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Research Article

Data Acquisition System for Clinical Research in Plethysmographic Signal

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I N F O

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A B S T R A C T

Photoplethysmography (PPG) is a non-invasive optical technique used to monitor blood volume changes in peripheral tissues. This paper presents the design and implementation of a low-cost, modular data acquisition (DAQ) system for capturing PPG signals using the MLT1020 sensor. The system includes a custom analogue front end with a bandpass filter (0.5–5 Hz), combining a 5th-order high-pass and 7th-order low-pass filter to suppress noise and motion artefacts. The output signal is visualised in real-time on a Digital Storage Oscilloscope (DSO) and later analysed in MATLAB. Experimental results from human subjects showed clean, periodic waveforms with reliable cardiac cycle representation. Signal quality was comparable to that obtained from commercial DAQ systems, confirming the system's effectiveness for basic biomedical research. The setup is particularly suited for educational and research settings where cost and customisation are key. Future versions may include microcontroller integration, wireless communication, and digital storage. This system bridges the gap between theory and hands-on experimentation, providing an accessible platform for physiological signal processing.

Keywords: Photoplethysmography, Data Acquisition System, Physiological Signal Processing, Analogue Filter Design

Introduction

Photoplethysmography (PPG) is a non-invasive, low-cost, and simple optical method of detecting volumetric blood circulation changes. Introduced in the early 1930s, it has developed into a critical signal acquisition tool in current clinical application and wearable health monitoring.[1] The method applies transmission or reflection of light into the tissue and detects changes in the absorption of light due to pulsatile blood flow. These variations are synchronised with the cardiac cycle and create a waveform that is filled with physiological and pathological information regarding cardiovascular health.[2]

The PPG waveform consists of two primary components: the pulsatile (AC) component and the slowly varying (DC) component. The AC component is in line with cardiac synchronous changes, i.e., every heartbeat causes a sudden spike and gradual decline in the waveform. The DC component is affected by respiration, sympathetic nervous activity, and thermoregulation. This dual capability makes PPG not only supply essential signs such as heart rate (HR) but also function as an alternative indicator for more sophisticated physiological measures such as blood pressure estimation (through pulse transit time), respiration rate, vascular stiffness, and even stress levels.[3]

PPG signal monitoring has become more crucial in clinical and research applications. It offers a noninvasive method to monitor cardiovascular health, particularly in long-term care and ambulatory populations. Unlike ECG or invasive blood pressure measurements, PPG is simpler to use and doesn't require much setup or discomfort for patients. With signal processing, machine learning, and miniaturisation of sensors, PPG is increasingly applied for early cardiovascular abnormality detection, diabetic neuropathy, autonomic dysfunction, peripheral artery disease, and sleep apnoea.[4-5] Its use in the assessment of mental illness through heart rate variability (HRV) and detection of stress has also picked up speed.

The typical range of the amplitude of the PPG signal is between 0.5 mV and 5 mV, and its frequency is between 0.5 Hz and 5 Hz, which translates into a range of heart rates from 30 beats per minute to 300 beats per minute. The signal, however, suffers from motion artefacts, interferences caused by ambient light, and non-uniform skin contact. Thus, the effectiveness of an acquisition system of a PPG is greatly reliant on the analogue signal from the sensor and on environmental stability.[6]

With time, the significance of PPG has increased dramatically, much like ECG and invasive blood pressure measurements used to become standards for cardiac monitoring. The integration of artificial intelligence and wearable biosensors is propelling PPG into an era where it is not only an ancillary signal but also an independent modality for multi-modal health monitoring.[7] Its simplicity and noninvasiveness permit it to be incorporated into smartwatches, mobile health apps, and even remote diagnostics platforms.

Notwithstanding the popularity of commercial pulse oximeters and smartwatches, there remains a wide gap in cost-effective, raw-signal acquisition systems that can be customised for clinical research and academic inquiry. All readily available systems are either closed source or restricted in what they can deliver as clean, unprocessed signals appropriate for algorithm development or physiological investigation. Closing this gap, our effort is to design a low-cost, user-built PPG acquisition system that is high-accuracy, modular, and accessible — allowing researchers and students to experiment, customise, and analyse physiological waveforms with a research-grade setup.

The heart of our system relies on the MLT1020PPG sensor from AD Instruments, a highly accurate optical sensor that provides robust detection of arterial pulse signals with reduced noise. It is designed on the principle of infrared light absorption with excellent tissue penetration and a high signal-to-noise ratio. The clinical-grade accuracy of the sensor and its compatibility with custom analogue circuitry make it a perfect candidate for this study.

In order to obtain a clean PPG signal, a 7th-order analogue bandpass filter was carefully configured. The intended purpose of this filter is to separate the physiological frequency range of interest from both low-frequency baseline drifts (e.g., respiration-induced fluctuations) and high-frequency noise (e.g., muscle contractions, electrical noise).The bandpass region was chosen to be around 0.5 Hz to 10 Hz such that both heart rate and its harmonics are maintained and noise is reduced to a minimum. The 7^{th}-order filter provides high-order roll-off behaviour, which greatly enhances the selectivity and quality of the detected signal over low-order first- or second-order filters.

The filter and sensor interface that are designed collectively constitute a whole analogue front-end system, enabling real-time monitoring of the PPG signal on a Digital Storage Oscilloscope (DSO). This eliminates digital signal processing during the first stage and enables researchers to visually confirm waveform morphology, timing characteristics, and signal quality immediately. Because the output is conditioned and analogue, it can be straightforwardly digitised by any conventional DAQ system or microcontroller platform if additional processing or storage is warranted.

One of the main driving forces for this work was to facilitate individual-level research. In most academic environments, particularly within developing nations, access to biomedical acquisition systems is restricted and commonly shared between groups. This makes individual experimentation, innovation, or sole validation of an algorithm challenging. With the development of a cost-effective, high-quality acquisition system, our solution enables undergraduate and postgraduate researchers to explore independently PPG signal processing, feature extraction, and clinical correlation without the constraints of hardware or licensing problems.

Also, the system is built with scalability in mind. Future versions may make it possible to integrate with microcontrollers for real-time logging of data, wireless transmission modules for wearable use, or machine learning interfaces for automated disease prediction. The modular design of our setup fosters incremental development and academic innovation.

This paper provides a comprehensive description of the system design, component choice, circuit implementation, and performance assessment. We begin with the system architecture, followed by the description of the MLT1020PPG sensor and technical breakdown of the

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7th-order bandpass filter in the Materials and Methods section. Experimental results demonstrating real-time PPG acquisition and waveform quality are presented, with a discussion on the usability, limitations, and potential for future improvement of the system. This paper offers an empirical, research-based solution for obtaining pure, raw PPG signals with a low-cost but high-performance system. It fills the gap between theoretical understanding and experimental application, offering a concrete platform for clinical and academic research into physiological signal observation.

Materials And Methods

This section contains details of the architecture, sensor and design of our custom DAQ.

System architecture (Block Diagram)

The system architecture primarily comprises three major functional stages: signal acquisition, signal conditioning (filtering and amplification), and signal output/visualisation. A block diagram illustrating the architecture is shown in Figure 1.

Input Stage

A photoplethysmographic (PPG) sensor was used for signal acquisition. The sensor detects variations in blood volume within peripheral tissue and was positioned on the participant's index finger..An excitation voltage of 9V was given to the sensor, and analogue signals were obtained from it, which served as the primary input for the system.

Signal Processing Stage

Given that the frequency range of PPG signals typically lies between 0.5 Hz and 5 Hz, signal conditioning is essential for accurate analysis. The pins of the sensor[1] were connected to an 8- pin DIN female connector to obtain the signal. The acquired signal was amplified and passed through a custom-designed band-pass filter to attenuate high-frequency noise and low-frequency drift.

Output Stage

The filtered analogue output was visualised using a digital storage oscilloscope (DSO). This output could then be captured and used for further digital analysis.

Figure 1: Block diagram of the custom-built PPG-based DAQ system. The PPG sensor receives power from a dual (+9V/+12V) source and transmits the signal through an 8-pin DIN connector. The signal is then processed through a filter block comprising a 5th-order high-pass filter followed by a 7th-order low-pass filter to isolate the desired PPG frequency band. The filtered output is visualised on an oscilloscope, stored, and later analysed using MATLAB for further signal processing.

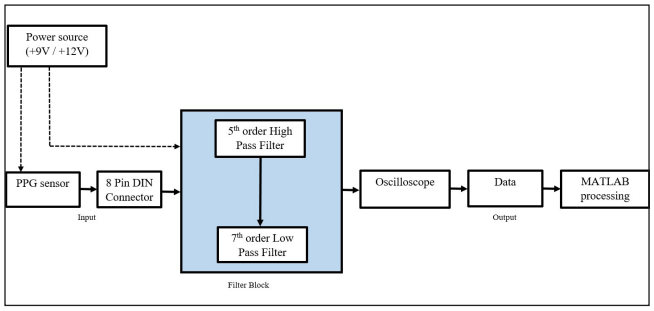

Figure 1.System architecture (Block Diagram)

Sensor

Peripheral pulse waveforms were recorded using the MLT1020 Pulse Transducer (AD Instruments, Australia), a photoplethysmography (PPG) sensor which uses photoelectric sensors for non-invasive monitoring of blood volume changes in peripheral tissue. The transducer was attached to the distal phalanx of the participant's index finger using its integrated Velcro strap, ensuring consistent sensor contact and minimising motion artefacts. The MLT1020 was chosen for its ability to produce high-resolution, raw PPG signals suitable for advanced waveform analysis. All recordings were conducted under controlled ambient lighting conditions with subjects in a seated and relaxed posture to ensure data consistency. The sensor requires an excitation voltage of 6V to 9V DC. The wavelength is 950 nm, which is in the infrared range of the electromagnetic spectrum. The connector of the sensor is of the 8-pin DIN type.

Figure 2: MLT1020 PPG probe used for detecting blood volume changes via infrared light, connected to the DAQ system for signal acquisition.

CustomBuilt DAQ

The filtering unit is the core of the system. It consists of higher-order low-pass and high-pass filters, which filter out the PPG signals obtained from the sensor and reduce its noise component. Together, both of these circuits have a bandpass frequency range of 0.5 to 5 Hz.

- **High-pass filter (5th order):** The first stage is an active high-pass filter which has a cut-off frequency of 0.5 Hz. The cutoff frequency is calculated as fc (HPF1) = 1/(2.л.R.C1) Hz.
- **Low-pass filter (7th order):** The next stage is an active low-pass filter set at a cut-off frequency of 5 Hz. The cut-off frequency of this filter is given by the relation fc (LPF1) = 1/(2.л.R.C2) Hz.
- **Figure 3:** Assembled circuit on a prototyping board implementing the analog filtering stages for PPG signal conditioning.

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Figure 4: Output of the bandpass filter circuit as displayed on the DSO. The filtered signal shows a clean and stable waveform, indicating successful removal of unwanted frequency components and retention of the PPG signal's core structure.

Figure 5: Output of the custom-built DAQ system. The periodic analog signal represents the processed PPG waveform after passing through the designed filter circuitry, confirming the functional performance of the DAQ hardware.

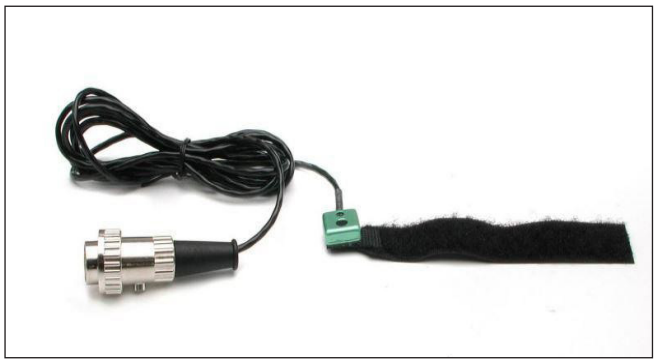

Figure 2.Sensor

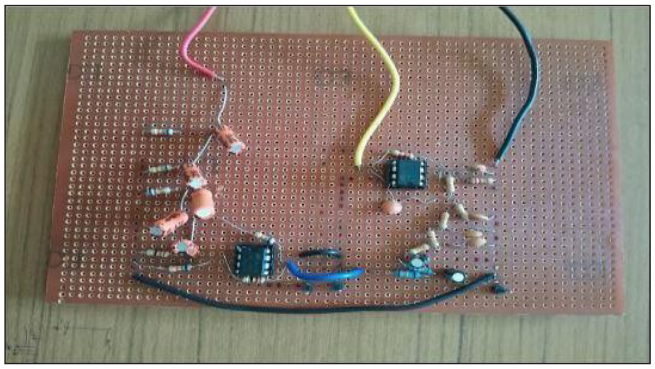

Figure 3.Filter design

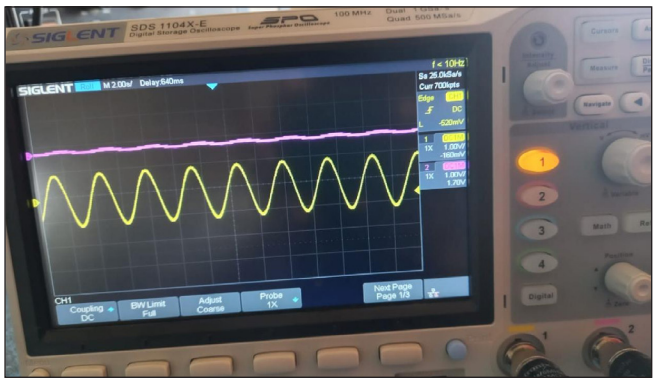

Figure 4.Output of our bandpass filter circuit

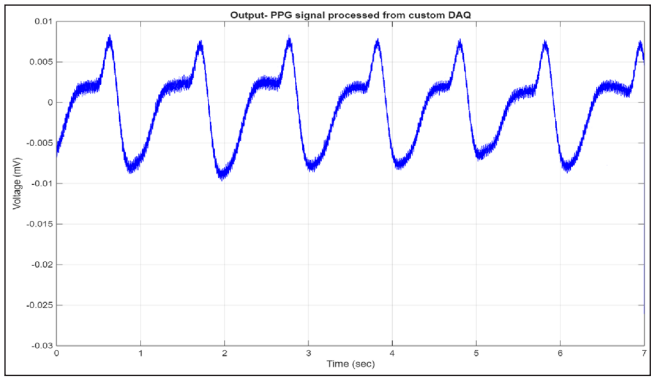

Figure 5.Output- PPG signal processed from custom DAQ

Declaration of Interest

The authors declare that there are no known financial or personal relationships that could have appeared to influence the work reported in this manuscript. This research was conducted solely for academic and educational purposes, with no commercial affiliations or external funding sources that could result in a conflict of interest.

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Conclusion

This study successfully demonstrates the design, development, and preliminary evaluation of a custom-built data acquisition (DAQ) system for capturing photoplethysmography (PPG) signals using an MLT1020 probe. The acquired signals consistently exhibited clean, periodic waveforms representative of the underlying cardiac cycles, thereby validating the efficacy of the system's analogue front-end design. The use of a well-calibrated bandpass filter (0.5–5 Hz) and a notch filter substantially reduced baseline drift and environmental noise, resulting in enhanced signal fidelity during stable recording intervals. As shown in Figure 4, the output of the bandpass filter circuit was firstly observed on the oscilloscope, where a clean and periodic waveform was visible. This confirms that the filter

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design effectively attenuated both low-frequency baseline drift and high-frequency noise components, preserving the essential PPG signal characteristics. This also confirms the system's ability to acquire stable biosignals under resting conditions. Figure 5 presents the output of PPG processed from the custom-built DAQ system, highlighting the real-time analogue signal behaviour. The waveform exhibits consistent pulse cycles, validating the performance of the designed hardware setup.

Notably, the DAQ system enabled real-time monitoring via Digital Storage Oscilloscope (DSO), with data subsequently exported for offline visualisation in MATLAB. While the current phase of analysis focused primarily on time-domain characteristics and spectral representation, the quality of the captured signals indicates that the system holds potential for advanced feature extraction and physiological parameter estimation in future work.

A comparative evaluation with commercial-grade systems compatible with the same optical probe, such as those developed by AD Instruments, revealed that the custom DAQ setup delivers comparable signal quality at a significantly reduced cost. This makes it particularly advantageous for academic institutions, biomedical engineering laboratories, and student-driven research initiatives where budget constraints are common.

However, the current hardware configuration lacks portability and compact form factors, limiting its deployment in ambulatory or wearable health monitoring scenarios. Future development efforts will aim to integrate digital signal processing, wireless communication, low-power design considerations and multiple commercial PPG probes sharing the same data acquisition design to enhance its applicability in mobile health technologies and broader translational research domains.

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