BRNO UNIVERSITY OF TECHNOLOGY
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# VITAL SIGNS MONITORING


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## 1 Motivation

- Propose a low-cost, low-power solution for centralized vital signs monitoring
- Provide an easily-maintainable and scalable solution for medical facilities
- Non-invasive acquisition of heart rate (HR) and oxygen saturation ($SpO_2$) data using photoplethysmography (PPG) for continuous monitoring and early prediction of medical conditions
- Minimization of the infrastructure required for wireless communication in clinical and home environments
- Design and evaluation of an affordable system of wearable wireless devices communicating via Bluetooth Low Energy (BLE) mesh

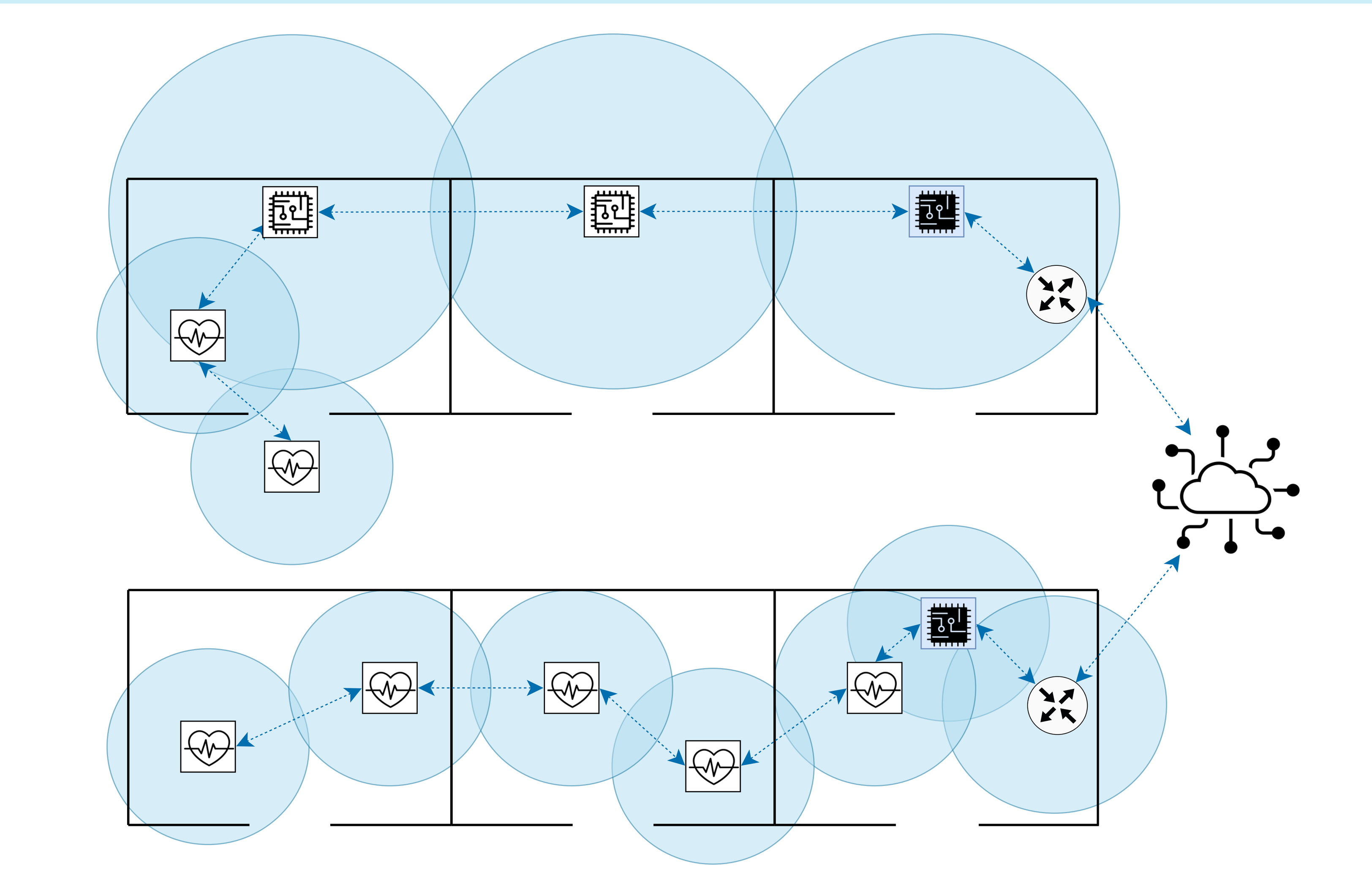

*Figure 1: Proposed system of acquired data transmission with relay nodes (top) or purely by the relaying features of wearable devices (bottom).*

## 2 Biometric Data Acquisition and Analysis

For data transmission into the low-throughput mesh network, the biological indicators need to get extracted from the collected PPG waveform. The signal processing takes place directly *in situ* on a wearable embedded microprocessor with constrained processing power and memory resources.

### Filtration

A fourth-order Chebyshev II bandpass IIR filter is applied for effective removal of both noise and motion artifacts. While the collected signal is filtered forward and backward to reduce time shifts, the initial filter oscillations are trimmed out completely.

### Smoothing

Convoluting the data with a kernel of ones of sufficient size detrends signal and emphasizes the cardiac cycle modulated onto the waveform.

### Peak Detection

Experimentally developed peak-and-trough detection algorithm, based on standard deviation delta parameter, robustly calculates HR from PPG waveform (Figure 2) in a single pass-through with minimal required stack size.

### $SpO_2$ Approximation

The arterial oxygen saturation is approximated based on different molar extinction coefficients of oxygenated and deoxygenated haemoglobin ($HbO_2$ and Hb, respectively) with a LED wavelength in the 600-700 nm range.

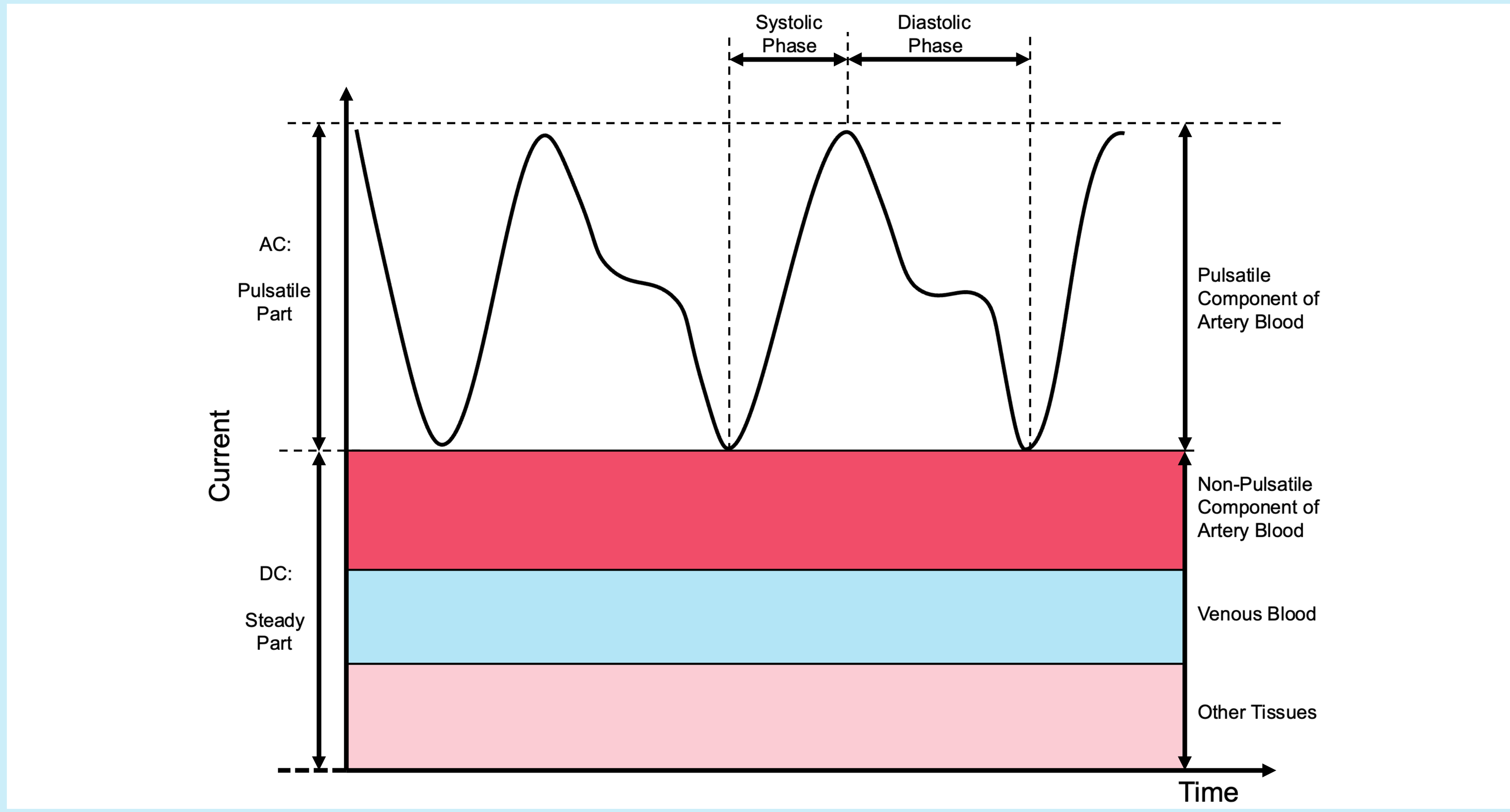


*Figure 2: A theoretical overview of various components comprising the PPG waveform. Cardiac-cycle-modulated part (top) accounts for approximately 1% of the amplitude [1], while the DC part alters in time.*

## 3 System Design

- Bluetooth Low Energy Mesh networking is used for its low energy requirements, stable topology, extensive cover range, and emphasis on security.
- System implemented in Zephyr RTOS (real-time operating system), with custom sensor driver and functions for data transmission.

### Types of Nodes in the Mesh Network:

- BLE mesh provisioner node is used for creating the mesh, generating and spreading encryption keys, and setting subscriptions and publications on all other nodes.
- Each patient wears a wrist-mounted data-collecting device that processes and transmits the indicators of vital signs into the mesh network.
- Data gets transmitted (by managed flooding) into the mesh network towards one or more end nodes with a Wi-Fi connectivity. Messages can be relayed by other devices or, alternatively, by deploying relay nodes (Figure 1).
- Distribution of relay nodes across a building can be used to ensure stable mesh network coverage for patents' monitoring devices.
- An endpoint node with Wi-Fi connectivity (e.g., ESP32-S3) sends timestamped and labelled messages to an MQTT (Message Queuing Telemetry Transport) broker, which can save them in a database.
- Medical personnel can access the collected information via a web graphical user interface and get alerted in case of any medical problem.
- For prototyping, an nRF52833 Development Kit board (provisioner, wearable monitoring device, relay node), and ESP32-S3 (end node) were used.

## 4 Benefits of the Proposed Solution

- Applicability in many areas (e.g., hospitals, nursing homes, athletic training facilities).
- Extremely low estimated cost of a patient-worn device (10-20€) compared to other solutions.
- Customizable filtering and smoothing allow for adjustments based on specific healthcare facility or patient requirements.
- Convenience for patients and supervisors in healthcare facilities.
- Accessibility of collected data on the internet in real-time.
- Alerts and possibility of location tracking enhancement for improved patient safety and rapid intervention.


**References:** [1] Alharbi, Samah & Hu, Sijung & Mulvaney, David & Barrett, Laura & Yan, Liangwen & Blanos, Panos & Elsahar, Yasmin & Adema, Samuel. (2018). Oxygen Saturation Measurements from Green and Orange Illuminations of Multi-Wavelength Optoelectronic Patch Sensors. *Sensors*. 19. 118. 10.3390/s19010118.