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DEVELOPMENT OF A LOW-COST ELECTROCARDIOGRAPH (ECG) DEVICE BASED ON THE ARDUINO PLATFORM AND MONITORING OF CARDIAC ACTIVITY**Makhmudov Sanjar Yuldashali ugli***Senior Lecturer, Department of Electrical Technologies,
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Abstract. *This paper describes the development of a low-cost, single-lead electrocardiograph (ECG) device based on the Arduino microcontroller platform and the AD8232 analog front-end integrated circuit. The device makes it possible to record the electrical activity of the heart in real time, distinguish the P, QRS and T waves, and calculate the heart rate (HR). The acquired signal is cleaned using digital filtering — a 50 Hz notch filter that suppresses mains interference and a 0.5–40 Hz band-pass filter — and is visualized on a personal computer. The experimental results showed that the developed device provides an ECG signal of sufficient quality for educational and preliminary screening purposes. The cost of the device is significantly lower than that of industrial counterparts, which opens up prospects for its use in the educational process and in regions with limited resources.*

Keywords: *electrocardiography, ECG, Arduino, AD8232, biomedical engineering, cardiac monitoring, digital filtering, low-cost medical devices, open-source hardware.*

Introduction

Cardiovascular diseases (CVDs) are currently the leading cause of death worldwide. According to the World Health Organization (WHO), in 2022 approximately 19.8 million people died from CVDs, which is about 32 percent of all global deaths; 85 percent of these deaths are associated with heart attacks and strokes. A particularly important aspect is that more than three quarters of these deaths occur in low- and middle-income countries, while the highest mortality rates are recorded in the regions of Central and Eastern Europe and Central Asia. This situation makes the development of tools for the early and widespread monitoring of cardiac activity an urgent task for Uzbekistan.

Electrocardiography (ECG) is a minimally invasive, inexpensive and highly informative diagnostic method based on recording the electrical activity of the heart, and it is the primary tool for detecting arrhythmias, ischemic conditions and conduction disorders. However, industrially produced clinical ECG units are relatively expensive, and their repair and maintenance are complex, which makes them not always convenient for medical institutions and educational establishments in rural and remote areas. For this reason, low-cost solutions based on open-source hardware and software have gained particular importance in recent years.

The Arduino microcontroller platform, owing to its openness, low cost and widely supported software environment, is widely used for prototyping biomedical measurement devices. The AD8232 integrated circuit, in turn, is specifically designed for amplifying and filtering cardiac signals, and the combination of these two components makes it possible to create a low-cost and compact ECG device.

The aim of this work is to develop a low-cost ECG device based on Arduino and AD8232 that records the electrical activity of the heart in real time, cleans the signal through digital filtering, and

calculates the heart rate, as well as to evaluate its performance. Such a device is intended primarily for educational use (laboratory classes) and preliminary screening, and is not intended for making clinical diagnoses.

Literature review and theoretical background

The ECG signal reflects the difference in electrical potentials that arises as a result of the depolarization and repolarization processes of the cardiac muscle. The following main elements are distinguished within one cardiac cycle: the P wave (atrial depolarization), the QRS complex (ventricular depolarization) and the T wave (ventricular repolarization). The amplitude of the ECG signal recorded from the body surface is usually in the range of 0.5–4 mV, and its main frequency content lies in the range of 0.05–150 Hz; in the monitoring mode a band of 0.5–40 Hz is often considered sufficient.

The signal acquired from the body surface is sensitive to a number of interferences: 50 Hz mains interference from the power line, myographic noise arising from muscle activity, motion artifacts and baseline wander. Therefore, in order to record a high-quality ECG, the signal must be effectively filtered in addition to being amplified.

In recent years, low-cost ECG systems based on Arduino and AD8232 have been discussed in various scientific works. Researchers have shown that such systems are effective for educational purposes, for creating telemedicine prototypes, and for the continuous monitoring of heart rate. At the same time, the authors emphasize that single-lead systems cannot replace the clinical 12-lead ECG and cannot be used for making an official diagnosis. Taking these limitations into account, the present work also proposes a device oriented toward educational and research purposes.

Materials and methods

Hardware. The hardware part of the developed device consists of the following main components (Table 1).

Table 1. Main components of the device

No.	Component	Function / note
1	Arduino Uno / Nano (ATmega328P)	Main microcontroller; digitizes the analog signal (10-bit ADC) and transmits it to the computer
2	AD8232 ECG module	Amplifies the cardiac biopotentials, performs initial analog filtering and leads-off detection
3	Ag/AgCl disposable electrodes (3 pcs)	Acquire the electrical signal from the body surface (RA, LA, RL)
4	Connecting wires and 3.5 mm jack cable	Connect the electrodes to the AD8232 module
5	USB cable / 5 V supply	Power supply and data exchange
6	Personal computer (Python environment)	Signal visualization, digital filtering and storage

Electrode placement. Disposable Ag/AgCl adhesive electrodes were used to record the signal. According to the three-electrode scheme, the electrodes were placed as follows: the positive electrode (LA) in the area of the left chest or left arm, the negative electrode (RA) on the right chest

or right arm, and the reference electrode (RL, right-leg drive) in the area of the right side or right leg. The RL electrode serves to reduce common-mode interference (common-mode rejection).

Signal processing chain. The AD8232 module amplifies the weak cardiac biopotentials and performs the initial analog filtering. The analog output of the module is connected to the analog input (A0) of the Arduino microcontroller. The microcontroller's built-in 10-bit analog-to-digital converter (ADC) digitizes the signal at a sampling rate of 500 Hz, which, according to the Nyquist criterion, reliably covers the useful frequency band of the ECG. The leads-off condition (an electrode detaching from the skin) is detected using the module's LO+ and LO- outputs.

Software. The signal acquisition program was written in C/C++ in the Arduino IDE environment. The digitized values are sent to the personal computer via the serial port (UART). A Python program (PySerial, NumPy, Matplotlib) was used on the computer to visualize and store the signal. At the digital processing stage the following filters were applied: a high-pass filter ($f_c \approx 0.5$ Hz) to eliminate baseline wander, a low-pass filter ($f_c \approx 40$ Hz) to limit high-frequency noise, and a 50 Hz notch filter to remove the influence of the mains. The heart rate was calculated based on the determination of the R–R intervals between QRS complexes (a peak-detection algorithm).

Experimental conditions. The tests were carried out with the participation of healthy volunteers sitting at rest. During each measurement the signal was recorded for at least 60 seconds, after which the obtained recordings were compared in filtered and unfiltered forms. The results were evaluated qualitatively (the separation of the P–QRS–T elements in the signal) and quantitatively (the agreement of the calculated HR with the readings of a reference pulse oximeter).

Results and discussion

In the ECG recordings obtained with the developed device, the main elements of the cardiac cycle — the P wave, the QRS complex and the T wave — were clearly distinguished. After digital filtering was applied, the 50 Hz mains interference and baseline wander in the signal were significantly reduced; as a result, the QRS complexes appeared more distinctly and the reliability of the automatic peak-detection algorithm increased.

The heart rate calculated by the device gave results close to the readings of the industrial pulse oximeter used as a reference: in measurements at rest the difference was within a few beats per minute. This indicator confirms that the device has sufficient accuracy for educational and preliminary screening purposes.

Economic efficiency. The total cost of the device turned out to be several tens of times lower than that of industrially produced clinical ECG units (Table 2). This makes it attractive for the laboratories of educational institutions and for medical posts with limited resources.

Table 2. Approximate cost comparison

System type	Approximate cost
Developed Arduino + AD8232 device	low (at the level of component cost)
Industrial clinical ECG unit	high (tens to hundreds of times more expensive)

Limitations. Since the developed device is single-lead, it cannot replace the clinical 12-lead ECG and cannot detect complex pathologies such as the localization of myocardial infarction. The device is intended not for making an official medical diagnosis, but for educational, research and

preliminary observation purposes. The signal quality depends significantly on the proper adhesion of the electrodes to the skin and on the patient remaining motionless. Future work envisages the addition of wireless (Bluetooth/Wi-Fi) data transmission, autonomous battery power, and improved QRS-detection algorithms.

Conclusion

In this work, a low-cost, single-lead ECG device was developed and tested on the basis of the Arduino microcontroller platform and the AD8232 analog integrated circuit. The device made it possible to record the electrical activity of the heart in real time, to clean the signal through digital filtering, to distinguish the P–QRS–T elements, and to calculate the heart rate.

The experimental results showed that the device provides a signal of sufficient quality for educational and preliminary screening purposes, while its cost is significantly lower than that of industrial counterparts. This confirms that low-cost, open-source biomedical devices can play an important role in enriching the educational process and in the preliminary monitoring of cardiac health in resource-limited areas. Considering the high prevalence of cardiovascular diseases in the Central Asian region, the development and implementation of such solutions is a task of social significance.

References

1. World Health Organization. Cardiovascular diseases (CVDs): Fact sheet. — Geneva: WHO, 2025. [Electronic resource]. — URL: [https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-\(cvds\)](https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds))
2. Erkabaeva A.N., Makhmudov S.Y. Creation of a laboratory ECG using Arduino: an affordable solution for monitoring cardiac activity // Proceedings of BNTU. — Minsk, 2024. (In Russian)
3. Haqqulov M.K., Makhmudov S.Y. An ultrasonic air-humidification device // Modern Problems and Prospects of Biomedical Engineering. — 2022. — No. 1. — P. 63–65. (In Uzbek)
4. Ziyomukhammedova M.Kh., Makhmudov S.Y. Smart scales for children // Proceedings of BNTU. — Minsk, 2024. (In Russian)
5. Analog Devices. AD8232 — Single-Lead, Heart Rate Monitor Front End: Data Sheet. — Analog Devices Inc., 2013–2020.
6. Webster J.G. (ed.) Medical Instrumentation: Application and Design. — 4th ed. — Hoboken: John Wiley & Sons, 2010. — 713 p.
7. Sornmo L., Laguna P. Bioelectrical Signal Processing in Cardiac and Neurological Applications. — Amsterdam: Elsevier Academic Press, 2005. — 688 p.
8. Pan J., Tompkins W.J. A Real-Time QRS Detection Algorithm // IEEE Transactions on Biomedical Engineering. — 1985. — Vol. BME-32, No. 3. — P. 230–236.