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# Hardware 2 Project Requirements

Version 2.11

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Hardware 1 & 2 courses

School of ICT

Metropolia University of Applied Sciences

## Revision history

| Version | Date | Reason for changes | Author |
|---|---|---|---|
| 2.1 | 27.1.2023 | New version of the requirements specification using IEEE standard-based template | Sakari Lukkarinen |
| 2.2 | 2.2.2023 | Changes based on requests, comments of the first change request meeting 30.1.2023. | Sakari Lukkarinen |
| 2.3 | 5.2.2023 | Added missing hardware components, simplified the contents, use cases and functional requirements moved to Excel sheet | Joseph Hotckiss, Sakari Lukkarinen |
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| 2.5 | 9.3.2023 | Minor modifications and corrections | Sakari Lukkarinen |
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| 2.9. | 2.1.2024 | Changed the word “trend” to “history” in user requirements | Sakari Lukkarinen |
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| 2.11. | 7.1.2024 | Minor modifications and improvements | Sakari Lukkarinen |

## Document approval

This document has been accepted and approved by the project teachers and management team:

| Name | Title | Date |
|---|---|---|
| Joseph Hotchkiss | Senior Lecturer | 6.2.2023 |
| Keijo Länsikunnas | Senior Lecturer | 6.2.2023 |
| Saana Vallius | Senior Lecturer | 6.2.2023 |
| Sakari Lukkarinen | Senior Lecturer | 6.2.2023 |
| Marko Uusitalo | Senior Lecturer | 20.1.2024 |

## Contents

# 1 Introduction

This document is adapted from Software Requirements Specification Template prepared for Software Engineering Principles I course by A. David McKinnon, Washington State University, March 2005 [1]. The template is based upon the IEEE Guide to Software Requirements Specification (ANSI/IEEE Std. 830-1984) [2], and the SRS templates of Dr. Orest Pilskans (WSU, Vancover) and Jack Hagemeister (WSU, Pullman).

This document should contain all the information needed by an engineering student team to adequately design and implement the product described by the requirements listed.

## 1.1 Purpose

The purpose of this document is to give the requirements for the hardware project for the first year ICT engineering students studying at Metropolia University of Applied Sciences. The intended audience of this document is both the students and the lecturers guiding the project.

## 1.2 Scope

In this project a heart rate detection and analysis system is to be produced. The aims for the project are:

1) develop a heart rate detection algorithm that works on the device locally,

2) to calculate heart rate variability (HRV) analysis,

3) build a connection to Kubios Cloud HRV analysis service to calculate more detailed HRV analysis, and

4) show the estimated stress and recovery status indexes on the device.

The device is intended to be used in home or office environments either by the end users themselves or together with health and wellbeing professionals such as physiotherapists, nurses, or medical doctors.

The device detects the heart rate and its variability using a photoplethysmography (PPG). It measures optically blood volume changes in the microvascular bed of tissue. The change in volume is detected by measuring the light emitted by a light emitting diode (LED), absorbed by the tissues, and detected with a photodiode. The heart rate can be measured from the peaks of the alternating signal presenting the volumetric blood changes in the tissue.

## 1.3 Definitions, acronyms, and abbreviations

| | |
|---|---|
| α | Slope of the linear interpolation of the spectrum in a log-log scale |
| ADC | Analog-to-digital converter |
| ANS | Autonomous nervous system |
| ANSI | American national standards institute |
| API | Application programming interface |
| BPM | Beat per minute |
| CPU | Central processing unit |
| DIP | Dual in-line package |
| ECG | Electrocardiogram |
| GND | Electrical ground |
| Grove | A modular, standardized connector prototyping system |
| HF | High frequency (0.15 - 0.4 Hz) |
| HR | Heart rate, typically given in units of beat per minute (BPM) |
| HRV | Heart rate variability, measures how variability there is in the heart rate from beat to beat over a longer period, can be characterized by several parameters |

| | |
|---|---|
| Hz | Hertz, cycles per second, unit for frequency |
| I2C | Inter-Intergrated circuit, a synchronous multitarge serial bus interface protocol |
| IDE | Integrated development environment |
| IEEE | Institute of electrical and electronics engineers |
| IBI | Inter-beat-interval, measured from PPG signal, given in milliseconds (ms) |
| LAN | Local area network |
| LED | Light emitting diode |
| LF | Low frequency (0.04 - 0.15 Hz) |
| LF/HF | Ratio of LF/HF |
| MCU | Microcontroller unit |
| ms | millisecond |
| NN interval | Time difference between two peaks either in ECG or PPG signal, either PPI or RRI (ms) |
| NN50 count | Number of pairs of adjacent NN intervals differing more than 50 ms |
| OLED | Organic light-emitting diode |
| PCB | Printed circuit board |
| pNN50 | NN50 count divided by the total number of all NN intervals |
| Poincaré plot | a type of recurrence plot used to quantify self-similarity in processes, usually periodic functions |
| PPI | peak-to-peak interval, time difference between two pulse peaks in signal measured in ms |
| PPG | Photoplethysmography, optically detected heart pulse typically detected from peripheral blood circulation, like from finger, wrist, toe, or ear lobe |
| PNS | Parasympathetic nervous system, part of autonomic nervous system |

| | |
|---|---|
| PTSD | Post-traumatic stress disorder |
| QRS | Segment of ECG signal |
| RAM | Random access memory |
| REST | Representational state transfer and architectural style for distributed hypermedia systems |
| RMSSD | The square root of sum of squares of differences (ms) |
| ROM | Read only memory |
| RRI | RR-interval, time difference between two R-peaks in ECG signal (ms) |
| SD1 | Poincaré plot index, the first ellipse shape parameter estimated from the Poincaré plot |
| SD2 | Poincaré plot index, the second ellipse shape parameter estimated from the Poincaré plot |
| SDANN | Standard deviation of the average of NN intervals (ms) |
| SDNN | Standard deviation of all NN intervals (ms) |
| SDSD | Standard deviation of differences between adjacent NN intervals measured in milliseconds (ms) |
| SI | Baevsky’s stress index |
| SNS | Sympathetic nervous system, part of autonomic nervous system |
| SPI | Serial peripheral interface |
| ULF | Ultra-low frequency (0 - 0.003 Hz) |
| USB | Universal serial port |
| Vcc | Operating voltage |
| WiFi | Wireless fidelity |
| VLF | Very flow frequency (0.003 - 0.04 Hz) |

### 1.4 References

A complete list of all documents referenced is provided at the end of this document in chapter 5 References.

### 1.5 Overview

Chapter 2 describes the general factors that affect the product and its requirements. Chapter 3 gives the specific requirements that are used to guide the project's design, implementation, and testing. Chapter 4 identifies and describes the process that will be used when project scope or requirements change. Chapter 5 lists all documents referenced in this document.

## 2 General description

In this section the general factors that affect the product and its requirements are described. This section does not state specific requirements; it only makes those requirements easier to understand.

### 2.1 Product perspective

#### 2.1.1 Stress

Stress is defined as "a physical, mental, or emotional factor that causes bodily or mental tension" [3]. According to the American Institute of Stress [4] [5]:

- 77 % of people experience stress that affects their physical health
- 73 % of people have stress that impacts their mental health
- 48 % of people have trouble sleeping because of stress
- 33 % of people report feeling extreme stress

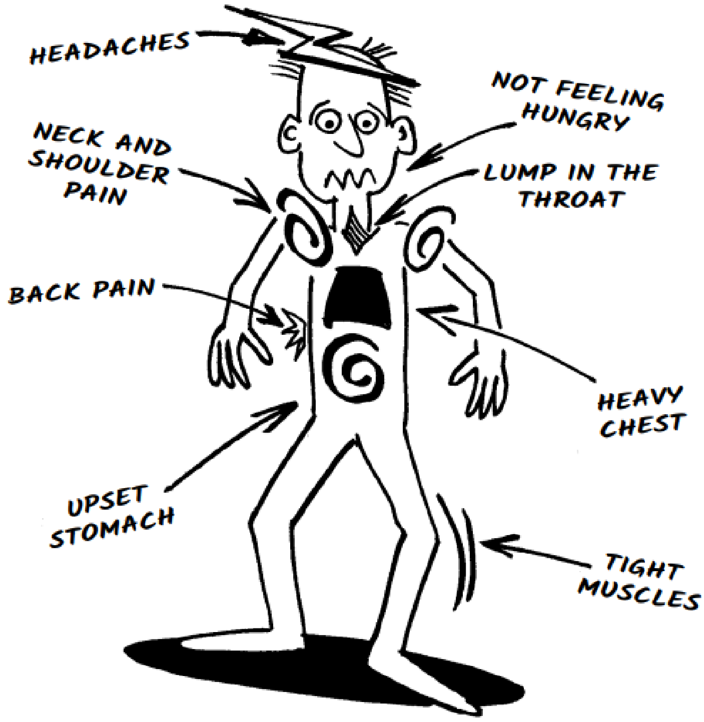


Figure 1. Very high stress often affects the body. Many people get unpleasant feelings. Original from [6].

Physiological or mental imbalance can induce stress. Our autonomic nervous system (ANS) quickly responds to physiological changes through our sympathetic (SNS) and parasympathetic (PNS) nervous systems. During the stress response our body's endocrine system releases hormones, and several changes in our physiological state occur. For example, heart rate (HR) can even double or triple and causes changes to HRV. [7]

### 2.1.2 Detecting heart rate

The heart rate or pulse rate measures how often the heart beats and is given in units of beats per minute (BPM). Usually, the heart rate varies on the body's physical need, but is also affected by physical fitness, stress of psychological status, diet, drugs, hormones, environment, diseases, and illnesses. The normal resting adult heart rate is 60-100 BPM. During sleep, a heart rate of 40-50 BPM is common and considered normal. [8]

Heart rate variability (HRV) is the variation of the time intervals between heartbeats, and it is measured in units of seconds (s), or more commonly, in milliseconds (ms). Other terms used include RR interval (RRI) variability, where R corresponds to the peak of QRS-complex of electrocardiography (ECG), and Peak-to-Peak interval (PPI, or inter-beat-interval = IBI), if the HRV is measured optically. Figure 2 illustrates how the heart rate variability is determined both from changes in PPG and ECG signals [9].

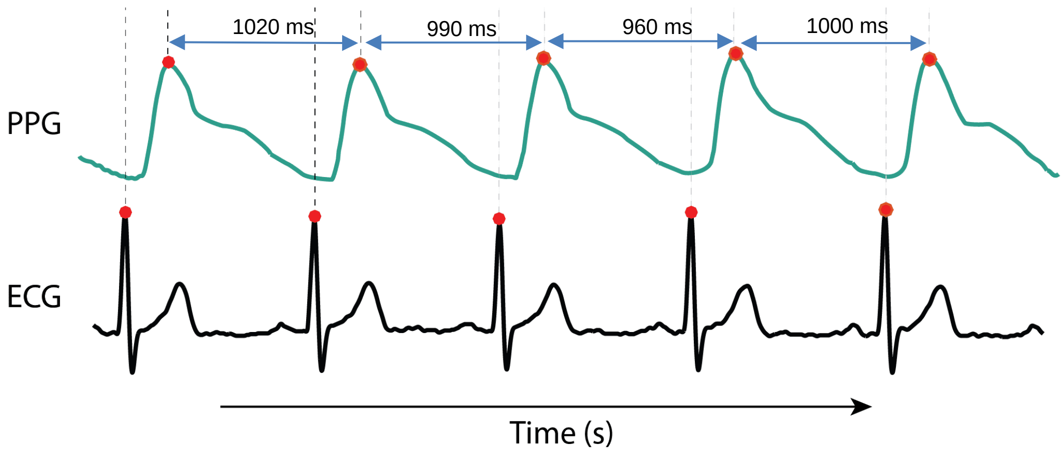


Figure 2. Heart rate variability (HRV) calculated from the Peak-to-Peak intervals (PPI) of photoplethysmogram (PPG) signal. Electrocardiogram (ECG) is shown as reference. Red dots mark the peaks either in PPG or ECG signal. [9]

Heart rate variability can be detected with various methods. ECG is considered the golden standard for HRV measurement [10]. Other methods are photoplethysmography (PPG), which detects the heart rate variability optically, usually measured from fingers, wrists, forehead or earlobes, blood pressure or ballistocardiography, which measures small changes in body's weight when the blood flows from the heart to the aorta.

Figure 3 shows a typical fitness and wellness watch having an optical heart rate sensor [11]. The light emitting diodes (LEDs) and optical detectors are seen on the back of the watch.


Figure 3. An example of fitness and wellness watch having an optical heart rate sensor. [11]

Figure 4 shows an example of photoplethysmography signal recorded with wrist worn pulse oximetry [12]. The device is shown on the left. The sensor is attached to the thumb. The PPG signal is shown on the right. The inter-beat-interval (IBI) is calculated from the negative peaks (the bottoms) of the PPG signal. It could be calculated also from the positive peaks (the maximum) or from the rising edges of the signal.

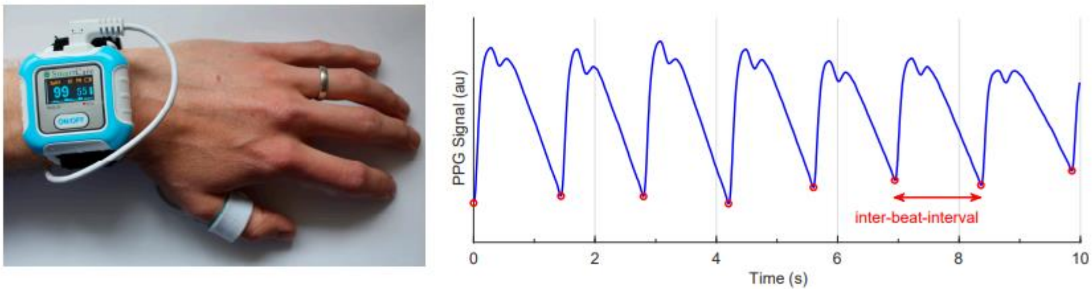


Figure 4. An example of photoplethysmography signal recorded with pulse oximetry used on the thumb. The inter-beat-interval (IBI or PPI) is calculated from the negative peaks. [12]

### 2.1.3 Heart rate variability

At present there is no accepted standard for stress evaluation. However, several HRV variables change in response to stress. Usually, stress induces low parasympathetic nervous system activity, which is associated with variation of some HRV variables such as high-frequency (HF) band and an increase in the low-frequency (LF) band. [7]

The European Society of Cardiology together with the North American Society of Pacing and Electrophysiology have defined and established the standards for the measurement, physiological interpretation, and clinical use of HRV [13]. The most used time-domain and frequency-domain measures of HRV are summarized in Table 1 and Table 2.

Table 1. Selected time-domain measures of HRV [13].

| Variable | Unit | Description |
|---|---|---|
| | | Statistical measures |
| SDNN | ms | Standard deviation of all NN intervals |
| SDANN | ms | Standard deviation of the averages of NN intervals in all 5-minute segments of the entire recording |
| RMSSD | ms | The square root of the mean of the sum of the squares of differences between adjacent NN intervals |
| SDNN index | ms | Mean of the standard deviations of all NN intervals for all 5-minute segments of the entire recording |
| SDSD | ms | Standard deviation of differences between adjacent NN intervals |
| NN50 count | | Number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; three variants are possible counting all such NN intervals pairs or only pairs in which the first or the second interval is longer |
| pNN50 | % | NN50 count divided by the total number of all NN intervals |

Table 2. Selected frequency-domain measures of HRV [13].

| Variable | Units | Description | Frequency range |
|---|---|---|---|
| | | Analysis of short-term recordings (5 min) | |
| 5-min total power | $ms^2$ | The variance of NN intervals over the temporal segment | ≈≤0.4 Hz |
| VLF | $ms^2$ | Power in VLF range | ≤0.04 Hz |
| LF | $ms^2$ | Power in LF range | 0.04–0.15 Hz |
| LF norm | n.u. | LF power in normalized units LF/(total power-VLF)×100 | |
| HF | $ms^2$ | Power in HF range | 0.15–0.4 Hz |
| HF norm | n.u. | HF power in normalized units HF/(total power-VLF)×100 | |
| LF/HF | | Ratio LF/HF | |
| | | Analysis of entire 24 hours | |
| Total power | $ms^2$ | Variance of all NN intervals | ≈≤0.4 Hz |
| ULF | $ms^2$ | Power in the ULF range | ≤0.003 Hz |
| LF | $ms^2$ | Power in the VLF range | 0.003–0.04 Hz |
| VLF | $ms^2$ | Power in the LF range | 0.04–0.15 Hz |
| HF | $ms^2$ | Power in the HF range | 0.15–0.4 Hz |
| α | | Slope of the linear interpolation of the spectrum in a log-log scale | |

ULF = Ultra-low frequency, VLF = Very low frequency, LF = Low frequency, HF = High frequency.

Time-domain analysis measures variation in the intervals between successive cardiac cycles whereas frequency-domain analysis provides information on how power is distributed as a function of frequency. [7]

### 2.1.4 Recovery and stress indexes

Based on the common measures of HRV, special indexes representing the parasympathetic and sympathetic cardiac activity have been developed. For example, Kubios HRV software is based on the following parameters to calculate PNS and SNS indexes [14]:

- Mean PPI (or IBI or RRI)
- Root mean square of successive PPI differences (RMSSD)

- Poincaré plot index SD1 and SD2 in normalized units
- Baevsky's stress index (SI)

Each parameter is compared to their normal population values and the values are then scaled with standard deviations (SD) of normal population and finally a proprietary weighting is applied to obtain the index values. These are illustrated in Figure 5 and Figure 6.

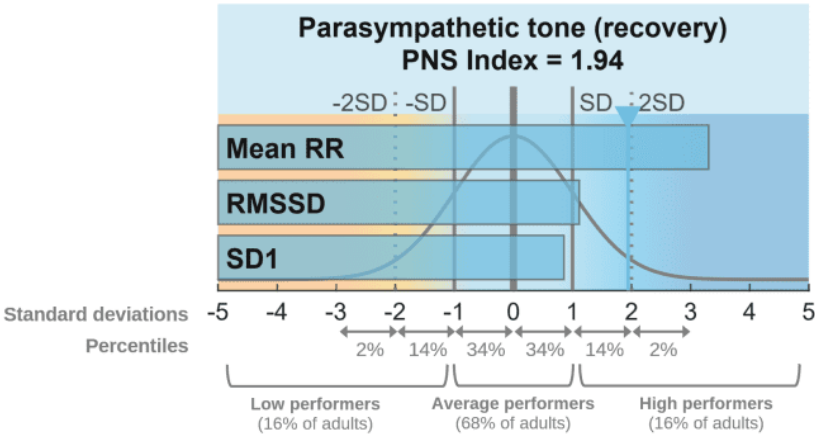


Figure 5. Parasympathetic nervous system (PNS) index. High positive values are interpreted as a good recovery of the test subject. [14]

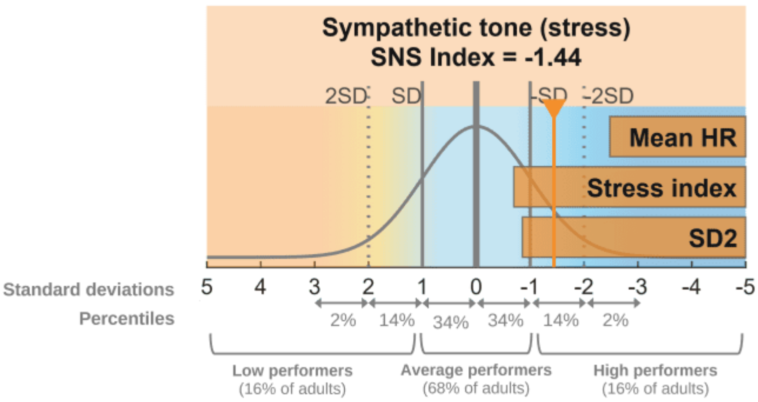


Figure 6. Sympathetic nervous system (SNS) index. High negative values are interpreted as a low stress of the test subject. Notice the reversed x-axis. [14]

Positive index values tell how many standard deviations above the normal population average values are, whereas a negative value tells the value is below normal values [14]. PNS index describes the parasympathetic tone and can be interpreted as the ability to recover from stress, as SNS index describes the sympathetic cardiac activity and can be interpreted as the current stress situation. An article “HRV analysis methods” gives a more detailed description of the analysis methods [15].

## 2.2 Product functions

### 2.2.1 The purpose

The aim is to develop a working proof-of-concept of the recovery and stress meter. A suitable microcontroller board and additional components are used. The Raspberry Pi Pico was selected for that purpose, as the Raspberry Pi products are extensively supported by the manufacturers and by the user community.

Metropolia University of Applied Sciences’ teaching personnel together with senior students have evaluated and selected the hardware components for the project. In addition, a special board for development of IoT devices with Raspberry Pi Pico is designed and tested by one of the senior lecturers. The background development and research results are openly available and readable in Theseus [16] [17] [18].

### 2.2.2 Application concept

The core of the proof-of-concept is Raspberry Pi Pico, a small and versatile microcontroller board designed for IoT devices. The device is adaptable to a wide range of applications in home, hobby, education, and industry. It is programmable both in C and MicroPython, of which MicroPython is used for this project. The device has a rich set of peripherals, including SPI, I2C, and programmable I/O state machines for custom peripheral support. It also has a wireless version, Raspberry Pi Pico W, having a fully certified wireless LAN module. [19]

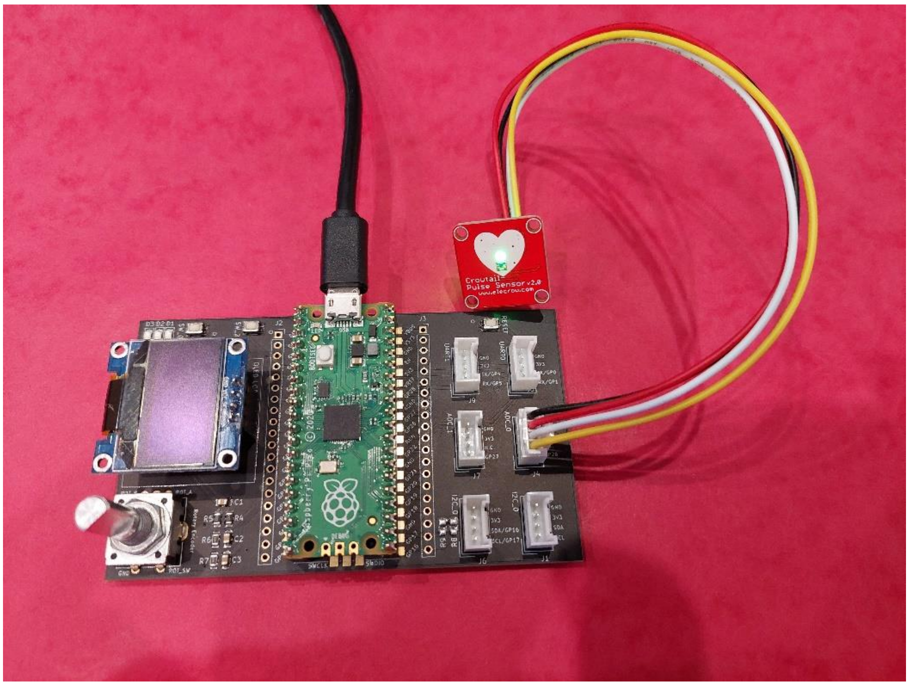

Figure 7. Photograph of the development board with connected Raspberry Pi Pico board, OLED display and optical heart rate sensor.

The development board is shown in Figure 7. To the bottom left the rotary switch and knob is shown. Above it is a 128x64 wide OLED display. At the upper left corner 3 LEDs and two of the three micro buttons are shown, which can be used for interacting with the development board. In the middle, the Raspberry Pi Pico board with soldered pins is shown. The Pico board is connected to the laptop or desktop through a USB-cable (black cable at the top of the figure). On the right, 4-pin Grove-connectors for connecting serial communication devices, like I2C sensors or analog input sensors, are shown. The optical heart rate sensor is connected to one of the Grove-connectors and Pico’s ADC_0 pin and is shown above the development board. The components used in the proof-of-concept product are listed in Table 3.

Table 3. Components used in the proof-of-concept product.

| **Component** | **Description** | **More info** |
|---|---|---|
| Raspberry Pi Pico | Dual-core ARM processor microcontroller having 246 kB SRAM and 2 MB on-board Flash. It also includes 2.4 GHz wireless LAN and 26 multifunction GPIO pins. | Raspberry Pi Pico series – Raspberry Pi |
| Crowtail Pulse Sensor v2.0 | Optical heart rate sensor having LED, photodiode, analog amplifier, and analog signal output. Operating voltage 3-5 V | Crowtail- Pulse Sensor 2.0 (elecrow.com) |
| OLED display | SSD1306 compatible 128x64 monochrome organic LED-display. Communicates with I2C or UART-protocol. | SSD1306 Oled Display \| Sensors Modules<br>Using a SSD1306 OLED display |
| Protoboard | Passive protoboard specially designed for this project to help connect the other components to the Raspberry Pi Pico. | Joseph Hotchkiss, Project Engineer, Metropolia UAS |
| Rotary encoder | Digital rotary encoder knob with push button. | What is Rotary Encoder? Types, Principle, working in detail – Circuit Schools |

### 2.2.3 Operating principle

The heart rate is detected using the optical heart rate sensor (Pulse Sensor v2.0, Crowtail) [20]. The analog signal is converted into digital using Raspberry Pi Pico's AD-converters. The heart rate is calculated using peak-detection algorithms for photoplethysmography (PPG) signals using Pico's central processing unit (CPU). The operation can be controlled using the rotary switch and knob. Results and feedback to the user are shown on the OLED display. In addition, the extra LEDs can be used to indicate, for example, the quality of the signal or the data collection operations to the user.

The data is preprocessed with Pico. Pico's wireless connection can be used to send the data to a cloud server and return the analysis results to the development board and show them to the user. Figure 8 illustrates the architecture of the whole system.

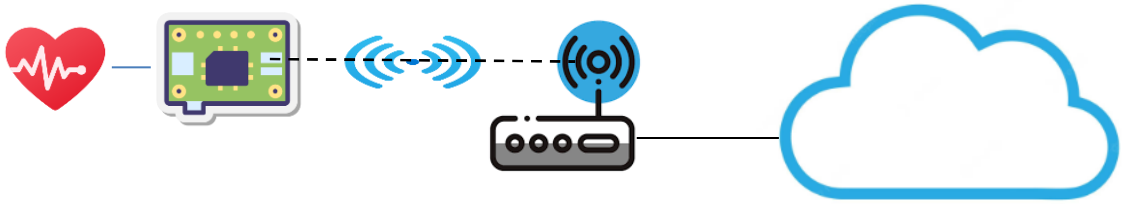

Figure 8. Illustration of the architecture of the whole system. From left to right: PPG sensor, hardware development board, wireless link, WiFi base station/Linux server, and cloud service.

The development board acquires and records the optical heart pulse data and preprocesses the data as seen in Figure 8. All heart rate calculations can also be processed on the development board. The preprocessed pulse data is sent wirelessly to the WiFi base station and Linux server which sends the data to the cloud server where detailed HRV analysis is done. The analysis results are sent back to the development board.

### 2.2.4 Key features

The following Table recaps the key features of the system.

Table 4. Key features of the system.

| **Key Feature** | **Description** |
|---|---|
| HRV detection | PPG signal is detected using the optical pulse sensor and the heart rate variability is measured using the development board's MCU. |
| Display | The system has an OLED display capable of showing both text and graphics. |
| Controls | The system has a rotary switch control knob with push button. The control knob can be used for controlling the operation of the system. |
| MCU | The system contains an MCU with Flash and RAM memory and several peripheral connections enabling to process the detected PPG signal and calculate the inter-peak-interval variations.<br><br>The raw HRV data (PPI) can be further analyzed using the system or sent wirelessly to a cloud server for further calculations. |
| Wireless connection | The system contains a wireless WiFi transceiver. It gives the opportunity to send and receive data to WLAN and cloud servers. |
| USB connection | The system contains a USB connection. The USB can be used to control, code, and download the executable files. In addition, it can be used to debug the code and download and upload data files between the development board and laptop. The USB-port can also be used to power the system, if necessary. |

## 2.3 Use, users, and application characteristics

The final system is intended to be used for measuring the recovery and stress index based on HRV analysis detected optically from the finger, wrist, hand palm, arm, upper arm, chest, cheek, forehead, or earlobe.

The system is intended to be used by a person, patient, customer, or healthcare professional aiming to measure the subject’s recovery and stress index. The information can be used to help understand the study subject’s current situation. The system is used in a normal home or office environment.

The system can be used to analyze the psychophysiological state. HRV is related to emotional arousal, conditions of acute time pressure and emotional strain, and elevated anxiety state.  HRV has also been shown to be reduced in individuals reporting to worry more. In individuals with post-traumatic stress disorder (PTSD), HRV is reduced. [10]

## 2.4 Development tools

Thonny IDE for programming the Raspberry Pi Pico and MicroPython as a programming language are used for developing the software for the product.

MicroPython is a special limited version of the newest Python versions [21]. It has less libraries and options than the normal desktop Python and uses some special libraries like machine, utime, urequests, ujson, etc., which are developed for embedded systems.

Thonny IDE is a special Python IDE developed having focus on the embedded systems [22]. It is easy to get started with and comes with the Python 3.10 built in. In addition, it can be used to download the MicroPython firmware to embedded boards, like Raspberry Pi Pico, and you can start programming the Raspberry Pi Pico directly.

Ulab is an optional special NumPy-like module for MicroPython, and its derivatives may be used for advanced algorithm development, like for preprocessing the photoplethysmographic signal. Ulab module is “meant to simplify and speed up common mathematical operations on arrays.” [23] It is an asset, especially when more advanced heart rate detection algorithms are implemented.

Wokwi is an online electronic simulator [24]. It can be used to simulate Raspberry Pi Pico, Arduino, ESP32, and boards, electronic parts, and sensors. Links for Raspberry Pi Pico simulator with MicroPython, SSM1306 OLED, and Hardware project simulator are provided for developing the system [25] [26] [27]. The hardware project simulator is based on the protoboard. The simulator contains all the same components as in the real protoboard, except the heart rate sensor and WiFi connection. It can be used for learning and testing how the system works before using any real hardware.

Kubios Cloud is an Amazon Web Services (AWS) based cloud service using REST API interface [28]. The goal of this project is making a full HRV analysis based on the inter-beat-interval (IBI) calculations on Raspberry Pi Pico. The IBI data can be send to Kubios Cloud and get the HRV analysis results back. It is possible to get the full recovery and stress analysis results in the device.

# 3 Specific requirements

This section gives the requirements that are used to guide the project’s design, implementation, and testing. Attention has been paid to carefully organize the requirements presented, so that they may easily be accessed and understood. Furthermore, the reader should notice, that this document is not the system design document.

## 3.1 User interfaces

The user can control the operation of the device using the rotary switch and knob. Results and user feedback are shown on the OLED display. In addition, the extra LEDs can be used to indicate, for example, the quality of the signal or the data collection operations to the user.

### 3.1.1 OLED display

The OLED display has 128x64 pixels and can display both text and graphics as shown in Figure 9. The display is controlled by SSD1306 circuit which is embedded to the display. The SSD1306 compatible OLED display uses either a SPI or I2C interface. MicroPython documentation gives examples how to use the library [29]. A suitable SSD1306 MicroPython compatible library can be downloaded, for example, from here [30].


Figure 9. SSD1306 compatible OLED-display used in the project.

### 3.1.2 Rotary encoder

A rotary encoder is a device that will provide you with pulses to indicate the direction and speed of the rotation. The device has three outputs ROT A, ROT B, and Rot Switch. The Rot Switch behaves just like a standard push button tactile switch. When you press the knob in, the signal goes from high to low or low to high depending on how the encoder is wired up. Figure 10 illustrates the rotary encoder.

Figure 10. A rotary encoder with integrated push button switch.

When you rotate the knob in one direction or the other, then the Rot A and Rot B will output a series of pulses out of phase of one another. In one direction Rot A phase will lead Rot B and when turning the other direction Rot A will trail Rot B.

This means that we can essentially use one channel either Rot A or Rot B as a clock signal and then check the state of the other pin to identify the direction of the rotation. Let's look at two examples. In both cases we will use Rot B as the clock and Rot A will indicate the direction of the turn.

In Figure 11 you can see that when Rot B goes from low to high the value on Rot A is zero. In this case it is indicating Clockwise rotation. The more clock pulses per second indicates faster rotation of the encoder.

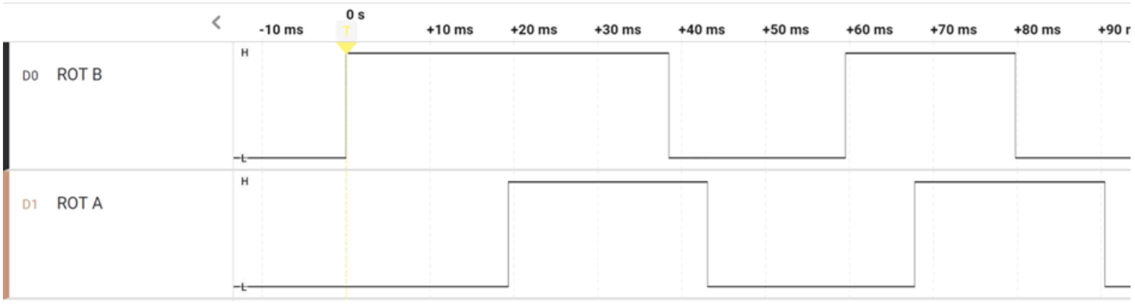


Figure 11. Illustration of the Rot A and Rot B signals when the rotary knob is turned Clockwise direction.

In Figure 12 the opposite case is true. When Rot B (clock signal) goes from low to high it can be observed that the state of the Rot A pin is high. This indicates Counter or Anti-clockwise rotation. The speed of rotation is indicated in the same way.


Figure 12. Illustration of the Rot A and Rot B signals when the rotary knob is turned Anti-clockwise direction.

### 3.1.3 Grove connectors

The hardware provides 6 modular, standardized Grove connectors for prototyping purposes [31]. The Grove connector is also compatible with Crowtail connectors and cables. The Grove connector and Grove cables are shown in Figure 13 and Figure 14.

Figure 13. A 4-pin 2.0 mm pitch DIP Grove female header [32].

Figure 14. A 4-bin buckled Grove cables [32].

The Grove connector has 4 pins. One of the pins is reserved for the operating voltage (Vcc) and the second for the ground (GND). For digital connectors the remaining pins are usually the clock and data pin. If the connector is used for analog signals, the remaining pins are usually reserved for the analog inputs.

### 3.1.4 Heart rate sensor

Crowtail's pulse sensor v2.0 is connected through the Grove-connector to the Raspberry Pi Pico's analog inputs [20]. The heart rate sensor is shown in Figure 15 and Figure 16.

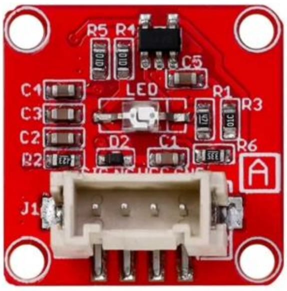


Figure 15. Crowtail pulse sensor v2.0 shown from the back (component) side.


Figure 16. Crowtail pulse sensor v2.0 shown from the front (sensor) side.

The electrical components of the heart rate sensor are soldered on the back side of the sensor PCB (Figure 15). The component side also includes the Grove-connector used for connecting the sensor to the protoboard.

The finger (or other place location on which the heart rate is detected) is on the front side of the sensor PCB (Figure 16). In the middle of the board is a LED, which is used to transmit the light to the body tissue. Below the LED is an optical sensor, photodiode, which receives the reflected light and converts the signal to voltage.

### 3.1.5 USB-port

The Raspberry Pi Pico has a micro-USB port that can be used to access the USB bootloader stored in the RP2040 boot ROM. It can also be used by user code, to access an external USB device or host [33]. Figure 17 shows the Raspberry Pi Pico W board and its USB-port.


Figure 17. The Raspberry Pi Pico W board. The USB-port is on the right edge of the circuit [34].

## 3.2 Use cases

The summary and details of use cases are described in Table 5 and Table 6.

Table 5. Summary of use cases.

| **ID** | **Name** | **User role(s)** | **Importance** | **Links to use cases** |
|---|---|---|---|---|
| UC01 | Recording new HRV analysis | U1: User | 1 | |
| UC02 | Reading previous HRV analysis | U1: User | 2 | UC01 |
| UC03 | Showing a history of HRV analysis results | U1: User | 3 | UC01, UC02 |

Table 6. Use cases details.

| Use case ID | UC01 | UC02 | UC03 |
|---|---|---|---|
| **Name** | **Recording new HRV analysis** | **Reading previous HRV analysis** | **Showing a history of HRV analysis results** |
| **Author and date** | Sakari Lukkarinen, 2.12.2022 | Sakari Lukkarinen, 2.12.2022 | Sakari Lukkarinen, 5.2.2023 |
| **User roles** | U1: User | U1: User | U1: User |
| **Importance** | 1 | 2 | 3 |
| **Links and sources** | | | |
| **Prerequisites** | The system is on and ready to record. | The system is on and ready to go. | The system is on and ready to go. |
| **Description** | 1. User selects new recording from the system. | 1. User selects "reading previous HRV analysis" from the system. | 1. User selects "History" from the system. |
| | 2. User attaches the sensor on the skin. | 2. List of previous recordings and their dates/times are shown to the user. | 2. A list of parameters, like mean RR, etc. are shown to the user. |
| | 3. User starts the recording. The system records the signal. | 3. User selects one of the previous recordings. | 3. User selects one of the parameters. |
| | 4. Recording period is over, and the heart rate is calculated. | 4. The results of the previous HRV analysis are displayed to the user. | 4. The history of the selected parameter is shown to the user. |
| | 5. The results are shown on the display. | | |
| **Exceptions** | 1. The signal is low quality, or the sensor is not properly on the skin. The user is warned about the situation and asked to restart recording. | 1. There are no previous HRV analysis results. The user is warned about that. | 1. There are no previous HRV analysis results, and the user is warned about that. |
| | 2. After the recording the signal is too low quality. The user is warned about the situation and the results are not stored. | | |
| **Result** | The HRV measurement is ready and shown to the user. | The previous HRV analysis results are shown to the user. | The history of the selected parameter is shown to the user. |
| **Other requirements** | See Q01 | | |

## 3.3 MicroPython modules and classes

In this subchapter the required MicroPython modules and classes to develop the system are introduced.

### 3.3.1 SSD1306

Micropython's ssd1306 library is used to control the OLED display [35] [29]. A fork of the driver can be studied at Github [30]. Ssd1306 library relies on MicroPython-specific library FrameBuffer, which provides support for graphics primitives (fill, pixel, hline, vline, line, rect, ellipse, poly), drawing text (text), and other methods (scroll, blit) [36].

## 3.4 Non-functional requirements

The non-function (quality) requirements are described in Table X4. Non-functional requirements.

Table 7. Non-functional (quality) requirements.

| ID | Description | Justification and source | Depends on | Importance |
|---|---|---|---|---|
| Q01 | Sampling rate | The sampling rate for the PPG data should be at least 50 Hz. Preferrable sampling rate is at least 250 Hz. | | 1 |
| Q02 | IBI calculations unit | The IBI (inter-beat-intervals) for the HRV analysis should be calculated in milliseconds. | Q01 | 2 |
| Q03 | Wireless link | The data should be sent to the server through Wifi-connection using standard WLAN frequencies and protocols. | | 3 |

# 4 Change management process

Team members can suggest changes to this document by discussing with the project teachers, sending emails, or directly reviewing and commenting this document. This document is maintained and updated by the project management team (project teachers).

The project scope and requirements changes are reviewed regularly, minimum every second week, during the hardware 1 and 2 courses. The changes are approved by the project management team after change review meetings.

# 5 References


[1] A. D. McKinnon, “Software Engineering Principles I,” Washington State University, March 2005. [Online]. Available: https://users.tricity.wsu.edu/~mckinnon/cpts322/. [Accessed 2 February 2023].

[2] “IEEE Recommended Practice for Software Requirements Specifications,” IEEE Computer Society, 1998. [Online]. Available: https://www.cse.msu.edu/~cse870/IEEEXplore-SRS-template.pdf. [Accessed 2 February 2023].

[3] C. P. Davis, “Medical Definition of Stress,” MedicineNet, 29 3 2021. [Online]. Available: https://www.medicinenet.com/stress/definition.htm. [Accessed 22 9 2022].

[4] E. Patterson, “Stress Facts and Statistics,” The Recovery Village, 05 Sept 2022. [Online]. Available: https://www.therecoveryvillage.com/mental-health/stress/stress-statistics/. [Accessed 23 09 2022].

[5] The American Institute of Stress, “What is Stress?,” The American Institute of Stress, [Online]. Available: https://www.stress.org/daily-life. [Accessed 23 09 2022].

[6] WHO, “Doing What Matters in Times of Stress: An Illustrated Guide,” 29 April 2020. [Online]. Available: https://www.who.int/publications/i/item/9789240003927. [Accessed 23 09 2022].

[7] H. Kim, E. Cheon, D. Bai, Y. LEE and B. Koo, “Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature,” *Psychiatry Investig.,* vol. 15, no. 3, pp. 235-245, 2018.

[8] “Heart rate,” Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Heart_rate. [Accessed 2 Dec 2022].

[9] “Beat-to-Beat Accuracy Compared With Wearable ECG in Broad Dynamic Range,” FibriCheck, [Online]. Available:

https://www.fibricheck.com/fibricheck-beat-to-beat-accuracy-compared-with-wearable-ecg-in-broad-dynamic-range/. [Accessed 11 Aug 2023].

[10] "Heart rate variability," Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Heart_rate_variability. [Accessed 2 Dec 2022].

[11] "Polar Ignite 3," Polar, [Online]. Available: https://www.polar.com/en/ignite3. [Accessed 02 Dec 2022].

[12] P. H. Charlton, P. Kyriaccou, J. Mant and J. Alastruey, "Acquiring Wearable Photoplethysmography Data in Daily Life: The PPG Diary Pilot Study," *Eng. Proc.,* vol. 2, no. 20, 2020.

[13] M. Malik, J. T. Bigger, A. J. Camm, R. E. Kleiger, A. Malliani, A. J. Moss and P. J. Schwartz, "Heart rate variability: Standards of measurement, physiological interpretation, and clinical use," *European Heart Journal,* vol. 17, no. 3, pp. 354-381, 1996.

[14] "PNS and SNS indexes in evaluating autonomic function," Kubios Oy, [Online]. Available: https://www.kubios.com/blog/hrv-ans-function/. [Accessed 09 Dec 2024].

[15] "HRV Analysis Methods," Kubios Oy, [Online]. Available: https://www.kubios.com/blog/hrv-analysis-methods/. [Accessed 09 Dec 2024].

[16] G. Zoltan, "Implementation of LoRaWAN : from end-device to application," Metropolia University of Applied Sciences, Helsinki, 2021.

[17] E. Besic, "Implementation of first-year hardware theme project for ICT students," Metropolia University of Applied Sciences, Helsinki, 2022.

[18] J. Piri, "Käsiproteesin ohjain – prototyypin kehitystyö," Metropolia University of Applied Sciences, Helsinki, 2022.

[19] "Raspberry Pi Pico: Powerful, flexible microcontroller boards, available from $4," Raspberry Pi Foundation, [Online]. Available: https://www.raspberrypi.com/products/raspberry-pi-pico/. [Accessed 25 11 2022].

[20] "Crowtail - Pulse Sensor," Electrow, 29 July 2022. [Online]. Available: https://www.elecrow.com/wiki/index.php?title=Crowtail-_Pulse_Sensor. [Accessed 28 Nov 2022].

[21] P. D. George, “MicroPython,” George Robotics Limited, 2014-2023. [Online]. Available: https://micropython.org/. [Accessed 2 February 2023].

[22] “Thonny - Python IDE for beginners,” University of Tartu, Cybernetica, and Raspberry Pi Foundation, 2014-2023. [Online]. Available: https://thonny.org/. [Accessed 2 February 2023].

[23] Z. Vörös, “The ulab book, Revision f2dd2230,” Read the Docs, [Online]. Available: https://micropython-ulab.readthedocs.io/en/latest/index.html. [Accessed 2 February 2023].

[24] “Wokwi - Simulate IoT Projects in Your Browser,” CodeMagic LTD, 2019-2023. [Online]. Available: https://wokwi.com/. [Accessed 2 February 2023].

[25] “New MicroPython on Raspberry Pi Pico Project,” CodeMagic Ltd, 2019-2023. [Online]. Available: https://wokwi.com/projects/new/micropython-pi-pico. [Accessed 02 Feb 2023].

[26] S. Lukkarinen, “Pico with SSD1306 v2 - Wokwi Arduino and ESP32 Simulator,” CodeMagic Ltd, 2019-2023. [Online]. Available: https://wokwi.com/projects/354671838787709953. [Accessed 02 Feb 2023].

[27] S. Lukkarinen, “Hardware project simulator - Wokwi Arduino and ESP32 Simulator,” CodeMagic Ltd, 2019-2023. [Online]. Available: https://wokwi.com/projects/354682548125570049. [Accessed 02 Feb 2023].

[28] “Kubios Cloud,” Kubios Oy, 2023. [Online]. Available: https://www.kubios.com/kubios-cloud/. [Accessed 2 February 2023].

[29] P. D. George, P. Sokolovsky and contributors, “Using a SSD1306 OLED display,” 01 Feb 2023. [Online]. Available: https://docs.micropython.org/en/latest/esp8266/tutorial/ssd1306.html?highlight=ssd1306. [Accessed 02 Feb 2023].

[30] stlhemann, “micropython-ssd1306,” 16 Dec 2020. [Online]. Available: https://github.com/stlehmann/micropython-ssd1306. [Accessed 02 Feb 2023].

[31] “Grove System,” Seeed Technology Co, Ltd., 2008-2021. [Online]. Available: https://wiki.seeedstudio.com/Grove_System/. [Accessed 02 Feb 2023].

[32] “Grove accessories,” Seeed Studio, 2023. [Online]. Available: https://www.seeedstudio.com/Grove-Accessories-c-1969.html. [Accessed 02 Feb 2023].

[33] Raspberry Pi Ltd, “Raspberry Pi Pico Datasheet - An RP2040-base microcontroller board,” 09 06 2022. [Online]. Available: https://datasheets.raspberrypi.com/pico/pico-datasheet.pdf. [Accessed 02 Feb 2023].

[34] “Raspberry Pi Pico W datasheet,” Raspberry Pi Ltd, 30 Nov 2022. [Online]. Available: https://datasheets.raspberrypi.com/picow/pico-w-datasheet.pdf. [Accessed 02 Feb 2023].

[35] P. D. George, P. Sokolovsky and contributors, “SSD1306 driver,” 01 Feb 2023. [Online]. Available: https://docs.micropython.org/en/latest/esp8266/quickref.html#ssd1306-driver. [Accessed 2 Feb 2023].

[36] P. D. George, P. Sokolovsky and contributos, “framebuf - frame buffer manipulation,” The MicroPython Documentation, 01 Feb 2023. [Online]. Available: https://docs.micropython.org/en/latest/library/framebuf.html. [Accessed 02 Feb 2023].

[37] Admin, “Getting Started with Raspberry Pi Pico W using MicroPython,” How to Electronics, 12 Jan 2023. [Online]. Available: https://how2electronics.com/getting-started-with-raspberry-pi-pico-w-using-micropython/. [Accessed 02 Feb 2023].

[38] “Token endpoint,” Amaxon Web Services, Inc., 2023. [Online]. Available: https://docs.aws.amazon.com/cognito/latest/developerguide/token-endpoint.html. [Accessed 02 Feb 2023].