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Development of a Universal, Portable Bluetooth Low Energy (BLE) Data Logger for Biomedical Sensor Applications

BioMed Logger – an application example, based on a Polar H10 ECG system, 3D-printed, waterproof, open-source with low-cost components and raw-data access

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Abstract: In this work, we present a portable, open-source data logger with fully enclosed hardware that supports modification and operation under demanding conditions such as 100% relative humidity and exposure to chemical disinfectants. Based on a Raspberry Pi Zero W (RPI), the system manages BLE communication with various sensors to extract, analyse and store biomedical data during runtime. Its architecture is extensible with medical-grade, consumer-grade and custom-made hardware for multisensory applications. A web interface enables configuration and data export, making the device suitable for biomedical research. As an example, a Polar H10 sports chest strap is used for ECG- and acceleration (ACC) measurements.

Keywords: universal data logger, ECG, HRV, neurokit2, 3D-Printing, Internet of Medical Things, MQTT, open source, Polar H10

1 Introduction

In scientific studies reliably capturing biomedical sensor data can be challenging – especially for long-term measurements without limiting participant mobility. Although wearable systems like commercial smartwatches are common, they typically do not support custom software, restrict access to raw data and cannot be easily modified or extended with third-party or self-developed sensors. Retrieved data is often provided via manufacturers' cloud solutions, raising concerns about data privacy and proprietary dependencies.

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Therefore, an open-source, battery-powered data logger with runtime data-processing was developed on the example of logging ECG- and ACC-metrics captured through a Polar H10 ECG chest strap.

Demand emerged specifically during a study performed in Bad Gastein Healing Galleries, where autonomous nervous system activity is investigated during mild hyperthermia treatment in the high humidity environment at 100% relative humidity and 40° Celsius. [1]

2 Material and Methods

Our measurement setup consists of a single-lead ECG chest strap (see Figure 1) as ECG- and ACC-sensor, which is worn directly on the skin, and a body-worn data logger introduced in this work – both connected via BLE.



Figure 1: Polar H10 ECG chest strap, providing ECG- and ACC-data via BLE. [2]

2.1 Hardware

The data logger hardware unit consists of three main components: A computing platform, an enclosure and a power supply chain.

2.1.1 Computing Platform

A RPI is used for capturing, computing and logging BLE-data. Equipped with onboard WIFI- and BLE-Controller it allows setting up a WIFI-Access-Point.

2.1.2 Enclosure

All hardware components are held and secured into a defined position by an "internal framework" (see Figure 2), which is 3D-printed separately from the housing itself. After circuit-assembly, the framework is imprinted into the housing by pausing the process and inserting the pre-assembled components – as the framework also serves as a support-structure – ultimately creating a fully enclosed system.

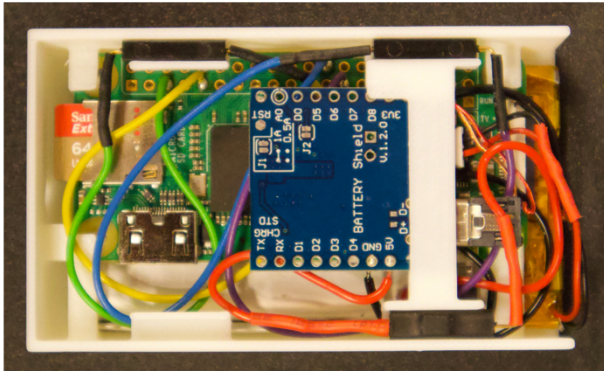


Figure 2: Hardware components are held in position by an "internal framework".

As printing material, Acrylnitril-Styrol-Acrylat (ASA) is used, which is highly chemically- and UV-resistant, making it suitable for medical disinfectants and long-term application.

Without post-processing the print, tests showed water-leakage at the z-hop position which was sealed by surface-smoothing with acetone-vapor (see Figure 3).

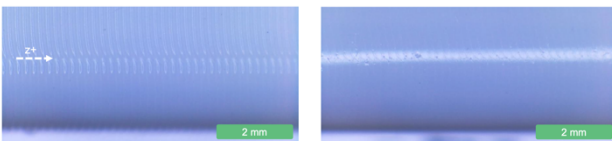


Figure 3: Enclosure before and after surface-smoothing with acetone-vapor. z⁺ indicates z-hop position where water-leakage occurred.

2.1 Power Supply

Battery charging is achieved via an inductive charging module, eliminating the need for cable connections. A power shield regulates the voltage as well as the charging process (see Figure 4). A magnetic switch opens the power circuit when inserted into a "storage shell" (see Figure 6) to prevent battery draining during storage.

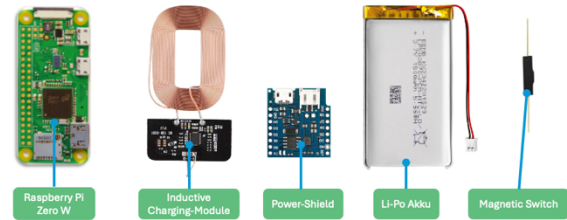


Figure 4: Hardware components of the power supply unit.

2.2 Software

All software is running on a lightweight RaspberrypiOS Linux-distribution and is organized into data processing (including sensor connection) and user interaction (including session control and data export).

2.2.1 Sensor Connection and Data Processing

A main script, written in Python, manages BLE communication, asynchronous data extraction, biomedical analysis and local storage of the information in .csv format.

ECG analysis including HRV calculations, the highly advanced module *neurokit2*, is used. It allows an integration of multiple custom-made, commercial and clinical-grade medical sensors, since it supports a standardised GATT-Protocol for BLE devices. *neurokit2* is also equipped with various analysis and visualisation tools. [3]

2.2.2 Session Control and Data Export

The user interface is implemented using Node-RED, a flow-based programming environment. [4] Through the interface, users can initiate and terminate recordings, enter subject details and adjust recording parameters. A real-time data visualisation provides feedback about the ongoing recording. (see Figure 5). In addition, the browser-based file-management-tool *filemanager* enables data export and user administration. [5]

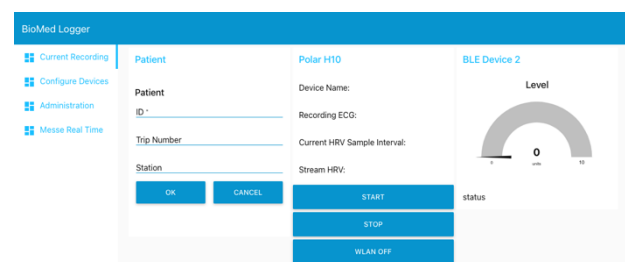


Figure 5: Web interface for configuration, session-control and real-time monitoring

3 Results

The ECG signal at 130 Hz, HRV-values and ACC-data – both at custom intervals – are reliably received, processed and stored. Each data point is assigned to a timestamp originating from the chest strap module for enhanced data integrity.

Battery life in this example use-case ranges from approximately 8-12 hours, depending on operation mode. CPU and memory usage showed 25% and 30% respectively during recording with only short peaks at HRV-value calculations.

Waterproof-tests on two test-prints were successful after submerging for 48 hours without leakage. Dimensions are smaller than typical smartphones (see Figure 6) while also being lighter in weight (85g).

The signal-input as well as opening the power-circuit during storage for preventing standby-current through magnetic switches had to be disabled due to unreliable operation, especially in high movement situations. However, the web interface and software-logic provide all necessary functions and can compensate this deficiency.

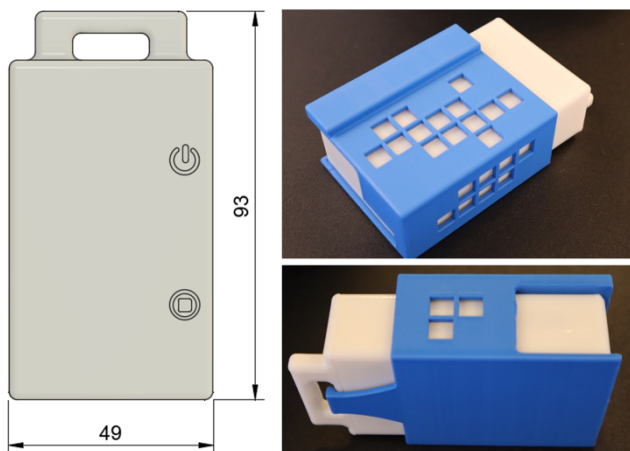


Figure 6: left: data logger with dimensions; right: data logger inside storage shell (blue) preventing standby current.

4 Discussion

The “BioMed Logger” demonstrates a concept for universal, portable data logging in biomedical sensor applications under demanding conditions, achieved through low-cost, open-source components and 3D-printing technology.

Our system’s design, centred on a compact RPI for BLE communication and data processing, combined with a fully enclosed, 3D-printed housing which provides a modifiable and extendable platform. This allows for easily available additional sensors such as pulse oximetry, galvanic skin response- or electromyographic sensory. It therefore

makes applications in multiple disciplines possible including sleep-monitoring, cardiovascular analysis, neurological studies, sports performance monitoring or balneotherapy.

Modification and hardware extendibility is a substantial advantage over commercial wearables, which typically restrict raw-data access and lack customisation options but are theoretically capable of delivering high-quality data from a measurement technology perspective. This is exemplified by the Polar H10 sports chest strap, which, was originally designed for consumer fitness applications. [6-7]

Furthermore, the use of low-cost components with high availability reduces the overall expense, making the system also accessible for individuals or research groups with limited funding.

In future iterations, the magnetic switches – which are intended for power management and to trigger specific functionalities by inserting the device into the storage shell from different orientations – are expected to be improved, as the current components cause instability.

Author Statement

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