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COMPUTER-BASED INFORMATION AND MEASUREMENT SYSTEM FOR PULSE SIGNAL ACQUISITION

A computer-based information and measurement system was developed for continuous acquisition, transmission, visualization, and subsequent digital processing of a pulse signal. The measurement principle is based on reflectance photoplethysmography: changes in blood volume in superficial vessels modulate the intensity of light detected by a photodetector. The system uses a Pulse Sensor Amped optical sensor comprising a green LED, an APDS-9008 photodetector, an active analog filter, and an amplifier based on the MCP6001 operational amplifier. Its integrated analog circuitry produces an output suitable for direct analog-to-digital conversion, allowing the system to operate without a separate pulse signal detector.

The analog signal is digitized by the 10-bit analog-to-digital converter of an ATmega8A microcontroller. Measurement data are transmitted to a personal computer through a UART-USB interface. MATLAB software was developed to receive data through the serial port, reconstruct digital samples from the received bytes, and display the signal graphically. To verify the prototype's operation, a single trial recording was obtained from the temporal region. The recorded signal contains recurring pulse-like oscillations and demonstrates the operation of the acquisition, transmission, and display chain. The proposed architecture can serve as a hardware and software platform for studies of peripheral hemodynamics, pulse rate estimation algorithms, and digital biomedical signal processing methods.

Keywords: pulse signal, photoplethysmography, optical sensor, information and measurement system, Pulse Sensor Amped, analog-to-digital conversion, ATmega8A; UART-USB, MATLAB.

Introduction. Pulse wave recording is a non-invasive means of obtaining information about blood circulation. The waveform of a pulse signal provides information about the timing of pulsations and changes in peripheral blood volume. The acquisition and analysis of such signals are used in physiological research, the assessment of vascular properties, and human health monitoring [1].

Photoplethysmography is one method of acquiring a pulse signal. It measures changes in light intensity after light interacts with biological tissue. Pulsatile changes in blood volume affect light absorption and scattering, thereby changing the electrical signal at the photodetector output. The pulse waveform can be used to determine the timing of pulsations and examine the characteristics of the pulse wave [2]. Depending on the positions of the light source and photodetector, the measured light either passes through the tissue or returns after being scattered within it [3].

Pulse signal quality is affected by body movement, sensor contact with the skin, ambient light, and individual tissue properties [4]. The pulsatile component may be small relative to the constant component of the optical signal, while changes in recording conditions can distort its waveform [5]. A system designed to acquire such signals must therefore account for the characteristics of the primary transducer, analog signal conditioning, digitization, data transmission, and computer-based display.

Existing systems for recording pulse signals differ in their measurement principles, sensor placement, and intended outputs. PulseTrace PCA2 records the pulse wave using an infrared finger sensor. An index related to arterial stiffness is then derived from the recorded waveform [6]. Its measurement channel is thus designed for a specific task in vascular assessment.

EndoPAT 2000 addresses a different task. It uses finger probes to record peripheral arterial tone when assessing vascular reactivity after temporary occlusion of blood flow in the arm [7]. It provides an example of a computerized assessment of vascular response under a defined protocol, although its measurement principle differs from optical photoplethysmography.

Modular systems are also used for research-oriented pulse signal acquisition. For example, the Shimmer optical probe, together with the Shimmer3R GSR+ unit, can acquire a signal from a finger, earlobe, or another suitable body site. The platform software supports

analysis of the recorded signal and pulse rate estimation [8]. In this system, the optical probe, data acquisition unit, and software form interconnected parts of the measurement setup.

Khvostivska L.V. and Khvostivskyi M.O. described an information system for pulse signal acquisition and processing comprising an optical sensor, separate filtering and amplification stages, a digitization unit, a data transmission interface, and a personal computer [9]. They justified the choice of electronic components and presented results obtained with an experimental prototype. Their work illustrates the importance of coordinating the optical, analog, digital, and computer-based parts of a pulse signal acquisition system.

Reference hardware designs provide another approach to developing compact optical devices. For example, MAXREFDES117 includes an optical module with red and infrared LEDs, can be integrated with microcontroller platforms, and provides example algorithms for estimating pulse rate and blood oxygen saturation [10]. Such designs demonstrate the feasibility of systems based on integrated optical modules, while the architecture of the complete acquisition chain depends on the recording task and the intended use of the data.

The systems reviewed above include devices designed to obtain specific vascular indicators and modular platforms for research-oriented signal acquisition. The task addressed in this study requires coordination of optical sensing, analog signal conditioning, digitization, transmission of digital samples, and graphical display on a computer. The output of this acquisition chain should be a pulse signal time series available for subsequent software analysis.

Aim of the study – to develop a computer-based information and measurement system for acquiring and visualizing the pulse waveform and to verify the operation of the prototype through a trial recording.

Structure of the Computer-Based Information and Measurement System. The block diagram of the developed system is shown in Fig. 1.

The system comprises an optical pulse sensor, an analog-to-digital converter (ADC), a microcontroller module, a UART-USB interface converter, and a personal computer running MATLAB software.

The optical sensor integrates four functional components: a green light source, a photodetector, an analog filter, and an amplifier. The LED directs light into the tissue. Some of the light is absorbed and

scattered, while a portion returns to the photodetector. The intensity of the detected light varies with pulsatile changes in blood volume.

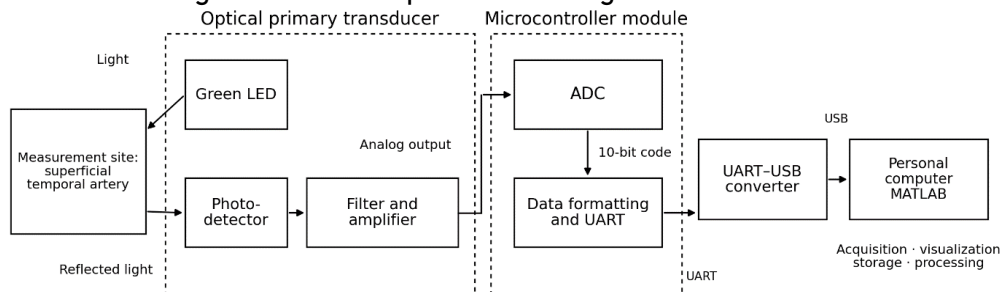


Fig. 1. Block diagram of the computer-based information and measurement system for pulse signal acquisition

The system comprises an optical pulse sensor, an analog-to-digital converter (ADC), a microcontroller module, a UART-USB interface converter, and a personal computer running MATLAB software.

The optical sensor integrates four functional components: a green light source, a photodetector, an analog filter, and an amplifier. The LED directs light into the tissue. Some of the light is absorbed and scattered, while a portion returns to the photodetector. The intensity of the detected light varies with pulsatile changes in blood volume.

The analog signal produced by the sensor is fed to a 10-bit ADC. The microcontroller initiates conversion at a specified sampling rate, reads the digital code, and transmits it via UART. The UART-USB converter provides the electrical and protocol interface between the microcontroller and the computer's USB port. On the computer, the MATLAB software receives the data, reconstructs the signal samples, and displays them as a graph.

This design follows the principle of functional separation. The sensor performs the initial measurement conversion; the ADC converts the analog signal into digital codes; the communication channel transfers the data; and the computer performs software operations that can be adapted to the research task.

Replacing a hardware pulse detector with software processing has two advantages. First, it preserves the full sequence of samples needed to analyze the pulse waveform. Second, the parameters of digital filtering and detection algorithms can be changed without modifying the electronic circuit.

Unlike architectures that place a separate pulse signal detector between the sensor and the ADC, the proposed system uses a primary

transducer with integrated amplification and frequency-selective filtering. This simplifies the hardware, reduces the number of intermediate processing stages, and allows the pulse waveform to be transmitted to the computer rather than only a sequence of detected pulses.

Optical Pulse Sensor. The primary transducer was selected based on the requirements of the measurement channel. The sensor must detect pulsatile changes in reflected light intensity with the light source and photodetector positioned on the same side of the tissue, provide an analog signal to the ADC input, and include amplification and filtering of the useful varying component. Compact size, secure placement on the skin, and reduced sensitivity to ambient light and changes in optical contact are also important in practice. The latter factors must be controlled during recording, as they cannot be eliminated solely through the choice of electronic components.

Pulse Sensor Amped meets the structural requirements of the primary measurement stage: it combines a green LED, a photodetector, analog filtering and amplification circuits, and an analog output [11]. It can therefore be connected to the system ADC without separate external filtering and amplification stages. The sensor design is shown in Fig. 2.

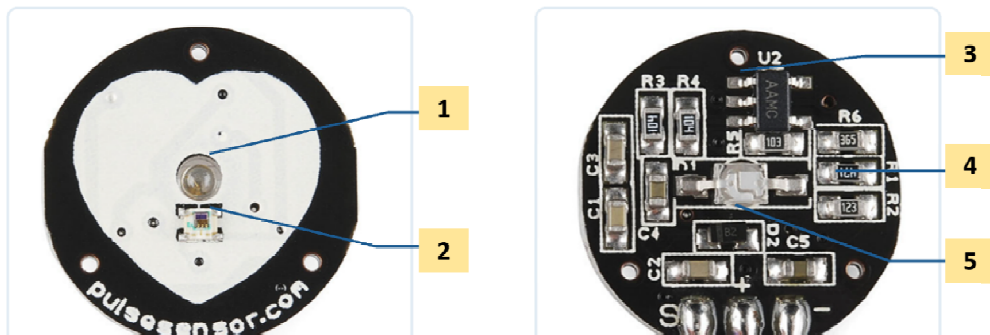


Fig. 2. Appearance and physical design of the Pulse Sensor Amped optical pulse sensor

The Pulse Sensor Amped is built on a circular printed circuit board. The contact side contains the light-emitting window of the green LED 1 and the APDS-9008 photodetector 2. The reverse side contains the amplifier integrated circuit 3, passive components for filtering and signal conditioning 4, and the body of the reverse-mounted LED 5, whose light is emitted through the contact side of the board. The sensor has three connections: power, ground, and analog output.

Placing the LED and photodetector on the contact side of the Pulse Sensor Amped enables pulse signal acquisition using reflected light. Light from the green LED penetrates the superficial tissue, where it is partly absorbed and scattered; some of it then returns to the photodetector. Pulsatile changes in blood volume alter the intensity of the detected light and, consequently, the sensor's electrical output. Fig. 3 shows the arrangement of the optical components and the principle of signal generation.

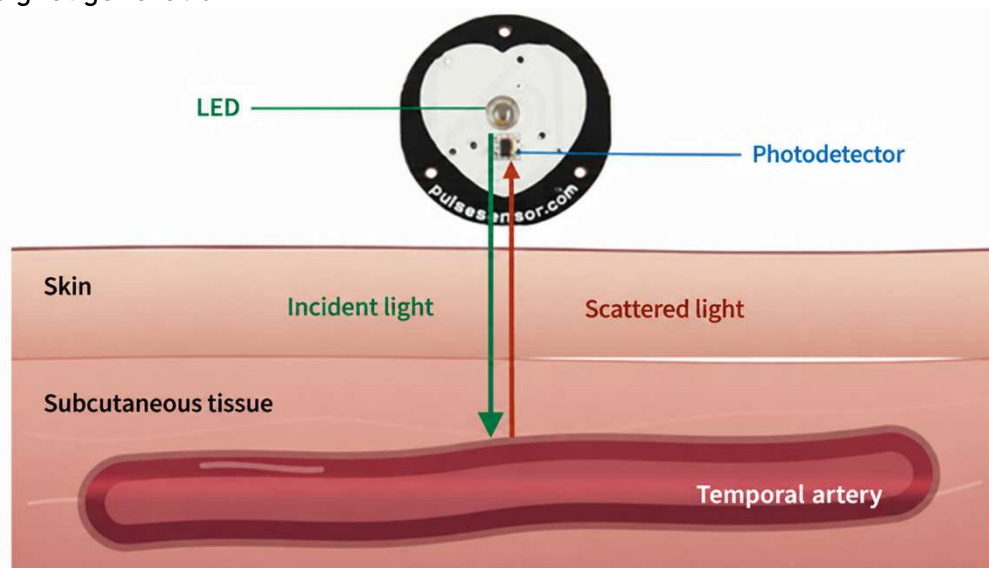


Fig. 3. Placement of the Pulse Sensor Amped optical sensor over the temporal artery and the principle of reflectance pulse signal acquisition

The reflectance geometry allows the light source and photodetector to be placed on the same side of the tissue. This makes it possible to position the sensor over the temporal region, where the temporal artery lies relatively close to the surface and is accessible to external sensor placement. Recording at this site requires stable sensor positioning and moderate contact pressure: changes in optical contact and local blood volume may distort the pulse waveform. The diagram illustrates the measurement principle rather than the actual paths of individual light rays through the tissue.

The main characteristics of the sensor and its functional components are presented in Table 1. The values were compiled from the manufacturers' technical documentation [11-13].

Table 1

Main Characteristics of the Optical Sensor

Parameter	Value / characteristic	Role in the system
1	2	3
Measurement principle	Reflectance photoplethysmography	Non-invasive acquisition of pulsatile changes in blood volume
Light source	Green LED	Provides optical illumination of superficial tissue
Peak LED wavelength	Approximately 515 nm	Falls within the spectral sensitivity range of the photodetector
Dominant wavelength	Approximately 525 nm	Determines the perceived color and operating spectral region
Photodetector	APDS-9008	Converts incident light into an electrical signal
Analog amplifier	MCP6001	Operates from a single supply and has rail-to-rail input and output capability
MCP6001 supply voltage range	1.8-6.0 V	Compatible with low-voltage microcontroller systems
Sensor output type	Analog	Enables acquisition of the pulse waveform
Number of external connections	3	Simplifies connection to the microcontroller module
Main functions of the analog front end	Amplification, removal of the DC component, and bandwidth limitation	Improves the prominence of the pulsatile component relative to interference

The electrical schematic of the sensor is shown in Fig. 4.

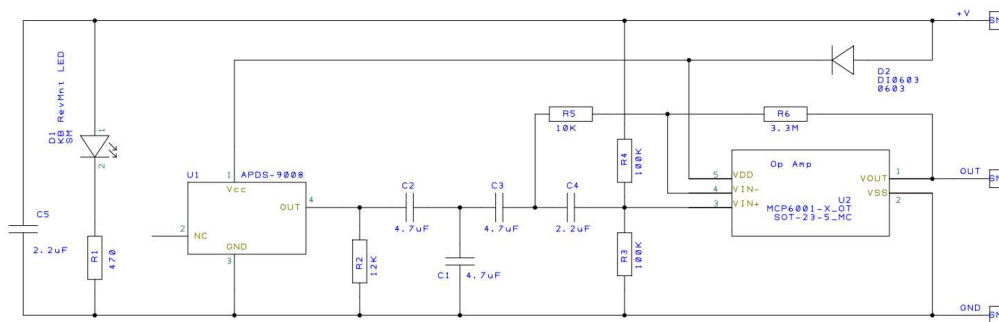


Fig. 4. Circuit diagram of the Pulse Sensor Amped optical sensor [11]

The LED circuit provides the illumination used to probe the tissue. A resistor limits the LED current and maintains the light source within its permissible operating range. Light returning from the tissue is detected by the APDS-9008.

The APDS-9008 is an analog ambient light sensor whose output current depends on incident light intensity. In the Pulse Sensor Amped circuit, it contributes to an electrical signal containing a substantial DC component and a smaller varying component. The DC component depends on the average illumination level, tissue reflectance, sensor position, and ambient light. The varying component is associated with pulsatile changes in blood volume.

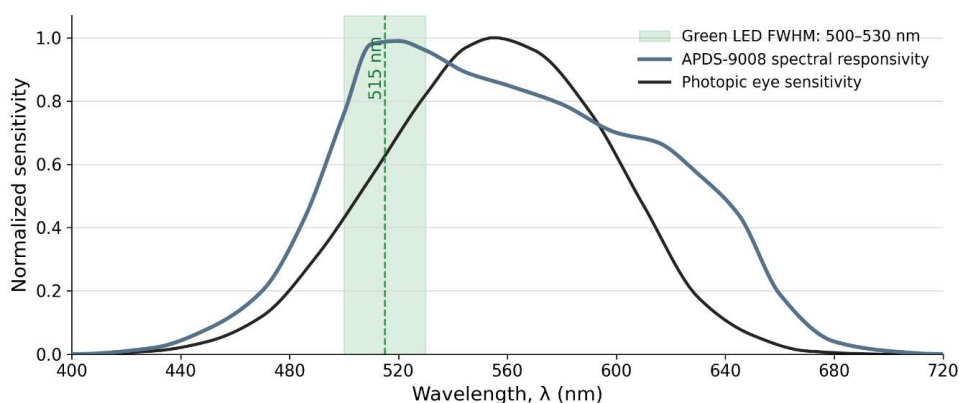
The RC networks provide frequency-selective filtering. The high-pass response attenuates the DC component and slow baseline drift, while the low-pass response attenuates noise and rapid changes outside the frequency range of interest for the pulse signal. The MCP6001 operational amplifier increases the amplitude of the useful varying component and produces an output within the supply voltage range.

The MCP6001 is suitable for this application because it operates from a single low-voltage supply, has low power consumption, and provides rail-to-rail input and output operation. Because the system does not use a dual supply, the output signal is biased above ground. This allows pulse-related variations above and below the mean signal level to be recorded while keeping the voltage within the ADC input range.

Thus, the Pulse Sensor Amped is a complete primary measurement transducer rather than an isolated photodiode. It combines optical illumination and detection with analog filtering,

amplification, and operating-point biasing. Its integrated analog front end enables the system to operate without a separate pulse signal detector.

Spectral Matching of the Optical Components. The effectiveness of optical sensing depends on matching the LED emission spectrum to the spectral responsivity of the photodetector. Fig. 5 shows the normalized spectral responsivity of the APDS-9008 and the operating wavelength range of the green LED.



APDS-9008 response redrawn approximately from Broadcom datasheet; LED specifications: Kingbright AM2520ZGC09.
The shaded LED band indicates FWHM, not the complete emission spectrum.

Fig. 5. Normalized spectral responsivity of the APDS-9008 photodetector and the emission wavelength range of the green LED

The photodetector's spectral responsivity curve was plotted using data from Broadcom's APDS-9008 technical documentation [12]. The LED emission range was marked according to the specifications of the Kingbright AM2520ZGC09, which is listed in the Pulse Sensor Amped bill of materials [11, 13]. Its peak emission wavelength is approximately 515 nm, its dominant wavelength is approximately 525 nm, and its spectral full width at half maximum is approximately 30 nm.

These characteristics show that the LED's emission range falls within a region where the APDS-9008 has appreciable sensitivity. The photodetector can therefore detect both the average level of reflected light and the relatively small changes associated with pulsatile blood volume.

Green light penetrates tissue less deeply than red or infrared light and can produce pronounced signal modulation in superficial

vascular tissue. This makes it suitable for the intended recording site over the temporal artery.

Analog-to-Digital Conversion. The analog signal is digitized using the built-in ADC of the ATmega8A microcontroller. Using a microcontroller with an integrated ADC simplifies the hardware design because it eliminates the need for a separate ADC chip and an additional interface for communicating with it.

The main characteristics of the digitization subsystem are presented in Table 2.

Table 2

Characteristics of the Analog-to-Digital Conversion Subsystem

Characteristic	Value
Microcontroller	ATmega8A
ADC resolution	10 bits
Digital output code range	0-1023
ADC type	Successive approximation
Number of analog input channels in the DIP package	Up to 6
Voltage reference	External AREF or an internal reference, depending on the configuration
Transmission format per sample	Two bytes
Communication interface	Hardware UART

The use of 10-bit conversion represents a compromise among hardware simplicity, data volume, and amplitude resolution. For a pulse signal acquisition system, it is important not only to distinguish individual pulses but also to obtain a sequence of samples suitable for waveform analysis.

The sampling rate is set by the microcontroller firmware; it was 900 Hz during the trial recording. This value is needed to construct the time axis and determine the intervals between successive pulse waves.

Data Transmission via UART-USB. The ATmega8A has a hardware universal asynchronous receiver-transmitter (UART). To communicate with a personal computer, a UART-USB interface module converts the UART signals for transmission over USB. The operating

system recognizes the device as a virtual serial port, allowing MATLAB to access it.

The prototype uses the following communication settings:

- Baud rate: 38,400 bit/s;
- Data bits: 8;
- Stop bits: 1;
- Parity: none;
- Flow control: none.

Because a 10-bit result cannot be transmitted as a single 8-bit byte, each sample is split into two bytes: $N=4B_H+B_L$, where B_H contains the upper eight bits of the result and B_L contains the lower two bits.

At the specified baud rate, the UART has sufficient capacity to transmit the pulse signal. However, transmission speed alone does not ensure reliable reconstruction. If one byte is lost, subsequent pairing of bytes in the stream may become misaligned. A future version of the system could therefore use a framed format with a start marker, sample number, and checksum. This would enable automatic resynchronization and detection of corrupted packets.

Software Architecture. The software was implemented in MATLAB. This environment was selected for its tools for serial port communication, array handling, graphical visualization, and digital signal processing. MATLAB also provides a single environment in which pulse signals can be acquired, stored, filtered, and analyzed spectrally, and algorithms for estimating pulse wave parameters can be developed [16].

The software architecture is shown in Fig. 6.

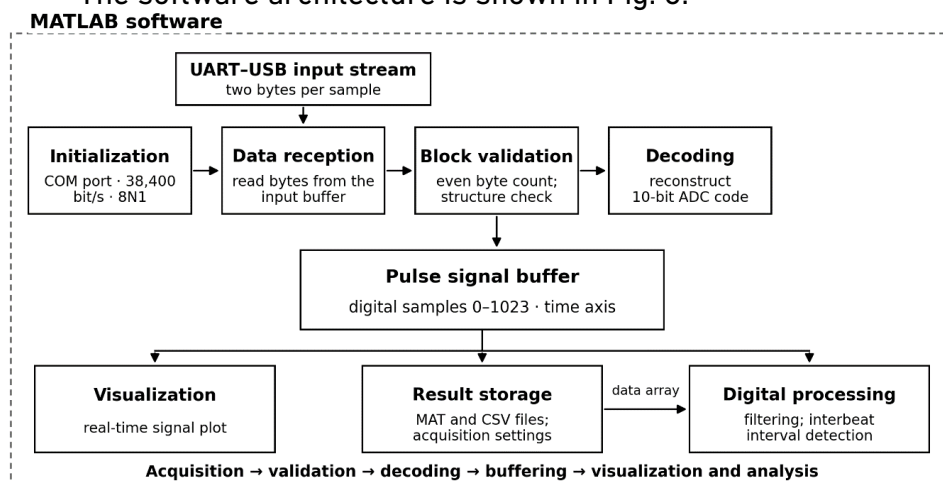


Fig. 6. Software architecture for pulse signal acquisition

During initialization, the program creates a serial port object, sets the UART parameters, and clears the input buffer. It then repeatedly checks how many bytes are available. Data are read in blocks containing an even number of bytes so that each pair corresponds to one ADC result.

After reception, the program reconstructs the 10-bit codes and checks that they fall within the valid range. Values outside 0-1023 must not be interpreted as valid ADC results. If a framed protocol is implemented, the range check should be supplemented by verification of the frame markers and checksum.

The resulting samples are appended to a software buffer. For graphical display, a fixed-duration sliding window is preferable to repeatedly redrawing the entire data array. This reduces computational load and makes it easier to observe the current waveform.

At the end of a recording session, the data are saved in two formats. MAT retains the arrays in MATLAB format, while CSV allows data exchange with other software environments. The sampling rate, recording date and time, ADC configuration, and serial interface settings are saved together with the samples.

Separating the software into acquisition, decoding, buffering, display, and storage modules allows individual functions to be improved independently. For example, a pulse rate estimation algorithm can be changed without modifying the UART module, and the display format can be changed without updating the microcontroller firmware.

Experimental Prototype. Fig. 7 shows the experimental prototype and an example of a recorded pulse signal.

The prototype comprises an optical sensor, a microcontroller board with a 10-bit ADC, a UART-USB module, a battery power supply, and a personal computer. The sensor was placed over the temporal artery, and its analog output was connected to the ADC input. The conversion results were transmitted to MATLAB via UART-USB.

To verify the system's operation, one trial recording was obtained with the sensor positioned over the temporal region. During recording, the sensor's analog output was digitized by the microcontroller ADC, transmitted via UART-USB, and displayed in MATLAB. The resulting pulse signal time series is shown in Fig. 7. The trial was intended to demonstrate that the signal passed through the complete measurement chain.

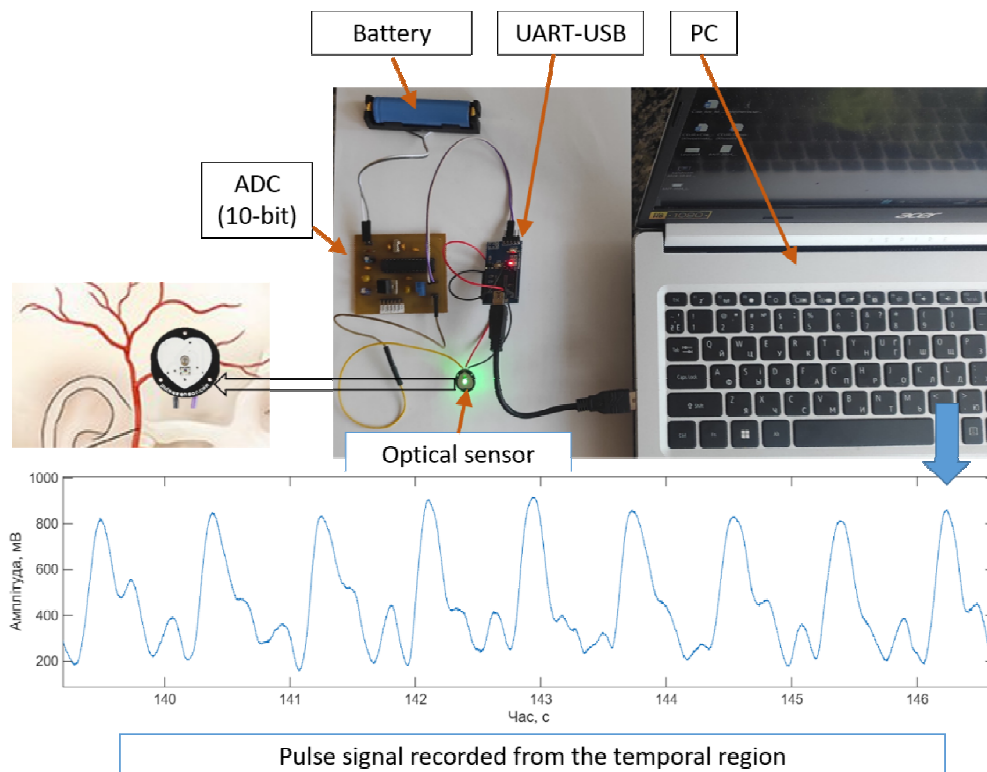


Fig. 7. Experimental prototype of the system and a recorded pulse signal

The recorded signal shows recurring oscillations with distinct peaks. Their presence indicates that the system acquires, transmits, and displays a varying signal whose appearance is consistent with a pulse waveform. A single recording without a simultaneous reference measurement cannot establish quantitative accuracy or repeatability, or confirm that each peak corresponds to an individual heartbeat.

Sensor position, contact pressure, ambient light, and participant movement affect the signal amplitude and baseline. The recorded values should therefore be interpreted as relative ADC codes. Converting them into physical units of blood volume change would require separate calibration against a reference method and is beyond the scope of this study.

Discussion of Results. The main outcome of this work is a system that acquires the complete digitized waveform of the analog pulse signal, rather than recording only the times at which pulse peaks occur. This provides more information for subsequent analysis than

architectures in which a hardware comparator or detector produces a binary output.

Removing the separate pulse signal detector does not eliminate the need for analog signal conditioning. Amplification and frequency-selective filtering remain necessary, but they are performed within the Pulse Sensor Amped. Consequently, the ADC receives an amplified signal biased within its permissible input range, while pulse peak detection can be performed in software.

The advantages of the proposed system include:

- a compact measurement channel;
- the use of readily available standard components;
- acquisition of the complete pulse waveform;
- the ability to extend the software with signal processing algorithms;
- compatibility with MATLAB tools for digital filtering and signal analysis;
- the ability to expand the system without replacing the primary transducer.

The prototype also has limitations. A single trial recording demonstrates that the acquisition channel operated under the conditions of that recording, but it does not establish measurement accuracy or repeatability. The waveform and its amplitude depend on sensor position and contact pressure, while movement during recording may distort the pulsatile signal. The transmission protocol does not include data integrity checks or automatic resynchronization after the loss of a byte. Assessing repeatability requires further recordings, including recordings after repositioning the sensor and under different acquisition conditions.

Future improvements should address:

- a stable mechanical mount for the sensor;
- shielding of the analog signal path against electromagnetic interference;
- a regulated power supply;
- a framed transmission protocol;
- timestamps and sample numbers;
- digital filtering of motion artifacts and power-line interference;
- automatic detection of pulse peaks;
- estimation of heart rate and interbeat interval variability;

— comparison with a simultaneously recorded reference signal.

Conclusions. A computer-based information and measurement system for pulse signal acquisition was developed. It combines an optical primary transducer, the 10-bit ADC of an ATmega8A microcontroller, a UART-USB communication channel, and MATLAB software.

The use of reflectance photoplethysmography for recording pulsatile changes over the relatively superficial temporal artery was justified. The Pulse Sensor Amped design was examined, including its green LED, APDS-9008 photodetector, frequency-selective RC networks, and MCP6001 amplifier.

Analysis of the spectral characteristics showed that the green LED's emission range overlaps with the spectral sensitivity range of the APDS-9008. The sensor's integrated analog circuitry amplifies and filters the signal, allowing the system to operate without a separate hardware pulse signal detector.

The 10-bit ADC produces a sequence of digital samples in the range 0-1023. Transmission via UART-USB allows a personal computer to be used for data acquisition, visualization, and subsequent processing.

The MATLAB program configures the serial port, receives the bytes, reconstructs the digital samples, and displays the signal. A single trial recording containing recurring pulse-like oscillations demonstrated the operation of the acquisition, transmission, and visualization channel under the conditions of the trial.

The proposed system can serve as a basis for research-oriented pulse signal acquisition. Further work should improve the channel's resistance to interference, refine the communication protocol, develop automated analysis algorithms, and validate the system against a reference device.

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КОМП'ЮТЕРНА ІНФОРМАЦІЙНО-ВИМІРЮВАЛЬНА СИСТЕМА РЕЄСТРАЦІЇ ПУЛЬСОВОГО СИГНАЛУ

Розроблено комп'ютерну інформаційно-вимірну систему для безперервної реєстрації, передавання, візуалізації та подальшої цифрової обробки пульсового сигналу. В основу вимірної перетворення покладено метод фотоплетизмографії у відбитому світлі, відповідно до якого зміни кровонаповнення поверхнево розташованих судин спричиняють модуляцію інтенсивності оптичного випромінювання, зареєстрованого фотоприймачем. Первинним перетворювачем системи є оптичний датчик Pulse Sensor Amped, до конструкції якого входять зелений світлодіод, фотоприймач APDS-9008, активний аналоговий фільтр і підсилювач на базі операційного підсилювача MCP6001. Завдяки інтегрованій схемі аналогового опрацювання датчик формує вихідний сигнал, придатний для безпосереднього аналого-цифрового перетворення, що дало змогу вилучити зі структури системи окремий детектор пульсового сигналу.

Аналоговий сигнал перетворюється в цифрову форму за допомогою 10-розрядного аналого-цифрового перетворювача мікроконтролера ATmega8A. Передавання результатів вимірювання до персонального комп'ютера реалізовано через інтерфейс UART-USB. Для приймання даних через послідовний порт, відновлення цифрових відліків із отриманих байтів та

графічного відображення сигналу розроблено програмне забезпечення в середовищі MATLAB. Для перевірки працездатності макета проведено один пробний запис сигналу в ділянці скроні. Отримана часова реалізація містить повторювані пульсоподібні коливання та демонструє роботу каналу реєстрації, передавання й відображення даних. Запропонована структура може бути використана як апаратно-програмна основа систем дослідження периферичної гемодинаміки, алгоритмів визначення частоти пульсу та методів цифрової обробки біомедичних сигналів.

Ключові слова: пульсовий сигнал, фотоплетизмографія, оптичний датчик, інформаційно-вимірювальна система, Pulse Sensor Amped, аналого-цифрове перетворення, ATmega8A, UART-USB, MATLAB.

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