Journal of Nano- and Electronic Physics
Vol. **17** No 5, 05020(5pp) (2025)

Журнал нано- та електронної фізики
Том **17** № 5, 05020(5cc) (2025)

REGULAR ARTICLE

Microelectronic Stimulator of the Optic Nerves

O.Y. Nebesniuk*, Z.A. Nikonova, A.A. Nikonova

Engineering Educational and Scientific Institute named after Yu. M. Potebni,
Zaporizhzhia National University, 69006 Zaporizhzhia, Ukraine

(Received 25 July 2025; revised manuscript received 18 October 2025; published online 30 October 2025)

We receive about 72 % of information about the world around us through vision, but full perception is possible only if the eyes work together in an equivalent way. One of the pathologies that leads to a violation of the harmony of vision is strabismus. Treatment of eye pathology, including such a serious disease as optic nerve atrophy, involves the use of a whole range of therapeutic measures, which organically include the method of electrical stimulation. Relevance of the topic lies in the application of electrical stimulation of the optic nerves using modern pulse generators to normalize the functioning of binocular vision in patients. This procedure is especially important for people whose work involves prolonged computer use. The article proposes new design solutions for the creation of a device for electrical stimulation of the optic nerves, which, using software with a connected control program, will allow it to function reliably and meet modern trends in vision treatment, as well as make this process much more efficient.

Keywords: Electric current, Eye muscles, Electrical stimulator, Analyzer, Ophthalmological device, Diagnostics, Microcircuit, Generator, Amplifier, Microcontroller.

DOI: 10.21272/jnep.17(5).05020 PACS number: 87.85.Ox

1. INTRODUCTION

During the period of high incidence of various strains of influenza among the multimillion population, nervousness due to the war in our country, periodic power outages, distance learning in institutions of all levels of education, and a large amount of computer work, the number of people with eye diseases has increased significantly. A significant number of military personnel with eye pathology also need rapid rehabilitation, preferably with minimal use of medication.

Therefore, the development of new constructive solutions for creating devices capable of providing effective treatment and diagnosis of eye pathology, especially in young children, has become an urgent problem.

It is known that the human visual organ is designed to perceive light, but visual sensations can be obtained by stimulation with other physical factors: mechanical, chemical agents and electric current pulses. The latter is universal, as it serves as a stimulus to living tissue, so it is easy to dose in terms of intensity, frequency and duration of pulses. To generate pulsed electric currents, generators are used, devices that convert the energy of DC voltage sources into the energy of electromagnetic oscillations of various forms. Treatment of ocular pathology and, in particular, such a serious disease as optic nerve atrophy, involves the use of a whole range of therapeutic measures, which organically include the method of percutaneous electrical stimulation (ES).

Despite the fact that this method has been known for a long time, electrical stimulation of the eye muscles in case of paresis and paralysis has been used relatively recently. Since 1961, it has been used for treatment at the Filatov Research Institute of Eye Diseases and Tissue Therapy in Odesa. In 1964, L.E. Cherikchi and I.V. Klyuka proposed to use it in the complex treatment of strabismus in the clinic of common strabismus, and the Kyiv Institute of Neurosurgery named after Academician A.P. Romodanov of the Academy of Medical Sciences of Ukraine used the method of ultrasound (US) therapy followed by ES of oculomotor muscles to treat patients. The treatment by electrical stimulation of the optic nerves, proposed by V.S. Ponomarchuk and V.S. Drozhenko, is based on the principle of increasing frequency ‘swing’ of the spatial frequency fields of the peripheral parts of the visual analyzer [1].

The effectiveness of using devices for stimulating the eyes with an electrical impulse directly depends on many factors, including the patient's age and the characteristics of the disease. The analysis of statistical data on the treatment of patients using well-known optic nerve stimulation devices showed that a positive result was observed in 60 % of cases (depending on the degree of visual function damage) and lasted from 6 months to 2 years. However, the authors believe that the maximum effect in the treatment of visual diseases can only be achieved with the help of new design solutions in the manufacture of eye stimulators.

Currently, a wide range of companies are engaged in the production of various types of eye care devices. The market for human vision devices is expected to grow steadily as companies continue to invest in smart

* Correspondence e-mail: 0811oksana@gmail.com

Cite this article as: O.Y. Nebesniuk et al., *J. Nano- Electron. Phys.* 17 No 5, 05020 (2025) https://doi.org/10.21272/jnep.17(5).05020

technologies, indicating their importance in modern consumer and industrial applications, and is also driven by several factors such as rapid technological development, increasing automation of various industries, and the growing need for improved safety measures. We believe that the area of expanding sensor technology will also lead to widespread use of such devices as they are integrated into robotics, automotive and healthcare. This expansion will be further accelerated by advances in artificial intelligence and machine vision, which will provide increased efficiency and accuracy.

In 2023, North America led the human vision sensors market with approximately 35 % of the total revenue, followed by Asia Pacific at 30 %, Europe at 25 %, Latin America at 5 %, and the Middle East & Africa at 5 %. Today, the human vision sensors market has been valued at USD 5.5 billion and is expected to reach USD 9.83 billion by the end of 2032, with a projected (CAGR) of 11.6 % over the forecast period (Fig. 1).

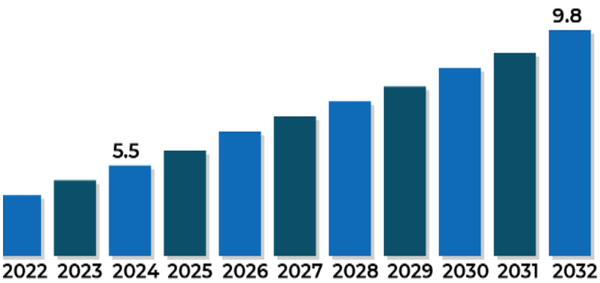

Fig. 1 – Vision sensors market size growth in bin (billion)

2. DESCRIPTION OF THE OBJECT AND METHODS OF RESEARCH

The authors believe that the adaptability and effectiveness of visual devices can be increased by ensuring the development of the following areas:

– technological: to expand the capabilities and applications of human vision sensors through ongoing advances in their technology, such as improved image processing and higher resolution;

– increased automation: improving the quality control and operational efficiency of vision sensors through the use of automation in sectors such as micro- and nanotechnology;

– combining AI (Artificial Intelligence) and machine learning: combining AI and machine learning technology to improve vision sensor performance and enable real-time data processing and decision-making;

– improving safety and quality standards: the accuracy and reliability of vision sensors will ensure quality in industries such as healthcare, automotive and others.

Today, competition in the vision sensor market is intense and companies are focused on product differentiation and innovation. Partnerships between manufacturers and AI developers are becoming more common, further accelerating the pace of innovation. This dynamic interplay of opportunities and challenges continues to shape the vision sensor market. Several key drivers underpin its growth.

One of the most important is the growing demand for automation and robotics in industrial processes. Such devices will provide the precise control and monitoring required to increase productivity, reduce defects and ensure operational efficiency. As industries adopt smart manufacturing practices, the reliance on vision sensors is expected to grow exponentially.

Technological advancements also play an important role in the market growth. The integration of AI and machine learning algorithms has expanded the capabilities of vision sensors, enabling them to perform complex tasks such as face recognition, object tracking, and 3D visualization. In addition, their growing adoption in new applications such as autonomous vehicles and smart cities is opening up new opportunities for market expansion.

As these technologies advance, the need for reliable visualization systems capable of processing real-time data is becoming increasingly important. The use of vision sensors can significantly improve the safety and efficiency of autonomous systems, opening up new markets for manufacturers and service providers. The rapid pace of technological change poses a significant challenge for manufacturers seeking to keep up with evolving standards and consumer expectations.

Such demands require each company to constantly innovate to remain competitive, which can lead to increased costs and resource allocation issues. Disruptions in the supply chain, whether due to geopolitical factors or global events such as a pandemic or war, can affect product availability and prices. Addressing these challenges requires strategic planning and cooperation between industry stakeholders to create a sustainable market ecosystem. Another important factor is the growing need for quality control in various industries. Vision sensors can detect the smallest defects in products and ensure compliance with strict quality standards. This capability is particularly important in sectors such as pharmaceuticals, automotive and electronics, where product reliability is of paramount importance.

However, one of the most promising opportunities is the application of vision sensors in the healthcare sector. As medical imaging technologies advance, dynamic vision sensors can provide enhanced diagnostic capabilities, especially in minimally invasive surgical procedures and real-time patient monitoring. The demand for Telehealth solutions, accelerated by the Covid-19 pandemic, has further emphasized the need for advanced imaging technologies.

Today, the vision sensor market faces several constraints that may hinder its expansion. One notable challenge is the high cost of the manufacturing technology compared to traditional imaging systems. This financial barrier may prevent SMEs from adopting these advanced solutions, limiting market penetration. In addition, the complexity of integrating vision sensors into existing systems requires specialized knowledge and expertise that may not be available in all markets. Many potential users may be hesitant to invest in such devices due to a lack of understanding of their benefits compared to conventional imaging systems.

Therefore, it is necessary to invest in educational initiatives, development and use of new design solutions for the creation of microelectronic optic nerve stimulators to inform stakeholders about its benefits to stimulate wider adoption. Although the market is facing challenges such as high costs and regulatory pressure, the overall outlook remains positive with numerous opportunities for growth and innovation.

An example is well-known companies operating in the market of dynamic vision stimulators: Inivation ag; Samsung; Hillhouse Technology Pte Ltd.; Sony; Panasonic; Teledyne Technologies.

However, the known electrical stimulators use rectangular and sharp-edged generators that do not provide a sufficient level of treatment. To this end, the authors propose a new approach to this problem - the creation of a microelectronic optic nerve stimulator (MESN) using generators with the most optimal parameters, which will provide the necessary frequency interval, and hence the duration of the stimulating pulse, which is very important in the treatment of optic nerve pathology.

Exposure of the human eye to current pulses of only a few tens of microamperes (μA) causes a light sensation in the form of very weak colorless or blue flashes, called electrical phosphene. It was found that the minimum current strength at which electrophosphene appears in the eye is defined as the threshold of retinal electrical sensitivity (RES), with current strengths of 20-70 μA taken as normal values [2].

In healthy people, the RES ranges from 35-80 μA, the critical electrophosphene disappearance frequency is 40-55 Hz, and individual differences are small. The lowest PEC is observed at the age of 20-25 years. In children aged 6-15 years, the RES is increased, which may be due, on the one hand, to the still imperfect development of the neurovisual apparatus and, on the other hand, to the general somato-psychological state of a person: excitability or inhibition, fatigue, and wakefulness [3].

Analysis of the results of domestic and foreign studies has shown that at a pulse current intensity 3-4 times higher than the threshold (250-300 μA), the critical frequency of electrophosphene disappearance reaches maximum values of 50-55 Hz (in rare cases, in a healthy person – up to 60 Hz).

3. DESCRIPTION AND ANALYSIS OF RESULTS

The authors found that during electrical stimulation, an artificial electrical signal replaces a natural nerve impulse and causes a muscle contraction. The resulting maximum muscle contraction can last longer and be repeated more times than with a maximum, arbitrary effort. To avoid slowing down the rate of contraction of the muscle undergoing electrical stimulation, it is advisable to use two modes:

– one ensures the occurrence of slow (tonic) voltages;
– another – fast (physical).

The duration of contractions and the intervals between them must be individualized for each muscle so that they do not cause severe fatigue. When a single threshold or suprathreshold electrical stimulation is applied to a muscle, action potentials, muscle contraction and relaxation phases arise after a latent period. The relaxation phase is 3-5 times longer than the contraction. The phase of muscle contraction is determined by the time from the beginning of contraction to the moment of its maximum voltage.

If electrical irritations arise with an interval at which the muscle has time to relax, then this periodicity is preserved. When the interval between stimulations is shorter, the relaxation phase is shorter, the muscle does not have time to relax and remains shortened at the moment of the next signal, as a result of which its continuous contraction occurs. Under these conditions, the muscle can contract 3-4 times more.

With a gradual increase in the current frequency, the moment comes when a person ceases to feel electrophosphene. This moment is defined as the critical frequency of electrophosphene flicker disappearance and is an indicator of the functional state of the axial (central) optic nerve bundle. The critical frequency of electrophosphene disappearance (lability) depends on the current strength and has a hyperbolic character.

It was found that irritation by pulsed current depends on the amplitude, magnitude, and shape of the pulse. With a significant decrease in the size of the stimulus, the threshold value of its intensity begins to increase. Very short pulses cannot induce excitation at all.

Under the action of a stimulus gradually increasing in intensity, there is a counteraction of the irritated tissue in the form of a decrease in excitation, as a result if which, in order not to lose its excitatory effect, the leading edge of the electrical impulse must grow steeply. The smallest value of the excitation threshold is observed with pulses of a rectangular shape.

To provide such a mode, the authors have developed a microelectronic stimulator of the optic nerve, which consists of the following main blocks (Fig. 2): power supply +9 V; 5 kHz sinusoidal oscillator; tunable oscillator from 5 to 100 Hz; mixer; key; «pulse-pause» generator; amplifier.

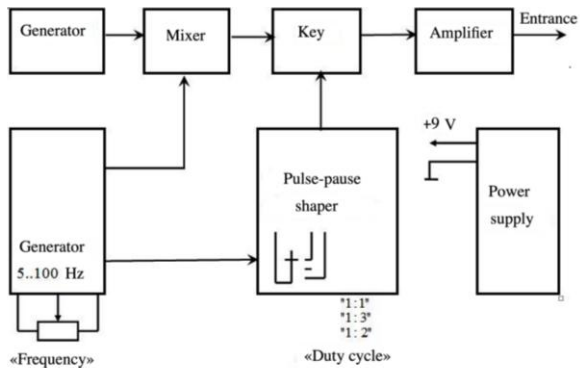

Fig. 2 – Structural diagram of an electrical stimulator

The 5 kHz generator, built according to the Wien bridge scheme, produces a sinusoidal voltage of stable amplitude, which is fed to one of the inputs of the mixer. The second input of the mixer is supplied with an exponential voltage from the generator, the frequency of which varies from 5 to 100 Hz. At the output of the mixer, a high-frequency signal of 5 kHz is formed from a low-frequency bypass, which repeats the exponential form of the 5 ... 100 Hz generator.

The generated signal is transmitted to the key. A «pulse-pause» duty cycle generator is connected to key control input. At the output of the key, packets of pulses are formed with a duty cycle of "1:1," "1:2," "1:3," which enter the output of the amplifier and are amplified to the required level.

The MSZN includes an active electrode that is applied to the skin of the patient's upper eyelid from the nasal or temporal side, depending on where the higher RES was determined. To obtain a therapeutic effect, electric monopolar current pulses are supplied from two generators. The pulse frequency of the first generator should always be less than the second, and range from 1 to 800 Hz, thus ensuring a burst mode of stimulation (frequency – time parameters of exposure are set according to the indications depending on the etiology of the disease).

In the pathology of the optic nerve of post-traumatic and glaucomatous etiology or resulting from vascular insufficiency, it is necessary to use the negative polarity of the stimulating electrode. In the disease of the optic nerve of inflammatory etiology, positive polarity is applied. The size of the stimulating current is 30-100 % higher than the limit value and was established depending on the subjective sensations of the patient. The current intensity either does not change throughout the session or changes cyclically for 1 minute and has a U-shape, in the form of a saw or a bath.

The authors believe that an indispensable condition for stimulation is the inversion of the polarity of the current, which is carried out once every 10 seconds with a pulse of 10 ms. The time of the stimulation session should last – from 6 to 10 minutes. Both eyes are necessarily stimulated. The course of treatment is offered from 10-15 sessions.

The method proposed by the authors using MSZN was recommended for diagnosis and treatment in a hospital in Zaporizhia (Ukraine) for 53 patients (30 men and 23 women) with partial optic nerve atrophy of atherosclerotic genesis.

It was established that, firstly, as a result of synchronous excitation of retinal cells and their fibers, the functions of nerve elements that were functional but did not produce visual information are restored. Secondly, in the visual cortex and in the cortex of adjacent areas, for example, the dark temporal cortex, a focus of stable excitability arises, which leads to the restoration of the activity of nerve cells and their connections, which were previously poorly functioning. In addition, a powerful flow of reverse efference to the retina occurs. Thirdly, due to the improvement of metabolic processes and blood circulation, prerequisites are created for the restoration of the myelin sheath around the axial cylinders of the optic nerve fibers, which leads to an acceleration of the action potential and the revival of the analysis of visual information.

Positive functional and electrophysiological results were also noted: visual acuity increased in 87 % of patients, the field of vision expanded in 67 % of patients, with an average of 104 μA after the electrostimulation course, it decreased to 82 μA and with an initial EL of 20.5 Hz.

The next step was the development of software that allows you to control the frequency of the sine wave generator connected to a personal computer, as well as a program that creates the ability to store patient information in the database, such as the last name of the patronymic, the number of sessions intended for each patient, the duration of one session, the number of sessions completed, the date of the last session. To develop the program, the Delphi programming system was used, where Object Pascal was used as a programming language, because the Delphi ideology is based on the design technology and methodology of object-oriented event programming. In addition to the main module, each program includes form modules that contain a description of the starting form of the module and procedures supporting its operation, which will ensure the accuracy of the operations.

For a long time, at the Department of Electronics, Information Systems and Software a research laboratory of physical and biomedical electronics with a large amount of medical equipment has been operating, it ensures the quality of research, development of new design solutions and training of specialists in the educational program, which includes educational components of medical direction.

4. CONCLUSIONS

Long-term dynamic observation of patients with partial atrophy of optic nerves of various etiologies during treatment with electrical stimulation methods allows us to draw the following conclusions.

1. The proposed microelectronic stimulator of the optic nerves is an effective method of restoring visual functions and can be recommended for use as part of a set of measures in the treatment and diagnosis of various etiologies of the eyes.

2. The use of MSZN in patients with visual acuity less than 0.09 direct stimulation of the optic nerves will be significantly more effective compared to other treatments.

3. The effect of the therapeutic effect of MSZN depends on the degree of disruption of the vital activity and functioning of the nervous tissue, on the number of damaged nerve fibers, on the prevalence of damage to the visual pathway and to a lesser extent on the etiology and duration of the pathological process.

4. It is advisable to reuse MSZN once every 6-12 months to stabilize the achieved effect and to further improve visual functions.

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Мікроелектронний стимулятор зорових нервів

О.Ю. Небеснюк, З.А. Ніконова, А.А. Ніконова

Інженерний навчально-науковий інститут імені Ю. М. Потебні, Запорізький національний університет, 69006 Запоріжжя, Україна

Близько 72 % інформації про навколишній світ ми отримуємо через зір, але повноцінне сприйняття можливе лише за умови рівноцінної співпраці очей. Однією з патологій, що призводить до порушення гармонії зору, є косоокість. Лікування патології очей, зокрема такого серйозного захворювання, як атрофія зорового нерва, передбачає використання цілого комплексу терапевтичних заходів, до яких органічно входить метод електростимуляції. Актуальність теми полягає в застосуванні електростимуляції зорових нервів за допомогою сучасних генераторів імпульсів для нормалізації функціонування бінокулярного зору у пацієнтів. Ця процедура особливо важлива для людей, чия робота пов'язана з тривалим використанням комп'ютера. У статті запропоновано нові конструктивні рішення для створення пристрою для електричної стимуляції зорових нервів, який, використовуючи програмне забезпечення з підключеною керуючою програмою, дозволить йому надійно функціонувати та відповідати сучасним тенденціям лікування зору, а також зробить цей процес набагато ефективнішим.

Ключові слова: Електричний струм, М’язи ока, Електростимулятор, Аналізатор, Офтальмологічний прилад, Діагностика, Мікросхема, Генератор, Підсилювач, Мікроконтролер.