodes.

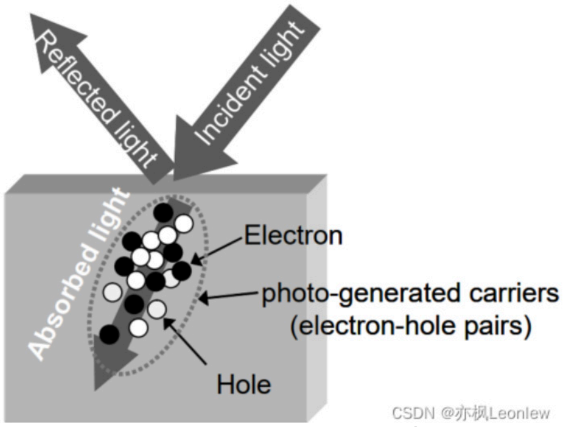

Figure 5 signal retain process of electrode

In retinal implants, Light-sensitive photodiodes is important for acquisition and transmission of visual information. When the semiconductor receives the incident light, part of the incident light is reflected, the rest is absorbed by the semiconductor material, and the electron hole pair is generated inside the material, and the current is formed. The light signal is then converted into an electrical signal and transmitted to the brain [12]. (figure 5)

One of its applications is The Alpha-IMS (Alpha-IMS is a retinal prosthesis with an array of low-light diodes under the retina), which acts as a receiver for visual information, usually in the form of a microelectrode array in the implanted device to collect visual information. The Alpha-IMS array consists of 1,500 pixels, each containing a photodiode to sense light intensity, an amplifying circuit, and an electrode to transmit electrical pulses to adjacent layers of the retina. The amplitude of the pulse transmitted by each pixel is related to the brightness of the incident light at the pixel point [13].(figure 6)

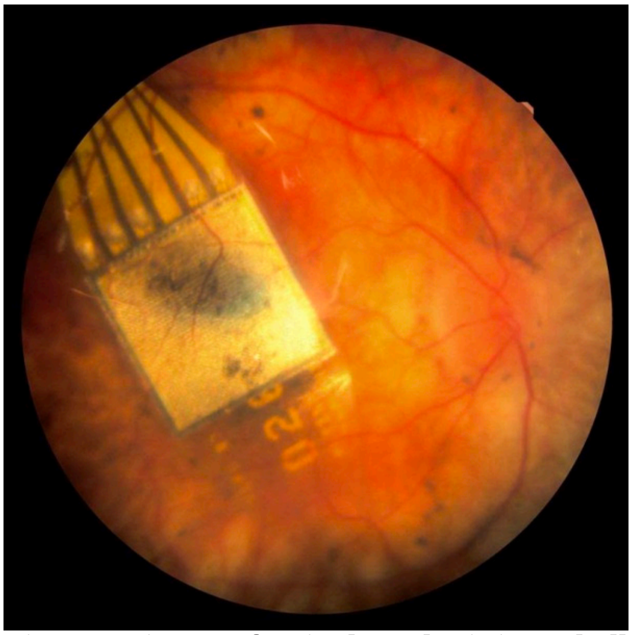

Figure 6 picture of retinal prothesis in eyeball

The next part is the signal processing and coding of the electrical signal. A VPU (Visual processing Unit) is used, which plays a different role than photosensitive photodiodes in retinal implantation.

The VPU is responsible for real-time signal processing and decoding of the electrical signals collected from the photosensitive diode array. It converts light signals into image information that the patient can understand and transmits it to the visual cortex of the brain, allowing the patient to perceive external visual information

The purpose of decoding is to convert the implanted electrical signals into image information that the patient can understand. The purpose of coding is to convert the image information into a form suitable for transmission to the brain. The signal being coded and decoded then transmitted to the brain. With the help of the retinal implant, the patient's brain receives these electrical signals and interprets them as visual information, which activates the brain's visual cortex and allows the patient to perceive external visual information.

6. Conclusion

To conclude, the overall technology of retinal implant has much space to improve. The system still requires improvement in resolution in terms of the images that was formed in the patient's brain. Though there are still lots to improve, retinal implant provided an approach to cure retinal disfunction and obtain sight for patients with retinal disorder. Retinal implant technology did provide us with a starting head of neuro-machine interface, with image processor changing image from the camera into electrical impulse, stimulating optic nerve. With the same way, skins, ears and more sensing organ disorder could be solved. Moreover, using the system oppositely, for example obtaining the neuro impulse and convert to mechenical movement, creating more efficient limb prothesis for those who lost their limbs. Overall, retinal implant opens up a new realm of neuro machine interface in medical situation which is worth discovering and exploring.

References

[1] Elflein, J. (2021, May 21). Number of people with blindness worldwide in 2020, by age and gender. Statista. Retrieved August 15, 2023, from https://www.statista.com/statistics/1237876/number-blindness-by-age-gender/

[2] Choi, H.G., Lee, M.J. & Lee, SM. Mortality and causes of death in a population with blindness in Korea: A longitudinal follow-up study using a national sample cohort. Sci Rep 10, 4891 (2020). https://doi.org/10.1038/s41598-020-61805-6

[3] Wu, K. Y., Mina, M., Sahyoun, J. Y., Kalevar, A., & Tran, S. D. (2023). Retinal Prostheses: Engineering and Clinical Perspectives for Vision Restoration. Sensors, 23(13), 5782.

[4] Karadima, V., Pezaris, E.A. & Pezaris, J.S. Attitudes of potential recipients toward emerging visual prosthesis technologies. Sci Rep 13, 10963 (2023). https://doi.org/10.1038/s41598-023-36913-8

[5] Greenemeier, L. FDA Approves First Retinal Implant. Nature (2013). https://doi.org/10.1038/nature.2013.12439

[6] Jiang, L., Lu, G., Zeng, Y. et al. Flexible ultrasound-induced retinal stimulating piezo-arrays for biomimetic visual prostheses. Nat Commun 13, 3853 (2022). https://doi.org/10.1038/s41467-022-31599-4

[7] Zrenner, E., Bartz-Schmidt, K. U., Benav, H., Besch, D., Bruckmann, A., Gabel, V. P., ... & Wilke, R. (2011). Subretinal electronic chips allow blind patients to read letters and combine them to words. Proceedings of the Royal Society B: Biological Sciences, 278(1711), 1489-1497.

[8] Ghezzi, D. (2020). Translation of a photovoltaic retinal prosthesis. Nature biomedical engineering, 4(2), 137-138.

[9] Huang, T. W., Kamins, T. I., Chen, Z. C., Wang, B. Y., Bhuckory, M., Galambos, L., ... & Palanker, D. (2021). Vertical-junction photodiodes for smaller pixels in retinal prostheses. Journal of neural engineering, 18(3), 036015.

[10] Dowling, J. Current and future prospects for optoelectronic retinal prostheses. Eye 23, 1999–2005 (2009). https://doi.org/10.1038/eye.2008.385

[11] Leonlew. (2022, June 3). Camera and Image sensor Technology Basics Notes (6) -- Photoelectric sensing basics, photodiode related notes. https://blog.csdn.net/vivo01/article/details/124420531

[12] Firl, K. C., Tang, P. H., Montezuma, S. R., Makawi, A., Shah, V. A., Kim, L. A., & Akkara, J. D. Retina Prosthesis.