Research of indoor temperature data transmission using visible light communication technology

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Abstract. In this article, we consider a system for wireless data transmission via visible light. An experimental stand for temperature control is presented. Transmitting and receiving devices have been developed to organize traffic. A digital temperature sensor is connected to the transmitter. The transmitting device has a white light-emitting diode (LED) with a power of 3W, which performs the function of lighting and additionally transmits temperature data. A silicon photodetector is used to receive the signal. Data is controlled and processed by Atmega 328 microcontrollers, which are located in both devices. The signal is encoded using the Universal Asynchronous Receiver-Transmitter (UART) protocol. Experimental results of the system operation are presented, which show stable data transmission over a long period of time.

1. Introduction
To ensure a comfortable microclimate in residential or industrial premises, it is necessary to control the air parameters. For transmission of measured data to control systems, both wired and wireless network technologies are offered. Global trends in the field of life and production, such as the Internet of Things, Device to Device, Smart House, are advancing thanks to the construction of their network architecture based on wireless communication technologies. Wireless networks are expected to surpass wired networks in terms of quantity and prevalence. This is due not only to modern trends, but their ease of use, low cost and sufficient bandwidth.

Popular wireless technologies today transmit data in a radio frequency spectrum that has limited capabilities. Already now, switching service providers have declared that the radio frequency in the 1-3 GHz range, which is optimal for data transmission, is overloaded [1, 2]. In connection with the forecasted data presented by analysts of world companies on the increase in the volume of mobile data transmission [3, 4], problems are expected with the provision of bandwidth and the quality of services for wireless technologies in the radio frequency range. One solution as an alternative for radio frequency communication is the additional use of the optical range in the visible spectrum.

The rapid advancement of light-emitting diode LED-based semiconductor lighting technology and the ability of high-power white LEDs to be quickly switched and controlled have influenced the development of optical wireless technology via visible light communication (VLC).

Data Encoding using VLC technology is performed by quickly off/on (flashing) switching a light source that simultaneously performs the function of a lighting device, which is not perceived by the human eye. Flickering light that occurs at a high frequency will allow you to transmit information without noticeable changes in the level of room illumination.
The dual functionality, provided by visible light data transmission technology, has created a number of interesting applications, such as high-speed data transmission through indoor lighting infrastructure, communication between cars, in airplane cabins, trains, power plants, and hospitals [5–9]. To date, research is mainly conducted in the direction of transmitting information in various formats between users, to explain, as an addition to existing technologies for organizing local or global networks. The authors presented their own works on solving problems of audio transmission [10] and character data [11].

This work is aimed at creating a real-time room temperature measurement system and data transmission using VLC technology. In the future, it is proposed to use the research results when organizing automated control systems in Smart Home.

2. Visible Light Communication technology for data transmission

Figure 1 shows a block diagram of the VLC temperature data transmission system. The proposed system consists of a transmitting and receiving module, which are structurally separated on two devices. Air space is used as the transmission medium.

A temperature sensor is connected to the transmitter. The module has a white LED light that is used for both lighting and data transmission. The sensor measures the current room temperature and transmits the data to the microcontroller, which processes the information, generates an electrical signal and sends it to the driver. The driver generates a control voltage and supplies it to the LED, which starts transmitting light pulses in the visible light spectrum. The driver is necessary for reliable operation of the LED and stable data transmission. The receiver is located at a distance from the transmitter. The receiver is equipped with a silicon photodiode for receiving optical signals from the transmitter and converting them into electrical signals. These signals pass through the amplifier and are sent to the microcontroller for processing. The decrypted information is transmitted in accordance with the system operation algorithm and displayed on the reader (indicator). Management and processing of data is carried out by the microcontroller.

VLC systems can use modulation methods used for radio frequency communication [12–14]. In article [11], the authors demonstrate a system for transmitting symbolic data by modulating it on a single carrier. The physical encoding of the signal coming from the microcontroller had the form of a two-level unipolar NRZ code (Non Return to Zero). The difference from the standard NRZ code Protocol was the use of two bits for the values 0 (no signal) and 1 (signal presence). This approach of physical encoding allowed to reduce the influence of both external and internal distortions that occur in a single clock cycle. The presented method of data transmission can be used in systems where the reliability of information is more important than the speed of data transfer.

In this work, UART (Universal Asynchronous Receiver-Transmitter) technology was used to organize data transmission over optical wireless communication using a lighting LED element. The devices use Arduino boards that support communication over this protocol for data processing.
In UART, data is transmitted one bit at the same time intervals. This time interval is determined by
the specified UART speed. For our system, when the speed increases above 9600 baud, the duration of
information transmission in time decreases accordingly. In the receiving part, the characteristics of
the nodes did not allow working out the incoming signal. When the speed is less than 9600 baud, the
duration of information transmission in time increases and, accordingly, the time of the LED
brightness decreases increases. In this regard, the optimal speed is set to 9600 baud.

The speed of the UART does not mean the data transfer rate, since the UART transmits service
pulses (start bit, stop bit, parity bit) along with the useful data. In our case, the 8-N-1 mode is used.
The transfer time of 1 MB at 9600 baud in the selected mode is 18 minutes and 12 seconds. Data
transfer speed was not the main criteria. The task was to obtain reliable data coming from the sensor,
as well as support the required level of illumination and the absence of LED flickering. This speed is
sufficient for the operation of the developed temperature control system.

3. Results of experimental researches

To obtain a stable signal, the level and shape of the signal were studied at various points of the
receiving and transmitting modules. Figure 2 shows the appearance of an experimental setup
consisting of a receiving and transmitting parts, an oscilloscope, and a laptop. The laptop is used to
upload the sketch to the microcontroller. We connect the oscilloscope to the receiving and transmitting
device to monitor the signal. The level and shape of the output signal from the transmitter
microcontroller and the signal coming to the receiver microcontroller are important.

![Figure 2. Appearance of the experimental setup.](image)

In the transmitting module, the signal from the DS18B20 integrated digital temperature sensor is
sent to the Arduino microcontroller, which transmits it to the LED driver. We selected a white LED
with a power of 3 W as the optical signal transmitter. On the waveform (Figure 3a), the first ray shows
the shape of the signal coming to the LED from the driver. Monitoring this point gives us information
about the efficiency of the driver. The signal coming from the transmitter microcontroller is a
reference. The waveform at this point is controlled by the second beam of the oscilloscope and is
present on all waveforms.

The circuit uses a cryo-silicon photodiode FD-K-155 as a receiver. The waveform taken at the
point after the photodiode (Figure 3c) shows that the signal is transmitted and this shows the efficiency
of the photocurrent source. However, after the photodiode, the signal is not stable and requires
amplification.
It is necessary to receive a signal identical to the signal from the transmitter. The light signal received by the photodiode is converted into a photocurrent. In order to reduce the amplification of high-frequency noise, you need to connect the resistance and capacitor in parallel to the operational amplifier, as well as carefully select their ratings depending on the current. All elements of the circuit must be selected so that at a data transfer rate of 9600 baud, the signal form takes the form of transistor-transistor logic signals.

In order to achieve good results, we have proposed a two-stage amplifier circuit in the receiving part.

The signal that passes the first stage through the split capacitor passes to the input of the second amplifier. As a buffer amplifier, we select a logic element that also inverts the signal for further processing. The signal must be inverted to form the desired polarity. The signal comes from the inverter to the input of the UART port of the Arduino microcontroller. The signal taken by the oscilloscope after the receiver's buffer amplifier-inverter will completely coincide with the reference signal (Figure 3b).

![Image](a)

![Image](b)

![Image](c)

Figure 3. Waveform of the signal from the transmitter (a), on the receiver's photodiode (b), after the receiver's buffer amplifier-inverter (c).

Setting up all parts of the receiver circuit was carried out with synchronization of the signal by the second channel of the oscilloscope (reference) in order to see each pulse separately in the sending. By tuning the amplifier stages, we achieved a similar signal shape and pulse duration. As a result, we received a stable transmission of sending pulses, which indicates the reliable operation of the system.

The waveforms (Figure 3) were obtained in natural light in the room where the research was conducted. The experimental stand was located on the plane of the table, the distance between the
receiver and the transmitter was 0.8 meters. Studies were conducted on the quality of the transmitting signal associated with additional disturbance from artificial light sources. With the ceiling lights turned on and the indoor light level within the normal range, the signal transmission was stable. When you turn on LED lamp with a directional light flux of less than one meter from the receiving and transmitting model, the system begins to work incorrectly.

A direct beam of light hitting the communication line interrupts the signal, as can be seen in Figure 4a, since the signal is completely lost. After a forced system reboot, the waveform clearly shows the appearance of data transmission losses (Figure 4b). The first control bit was lost, so the signal from the receiver to the transmitter did not come.

![Figure 4. Oscillogram of the signal with a directed light flux (a), after rebooting the system (b).](image)

It follows from this that when organizing data transmission indoor via LED lighting, it is necessary to take into account the influence of directional light from any sources. This problem can be solved when designing a lighting system due to the optimal location of LED lamps, or by adjusting the illumination level in order to uniform illumination.

4. Conclusion
The work proposes and implements a temperature control system. Data was transmitted over an optical wireless communication line using VLC technology. An experimental setup has been assembled. As a result of the experiments, stable data transmission was obtained using a 3 W white LED and physical encoding of the light signal using UART technology. When transmitting data, information is modulated and superimposed on the luminous flux emitted by the LED. The receiving device must be located within the luminous flux. Increasing the communication distance of more than 0.8 meters is possible when using high-power LEDs, as well as selecting high-gain amplifiers. The results obtained made it possible to control the room temperature using an optical wireless communication system via LED lighting system. The advantages of the proposed system are simplicity of design, low cost of used radio-electronic elements, high speed of transmission of the current temperature value with sufficient accuracy.

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