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A System for Visual Display of Changes in the Physiological State of Patients with Chronic Disorders Using Data Transmission via Optical Wireless Communication

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Abstract

Continuous monitoring of patient's state in intensive care units is crucial for displaying critical conditions and identifying signs of clear consciousness. Traditional monitoring on a bedside monitor represents digital value on the screen and has several shortcomings. The observer's perception of digital information is limited by visual acuity and affects the speed of decision-making. The radio frequency range is increasingly overloaded with the development of Internet of Things devices. It leads to numerous errors in the transmitted data. The developed system is aimed at the comprehensive elimination of the shortcomings through available means. An understandable visualization system is preferred for prompt recognition of changes in the patient's state, increasing the speed of perception of the observer, and receiving information in the form of a data set. A data transmission system via optical wireless communication is relevant for duplicative channel for displaying and eliminating the shortcomings of systems operating in the radio frequency range. The system being developed is universal and can be used in a wide range of professional fields. In particular, if the use of the radio frequency range is limited and the stability of the data transmission channel to electromagnetic interference is essential.

Keywords: Monitoring system; Chronic disorders; Intensive care unit

1. INTRODUCTION

Monitoring is the collection of information about an object, which is processed, systematized, evaluated, analyzed digitally and visually presented in a convenient form for the observer. Continuous monitoring of object's state (for example, patients with chronic disorders) is relevant for intensive care units. Especially, physiological state of patients with chronic impairment of consciousness needs to be monitored.

Monitoring systems present the reduction of workload. Traditional monitoring is carried out using wearable sensors that collect basic patient's vital signs and screens for their visualization. In addition to the high workload on medical staff, the ability of the observer is limited by visual acuity and the minimum angle of view between the image and the optical center of the eye (~ 1 arc minute) [1]. The value may be smaller due to the long distance from patient to practice. The data on a screen, therefore, may be difficult to distinguish. Additional disadvantages include the lack of mobility, high cost and the use of the radio frequency range for data transmission. The healthcare system is undergoing a shift from traditional systems to wearable devices. They are applicable in direct contact with the body. Wearable devices are equipped with sensing capabilities of user's electrical activity of the brain [2,3], heart rate, oxygen levels, body temperature, blood pressure [4–6]. Special attention is devoted to wearable monitoring devices that are aimed at providing emergency assistance to the elderly or patients at home after rehabilitation [7]. Present monitoring systems are designed to monitor user's physiological state with normal physical activity and transmit data in a radio frequency

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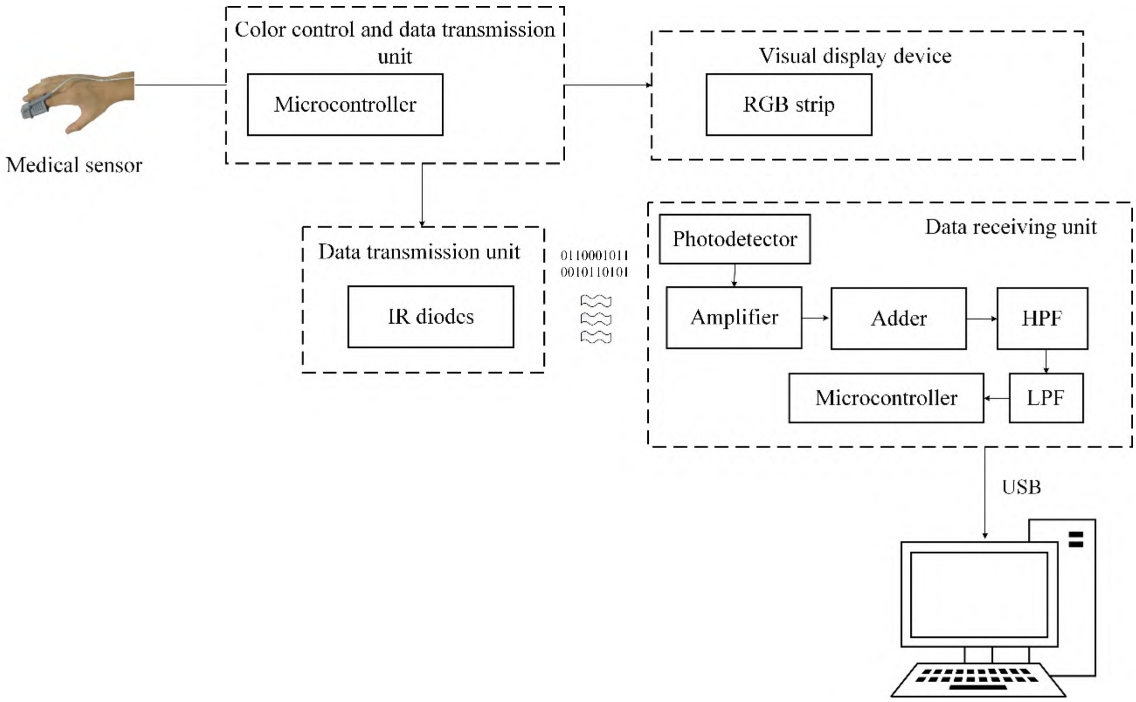


Fig. 1. Block diagram of the visual display and data transmission system.

range, making them not applicable for continuous monitoring in medical units, where the radio frequency range is limited. Optical wireless communication is more effective and has several advantages: wide spectrum, resistance to electromagnetic interference, and high data transfer rate [8,9].

Comfort visual observing in existing monitoring systems is limited by visual acuity of observer and ability to process digital information promptly. It is better adapted to recognizing shapes, colors, and movements than for reading digital values. By converting them into a simplified display form, the level of awareness is increased and the cognitive load on the brain is reduced [10]. Thus, monitoring can be supplemented by understandable visual display method for prompt decision-making and patient's safety.

Light-emitting diodes are used as indicators with a given emission chromaticity and operation mode to display changes in physiological state [11]. A device with matrix LED indicators for displaying character information [12] was developed in 2018 by scientists from the University of Tokyo together with the Japanese company Dai Nippon Printing. However, in existing display methods a principle based on the link between the given emission chromaticity and parameter recognition is missing.

The existing systems for displaying the physiological state are not enough to identify critical states in the observer's field of view. There is no universal and mobile system, providing visual and understandable display of physiological changes and noise-free data transmission. The proposed system will provide a clear visual display of the object's state, will be resistant to interference and applicable in any area, where the radio frequency range is limited, and resistance to interference is essential.

2. THE PRINCIPLE OF OPERATION

The block diagram of the developed system is shown in Fig. 1. It consists of four functional blocks: color control and data processing unit, visual display device, data transmission unit, data receiving unit. Body temperature, blood oxygen level and heart rate are reading parameters.

Two subsystems are being developed: a data visualization subsystem and a data transmission subsystem via optical wireless communication. The visualization subsystem is presented as follows: the sensors are connected via the I2C bus-line to the microcontroller of the color control and data processing unit. The signal is converted on the microcontroller to digital values and compared with a range of normal values. The patient's condition is displayed on a LED-based visual display device. The emission chromaticity of the LED strip is controlled by a microcontroller. The chromaticity and operation modes of the LEDs change according to the object's state: the parameters are in the range of normal values; the parameters are outside the range of normal values. If controlled parameters are outside the range of normal values, the alarm signal from the microcontroller is transmitted to the data transmission unit (subsystem for optical wireless data transmission). Data packets are formed and transmitted via an atmospheric optical communication channel using an array of infrared LEDs to the photodetector. The optical information signal through the atmospheric

(a) (b) (c)

Fig. 2. LED emission chromaticity on a visual display device: controlled parameter is lower than range of normal values (a); normal state (b); controlled parameter is higher than range of normal values (c).

communication channel goes to the data receiving unit and from the photodiodes goes the transimpedance amplifier afterwards. The amplifier converts the photodiode photocurrent into the information signal voltage. The output signal of the transimpedance amplifiers is inverted. The signal goes to the inverting adder to sum up the signal and compensate for the inversion from the transimpedance amplifiers. There is a high pass filter (HPF) at the output of the inverting adder to exclude the constant component of the signal and a low-pass filter (LPF) to suppress high-order harmonics in the signal. The signal goes to the analog-digital converter of the microcontroller in the data receiving unit. It analyzes, decrypts and transmits the decrypted packet to the converter of the UART data exchange interface to the USB interface for subsequent connection to a personal computer.

3. VISUAL DISPLAY DEVICE

The following criteria can be formulated for the type of visual display device: safe heating on skin contact, low energy consumption, design and usability on the patient's body. A LED-based bracelet was proposed.

LED strip is located on the visual display device and designed to display the physiological parameters of patients in several physiological states: the values of physiological parameters are normal, the values of physiological parameters are lower than normal values, the values of physiological parameters are higher than normal values. LEDs glow in a range of cold or warm colors (Fig. 2). The parameter is recognized by the operation mode for each deviated parameter. For blood oxygen level — sequential switching on of LEDs, body temperature — changing the intensity of LED emission, pulse rate — the frequency of flashing LEDs.

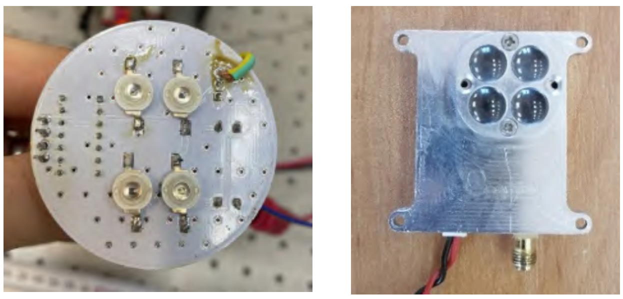
4. DATA TRANSMISSION AND DATA RECEIVING UNIT

The data transmission and data receiving module are demonstrated in Fig. 3. Optical model was presented by authors in Ref. [13]. The distance between the data transmission unit and the data receiving unit, where the maximum illumination distribution of the active region of the photodiode, was determined. With the average optical power of 54 μW at the 2 meters distance between units and voltage drop of 122 mV received signal significantly exceeds the noise level on the analog-digital converter, which is about 15 units. 2 × 2 array of infrared LEDs and 2 × 2 array of photodetectors with LA 1576 lens is enough to distinguish the signal.

The bandwidth of the data transmission module can be calculated according to the formula:

$$f_{BW} = \frac{1}{2\pi R_L C_j}, \tag{1}$$

where R_L is the load resistance equal to 3600 Ohms and C_j is the photodiode capacity equal to 0.25 μF. The value



(a) (b)

Fig. 3. The data transmission module (a) and data receiving module (b).

Fig. 4. Computer model of the color control and data processing unit (without cover).

of the operating frequency band of the photodiodes is ~ 170 MHz.

5. COLOR CONTROL AND DATA PROCESSING UNIT

A protecting case and the printed circuit board are the main elements of the color control and data processing unit (Fig. 4). STM32H745ZIT6 chip is the main component of the board. The sizes are selected to allow ease of installation of the printed circuit board while maintaining a high compactness.

6. SYSTEM LAYOUT

The layout of the designed system is shown in Fig. 5. The layout consists of a pulse oximeter and heart rate sensor SpO_2 MAX30102, a color control and data processing unit, a visual display device, a data transmission unit and a photodetector module. Checking the compliance of the LED operation mode with the type of rejected parameters is carried out by setting digital values in the microcontroller program.

7. RESULTS AND CONCLUSIONS

The developed system provides increased speed of data perception by observer in comparison with existing display methods and transmits data via optical wireless communication. A visual display method of physiological changes has been developed for this purpose. The proposed technical solution involves the collection of measured digitized values of physiological parameters and their conversion into emission chromaticity and LED operation modes on a visual display device. The bracelet was selected as a type of visual display device.

Additionally, the block diagram of the system has been developed, not previously used in the intensive care unit.

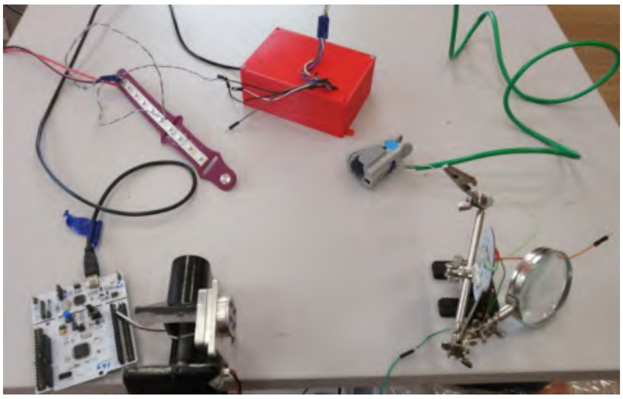


Fig. 5. Layout of the designed system.

It controls data from sensors, emission chromaticity, LED operation mode and forms data packets for modulation of the signal on the data transmission unit. A system layout for visual display of changes in the physiological state of patients and data transmission via optical wireless communication is proposed. Heart rate, oxygen saturation and body temperature were selected for the non-invasive monitoring of the physiological state of patients. Data transmission is carried out using optical wireless communication technology in infrared wavelength range.

REFERENCES

[1] M.K. Samokhvalov, *Elementy i ustroistva optoelectroniki (Elements and devices of optoelectronics)*, Ulyanovsk State Technical University, Ulyanovsk, 2015 (in Russian).

[2] C. Guger, B. Allison, R. Spataro, V. La Bella, A. Kammerhofer, F. Guttmann, T.J. von Oertzen, J. Annen, S. Laureys, A. Heilinger, R. Ortner, W. Cho, *MindBEAGLE – A new system for the assessment and communication with patients with disorders of consciousness and complete locked-in syndrom*, in: 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC), IEEE, 2017, pp. 3008–3013.

[3] Y.S. Kim, H.J. Baek, J.S. Kim, H.B. Lee, J.M. Choi, K.S. Part, *Helmet-based physiological signal monitoring system*, Eur. J. Appl. Physiol., 2009, vol. 105, no. 3, pp. 365–372.

[4] F.H. Wilheim, W.T. Roth, M.A. Sackner. *The LifeShirt: an advanced system for ambulatory measurement of respiratory and cardiac function*, Behav. Modif, 2003, vol. 27, no. 5, pp. 671–691.

[5] Y. Zhang, C.C.Y. Poon, C. Chan, M.W.W. Tsang, K. Wu, *A health-shirt using e-textile materials for the continuous and cuffless monitoring of arterial blood pressure*, in: 2006 3rd IEEE/EMBS International Summer School on Medical Devices and Biosensors, IEEE, 2006, pp. 86–89.

[6] C.H. Chan, Y.T Zhang, *Continuous and long-term arterial blood pressure monitoring by using h-Shirt*, in: 2008 International Conference on Information Technology and Applications in Biomedicine, IEEE, 2008, pp. 267–269.

[7] H. Maki, Y. Yonczawa, H. Ogawa, H. Sato, A.W. Hahn, W.M. Caldwell, *A welfare facility resident care support system*, Biomed. Sci. Instrum., 2004, vol. 40, pp. 480–483.

[8] S.R. Teli, S. Zvanovec, Z. Ghassemlooy. *Optical Internet of Things within 5G: Applications and Challenges*, in: 2018 IEEE International Conference on Internet of Things and Intelligence System, IEEE, 2018, pp. 40–45.
[9] Z. Ghassemlooy, S. Zvanovec, M.-A. Khalighi, W.O. Popoola, J. Perez, *Optical wireless communication systems*, Optik, 2017, vol. 151, pp. 1–6.
[10] D.W Tscholl, J. Rössler, S. Said, A. Kaserer, D.R. Spahn, C.B. Nöthiger, *Situation awareness-oriented patient monitoring with visual patient technology: A qualitative review of the primary research*, Sensors, 2020, vol. 20, no 7, art. no. 2112.
[11] F.K.C. Harun, N. Uyop, M.F.A. Aziz, N.H. Mahmood, M.F. Kamarudin, A. Linoby, *Color coded heart rate monitoring system using ANT+*, in: N.A.A. Osman, W.A.B.W. Abas, A.K.A. Wahab, H.N. Ting (eds.), 5th Kuala Lumpur International Conference on Biomedical Engineering 2011, IFMBE Proceedings, vol. 35, Springer, Berlin, Heidelberg, pp. 283–286.
[12] *Someya Group Organic Transistor Lab*, Electronic resource (accessed 28.04.2022).
[13] S.A. Vostrikova, K.O. Pogorelova, D.S. Shiryaev, E.V. Tkacheva, N.A. Belyakov, Y.N. Kovach, Y.S. Andreev, I.G. Smirnova, E.A. Kondratieva, *Visual display system of changes in physiological states for patients with chronic disorders and data transmission via optical wireless communication*, Scientific and Technical Journal of Information Technologies, Mechanics and Optics, 2022. vol. 22, no. 5. pp. 951–961.

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Система визуального отображения изменения физиологического состояния пациентов с хроническим нарушением сознания и передачи данных по беспроводной оптической связи

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Аннотация. Непрерывный мониторинг в отделениях интенсивной терапии важен для отображения критических состояний человека или признаков ясного сознания. Традиционный способ отображения на прикроватных мониторах представляет из себя отображение цифровых значений на экране и обладает рядом недостатков. Восприятие цифровой информации наблюдателем в условиях его высокой загруженности ограничено остротой зрения и существенно влияет на скорость принятия решения. С развитием технологий передачи данных увеличивается количество устройств, требующих подключения к Интернету, что приводит к ограничению по пропускной способности радиочастотного диапазона. Это может являться причиной наличия большого количества ошибок в передаваемых данных. Разрабатываемая оптико-электронная система визуального отображения изменения физиологического состояния и передачи данных по беспроводной оптической связи направлена на комплексное устранение вышеупомянутых недостатков в используемых системах доступными средствами. Для оперативного распознания изменения состояния объекта предпочтительна понятная система визуализации, увеличивающая скорость восприятия наблюдателя и позволяющая получать информацию об изменениях в виде комплекса данных. В то же время для обеспечения дублирующего канала отображения и устранения недостатков систем, работающих в радиочастотном диапазоне, актуальна система передачи данных по беспроводной оптической связи. Разрабатываемая система является универсальной и может быть применима в широком спектре профессиональных областей. В частности, когда применение радиочастотного диапазона ограничено и важную роль играет устойчивость канала передачи данных к электромагнитным помехам.

Ключевые слова: система мониторинга; хроническое нарушение сознания; отделение интенсивной терапии