Visual control and data transmission system by Li-Fi technology for patients in a vegetative state/unresponsive wakefulness syndrome and minimally conscious state

S A Degtyareva¹, E A Kondratieva², I G Smirnova¹, I S Polukhin¹, Y S Andreev¹ and V E Bougrov¹

¹Faculty of Laser Photonics and Optoelectronics, ITMO University, 49 Kronverksky prospect, Saint-Petersburg, Russia
²Polenov Neurosurgical Institute, the Branch of Almazov National Medical Research Centre, 12 Mayakovskaya street, Saint-Petersburg, Russia

E-mail: s.degtyareva94@gmail.com

Abstract. Due to the development of high technologies, there is a need to use computer systems to support the increasingly complex types of human activities. It provides high accuracy and speed of various research and medical examinations. Taking into account the daily workload of doctors in the Intensive Care Unit, remote medical diagnostics systems are being implemented in many referral hospitals to predict the course of diseases. Decision-making is the result of processing certain information, the medical history patients based on the use of accumulated knowledge. Therefore, it can be concluded that automatic and visual control systems make the diagnosis process more accurate and easier. The aim of the work is to develop an optoelectronic system for visual monitoring and data transmission for patients in a coma by Li-Fi technology.

1. Introduction

The concept of Li-Fi technology is currently attracting a great deal of interest in many research areas. Medical practice is one of them. The principle of Li-Fi (Light Fidelity) is to change the light intensity of the LED light bulb at a very high speed. The LED intensity is modulated so rapidly that human eyes cannot notice. Currently, the transfer rate for Li-Fi technology is 10 Gbit/s using various types of modulation [1-3]. One of the most important advantages of Li-Fi is that it could be used in hospitals and medical settings that require the lack of RF signals which affect the medical equipment. Wirelessly transmitting data from the patient to the machines cluttering hospital rooms creates the risk of electromagnetic interference. For example, a group of researchers in South Korea proposed that some machines use Li-Fi. The team used visible light communications to transmit readings from an electroencephalograph over a distance of about 50 centimeters [4]. Thus, the implementation of wireless data transferring from medical devices exempt patients from large number of cables during surgery or other procedures and avoids interference on a crowded radio spectrum.

Li-Fi technology does not use the radio frequency spectrum and can be used where Wi-Fi is not available. Another important advantage of technology is high security: because of the signal will not spread through walls, it is difficult to intercept that. Due to its advantages, Li-Fi has a lot of life applications.
The aim is a Li-Fi-based optoelectronic system for visual monitoring of vital signs from bedside monitor and transmission of its changes in cases of emergency.

2. Medical preconditions
A coma is a deep state of prolonged unconsciousness as a result of traumatic brain injury, stroke, brain tumor, diabetes or an infection. But coma usually lasts for less than 2 to 4 weeks in itself, then a person may wake up into a vegetative state/unresponsive wakefulness state (VS/UWS) or minimally conscious state (MCS). Patients in VS/UWS and MCS either do not perceive reality at all or perceive it partly. It requires operative action to preserve life and brain function as well as visual controlling of basic physical clues such as heart rate, pulse, body temperature.

The continuous visual-based monitoring of the VS/UWS and MCS coma patients could be more convenient and comprehensive, cause the usual monitoring process can lead to tough load for medical health cares. Imaging techniques, including functional magnetic resonance imaging, FDG positron emission tomography are proven to be useful in determining the diagnosis of VS/UWS and MSC [5]. However, diagnosis of the VS/UWS and MSC should be based on a patient’s clinical history and on simple visual observations as well. In this context the development of blanket with established light-emitting diodes allows to facilitate control process, that is commonly used in Intensive Care Unit, Critical Care Unit and Emergency Rooms of hospital. Thus, in the emergency cases, doctor is able to monitor patient condition efficiently to reduce time consumption.

3. Method

3.1. Monitoring system for patients in a coma by pain assessment
A diversity of pain for patients with prolonged disorders of consciousness (PDOC) - VS/UWS and MSC is defined by the International Association for the Study of Pain (IASP) as unpleasant sensory and emotional experience related to real or potential tissue damage…» [6]. It raises the question of whether sensory or emotional experience is possible for such illnesses. It is obvious that the conscious perception of pain in this category of patients is non-existent. Simultaneously, some processes which are afferent signals of pain are constantly presented in a patient with congestive heart failure. They are spasticity, contractures, calcifications and poyneuromyopathy.

One more issue is the influence of nociceptive afferentation without pain experience on the possibility of consciousness recovery. Traditionally, pain therapy is aimed at stopping pain experience. Assuming that patients with heart failure feel no pain, the stabilization of autonomic parameters may be insufficient. The main task to solve this issue is studying the functional features of the central nervous system. The group of patients highlighted in recent years with the phenomenon of “covert consciousness” is of particular interest. During the studies of the response to pain stimulus (PS), the informative significance of the scale for assessing pain in patients in a coma and device for the study of cardiac interval using the ANI monitor were studied (analgesia-nociception index). ANI monitor was used for 29 patients with congestive heart failure (9 patients in a VS/UWS and 20 patients in MCS). The age of the patients ranged from 22 to 56 years (the average age is 34.75 ±11.54).

The average value of the ANI index for patients in a VS/UWS is - 67.44 ± 10.73 before PS, 49.55 ± 14.49 during PS, and 73.66 ± 10.48 30 minutes after. The average score on the scale for assessing pain for patients in a VS/UWS during PS is 1.44 ± 1.07. The average values of the ANI index in patients in MCS: 66.25 ± 14.11 before, 45 ± 16.12 during PS and 66.55 ± 18.1 after. The average score on the pain scale in patients in MSC during the PS is 3.6 ± 1.83. A comparison of the average values of the ANI index between two groups of patients before, during PS and 30 minutes after PS did not reveal statistically significant differences (p> 0.05).

Thus, the same dynamics of changes in the ANI index was noted both in the initial and in response to PS. The initial value of ANI index was higher than 66.25, indicating the absence of pronounced vegetative reactions in the dormancy paradigm.
A special jacket based on light-emitting diodes for visual control according to ANI range of values was created as a first prototype. The visual control system, integrated in the ANI-monitoring scheme was tested in the Intensive Care Unit in Polenov Neurosurgical Institute. It was found that the ANI index is 10 minutes ahead of the change in hemodynamic response parameters within nociceptive stimulation during general anesthesia. So, in conclusion, the visual control system allows to make the process of informing about timely medical intervention faster.

3.2. Visual monitoring system by characteristics from bedside monitor
Further it describes controlling action and the design of visual control and data transmission system with continuous monitoring using bedside monitor.

The framework of visual control and data transmission system is presented.

![Figure 1. Design of visual control and data transmission system.](image)

Bedside monitor controls at least 6 curves simultaneously: electrocardiography, pulse oximetry, non-invasive measurement of blood pressure, continuous non-invasive measurement of blood pressure, impedance method of measuring respiration parameters, thermometry. Data is transmitted from the monitor via a USB cable. The current offer is monitor by Triton company MPR06.

Simplex connection from bedside monitor to Li-Fi control module with adaptive colour emission is realized via Ethernet UDP protocol. Data are processed in the control module, which consists of Ruspberry model 3+ microcomputer, a power supply and a signal amplification board. The control module is responsible for signal modelling and generating a protocol coming to light-emitting diodes on a blanket. Light-emitting diodes on the blanket are divided into several groups and show the main vital signs: heart rate, arterial oxygen saturation and body temperature difference. Colour scale on blanket depending of the values has been developed to allow observing not only on a screen, but visually as well.

The set-up is shown in the figure below.
Light-emitting diodes have a permanent lighting effect in the absence of critical changes. In case of changing one of them, the group of diodes lights up in red, infrared diodes transmit information via infrared light to the photodetector module. Arduino receives a signal coming from the photodetector and send it to the local network.

3.3. Methods for measuring in bedside monitor
The principle of operation for cardiometry module is based on measuring cardiac action potential using electrodes on the surface of the patient’s body. The electrical signals are converted into an ECG after processing, which is displayed on the monitor screen and used to calculate heart rate.

The principle of operation for the thermometry module is based on measuring the resistance of the temperature sensor. The resistance of a thermistor is measured using electrical circuits and converted to a temperature value displayed on the monitor display.

Arterial oxygen saturation (SpO₂) is measured by SpO₂ sensors. A measuring range of the ratio of modulation index (A) of two in-phase modulated signals is expressed in units of saturation (SpO₂). The relationship between SpO₂ and A is determined as the calibration curve, %.

4. Summary and discussion
Obviously, the role of visual diagnostic system has greatly evolved in the last years. The interpretation is not anymore limited for the monitoring of brain activity, pain assessment or other characteristics on the bedside monitor. Visual analysis was suggested to provide sufficient information, but it can be time-consuming for clinicians. The development of an automated visual control system should make it more feasible in clinical settings.

The optoelectronic system for monitoring patients in a coma was developed to read vitally important bodily characteristics from a distance and respond to patients alarms promptly by using high-speed wireless communication technology. It will help to control the physical state instead of being in stuck into the monitor. Although Ethernet transfer technology is an essential feature of modern bedside monitor, data transmission Li-Fi technology is faster and can be used where Wi-Fi is not applicable. It does not replace bedside monitoring, but may be a flexible way of continuous surveillance within the care unit. Further scientific and measurement results will be presented in the next articles.

Simplex connection from bedside monitor to blanket as visual object was realized. Currently set-up of the data transmission system is in the process. Testing in the Intensive Care Unit of Polenov Neurosurgical Institute (branch of Almazov National Medical Research Centre) is the next step.
In conclusion, the visual control system represents a very useful tool for the assessment of patients in a vegetative state or state of minimal consciousness. The received information should be combined with behavioral evaluations to improve the prognosis and diagnosis of the patients.

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