Group 3: Mong Phan, Berhanu Muche, Khai Cao, Xuan Dang

iPiStress: Raspberry Pi Pico as Stress Monitor

Project Report

First-year Hardware Project

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Abstract

Authors:	Mong Phan, Berhanu Muche, Khai Cao, Xuan Dang
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This study aims to create a portable and affordable Heart Rate Variability (HRV) monitoring system using Raspberry Pi Pico W, Crowtail pulse sensor, and Kubios software for HRV analysis. The system collects heart rate data from the pulse sensor, analyzes the HRV using Kubios, and displays the results on an OLED screen or sends them to a mobile app. The application features real-time heart rate monitoring, HRV analysis, and data visualization. The system can be used by individuals who want to monitor their heart rate variability and track changes over time. The project also explores potential ideas for further development, including adding more sensors to the system and integrating it with a fitness app or wearable device. The software architecture involves using MicroPython to interface with the Crowtail pulse sensor and Kubios software for HRV analysis. The system can be tested for accuracy, durability, and portability to ensure reliable and practical use. This project provides insights into the challenges and benefits of integrating different technologies and platforms to create an effective and affordable health monitoring solution.

Keywords: Kubios, Raspberry Pi, Heart Rate , Stress, MicroPython

Version history

Ver	Description	Date	Author(s)
1.0	Created structure for the project report. Added instructions for what should be included in the different parts of the document.	13.03.2023	Saana Vallius
1.1	Added Instructions (REMOVE WHEN READY), minor editions.	14.03.2023	Sakari Lukkarinen
1.2	Highlighted all instructions with red font.	19.03.2023	Sakari Lukkarinen
1.3	Updated Appendix 2 based on comments. Updated table of contents.	22.03.2023	Saana Vallius
1.4	Updated Introduction and Theoretical Background	9.04.2023	Mong Phan
1.5	Moved hardware description from theoretical background to methods and material section	22.04.2023	Perhanu Muche
1.6	Fixed some grammar errors, added the first draft of the abstract and conclusion	29.04.2023	Khai Cao
1.7	Updated Implementation section	06.05.2023	Mong Phan

Contents

1 Introduction

The project aimed to develop a working proof-of-concept of the recovery and stress meter. We used a suitable microcontroller board and additional components. 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.

The Raspberry Pi Pico detects heart rate by using the optical heart rate sensor (Pulse Sensor v2.0, Crowtail). The analog signal was converted into digital using Raspberry Pi Pico's AD-converters. The heart rate was 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. The data was collected by Pico and processed later according to a selected working mode. In the "HR measurement" mode, data is collected continuously by the Crowtail sensor, and then calculated the heart rate BPM (beats per minute) without analysis. In the "Offline Analysis" mode, pi pico analyzes HRV after collecting enough twenty intervals. In the "Online Analysis" mode, instead of analyzing HRV data, pi Pico connects to a wifi network and sends the data to Kubios cloud server for HRV analysis.

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 users of this device could be a person, patient, customer, or healthcare professional who are aiming to measure the subject's recovery and stress index. The information can be used to help understand the study subject's current situation.

2 Theoretical Background

The heart is a muscular organ that is responsible for pumping blood throughout the body. The heart is composed of four chambers: the right and left atria, and the right and left ventricles. The right side of the heart pumps deoxygenated blood to the lungs, where it picks up oxygen and releases carbon dioxide. The left side of the heart pumps oxygenated blood to the rest of the body [2].

The heartbeat is controlled by the electrical and autonomic nervous systems. The sinoatrial (SA) node, located in the right atrium, serves as the natural pacemaker of the heart, generating electrical impulses that travel through the atria and cause them to contract. The impulses then reach the atrioventricular (AV) node, which acts as a gateway to the ventricles, allowing the impulses to pass through to the ventricles and cause them to contract.

The autonomic nervous system also plays a role in regulating heart rate. The sympathetic nervous system, which is activated during times of stress or exercise, increases heart rate by releasing the hormone epinephrine (adrenaline), which stimulates the SA node and increases the force of contraction of the heart muscle. The parasympathetic nervous system, which is activated during periods of rest or relaxation, slows down the heart rate by releasing the neurotransmitter acetylcholine, which decreases the firing rate of the SA node and reduces the force of contraction of the heart muscle [3].

Heart rate can be affected by a variety of factors, including age, fitness level, body position, emotional state, and the presence of certain medical conditions [1]. Heart rate is a commonly measured vital sign and can provide important information about the health and function of the cardiovascular system.

Heart rate measurement involves measuring the number of times the heart beats per minute. There are several theories and methods for measuring heart rate, but one widely accepted theory is based on the electrical activity of the heart.

The heart contains specialized cells called pacemaker cells that generate electrical impulses that regulate the heart rate [2]. These impulses cause the heart muscle to contract and pump blood throughout the body. The electrical activity of the heart can be detected and measured using an electrocardiogram (ECG or EKG) machine.

An ECG machine records the electrical activity of the heart by attaching electrodes to the skin on the chest, arms, and legs. The electrodes detect the electrical impulses generated by the pacemaker cells and transmit this information to the ECG machine, which converts the electrical signals into a graph or waveform that shows the rhythm and rate of the heart.

Another method for measuring heart rate is to palpate the pulse. This involves placing the fingers on an artery, such as the radial artery in the wrist, and counting the number of beats felt per minute. This method is based on the physical sensation of the pulse as blood is pumped through the artery.

Overall, heart rate measurement is based on the electrical and physical activity of the heart, and can be measured using various techniques including ECG and pulse palpation. These measurements can provide important information about the health and function of the cardiovascular system [1].

3 Methods and Material

3.1 Overview

Stress is a common problem faced by people in their daily lives, and it can have negative effects on health if left unchecked. This project aimed to use Raspberry Pi Pico to measure heart rate and provide information related to HRV analysis. The Pico received signals from a pulse sensor attached to the user's fingertip and used this data to determine the user's heart rate. Additionally, the device could provide users with the HRV analysis results.

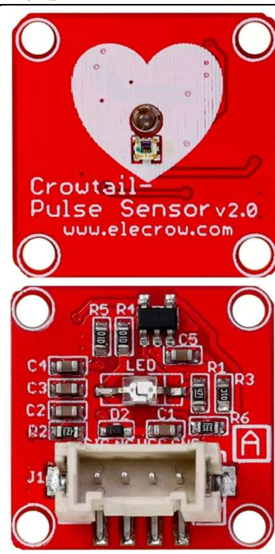
To verify the accuracy of the system, another smartwatch with heart rate monitoring capability is used to compare the results.

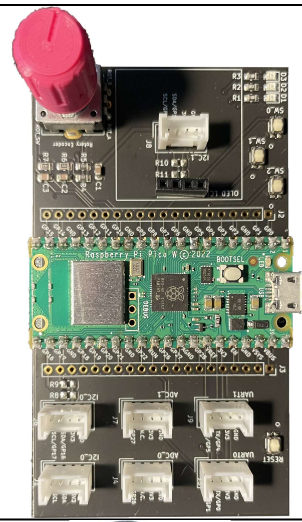
3.2 Hardware Components

The project utilized several components to achieve its goal. The Raspberry Pi Pico, a small yet powerful microcontroller, formed the core of the system and provided the necessary data processing and connectivities. The Crowtail pulse sensor is used to measure the user's heart rate and provided feedback in real-time. An SSD1306 OLED display is employed to display the heart rate data and other relevant information. A protoboard served as a convenient platform to connect and interface various components together. Finally, a rotary knob is used to allow the user to interact with the system and control its functionality. Together, these components formed a powerful and versatile system that can be used for a wide range of applications, from healthcare to fitness tracking and beyond.

The components used in this project are listed in Table 1.

Table 1. Components used in the project

Component	Image	Description
Raspberry Pi Pico W		Dual-core ARM processor microcontroller having 246 KB SRAM and 2 MB on-board Flash. It also includes a 2.4 GHz wireless LAN and 26 multifunction GPIO pins.
Crowtail Pulse Sensor v2.0		Optical heart rate sensor having LED, photodiode, analog amplifier, and analog signal output. Operating voltage 3-5 V
OLED display		0.96” with 128x64 pixels monochrome OLED based on SSD1306 drivers. It is controlled over the I2C protocol.

Protoboard		Passive protoboard specially designed for this project to help connect the other components to the Raspberry Pi Pico.
Rotary knob		Digital rotary knob with push button.

To assemble the project, the Raspberry Pi Pico, Crowtail pulse sensor, SSD1306 OLED display, and rotary knob were connected directly to the protoboard. The Pico was placed at the center of the protoboard, and the pulse sensor was connected to the GP26 pin. The SSD1306 OLED display was connected to I2C_1 of the protoboard. The rotary knob was connected to GP14 and GP15 pins.

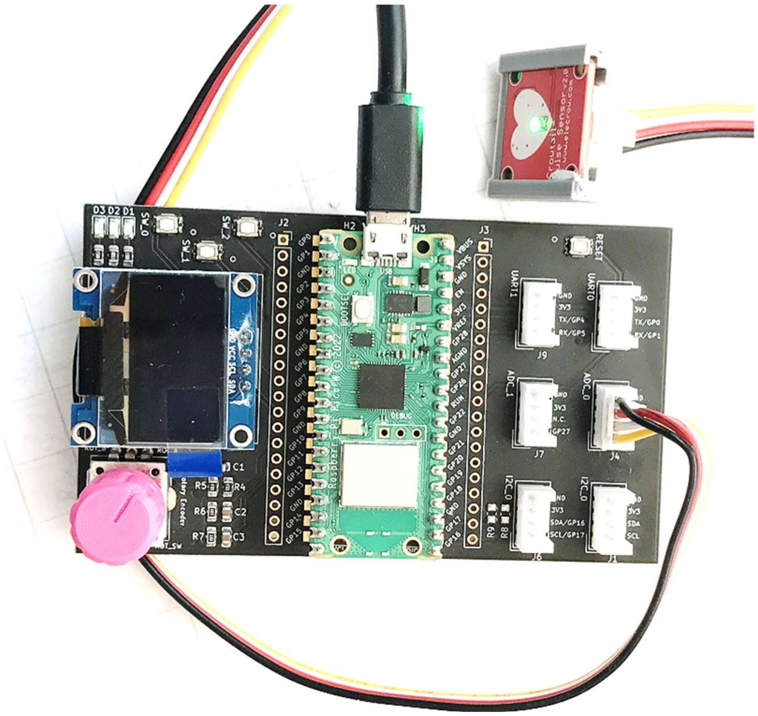


Figure 1. Photograph of the development board with connected Raspberry Pi Pico board, OLED display, and optical heart rate sensor.

The development board is shown in Figure 1. The components are assembled in a compact and portable format. The rotary switch is shown at the bottom left of the protoboard. Above the rotary switch is a 128x64 pixels OLED display. In 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. On the right, 4-pin connectors for peripheral connections, such as I2C sensors or analog input sensors, are shown. The optical heart rate sensor is connected to the ADC_0 connector and is shown above the development board.

3.3 Detecting Heart Rate

The heart rate or pulse rate measures how often the heart beats and is given units of beats per minute (BPM). Usually, the heart rate varies on the body's physical needs, but is also affected by physical fitness, the stress of psychological status, diet, drugs, hormones, environment, and 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 [4]. However, the accepted range of BPM is considered from 40 - 240 BPM.

Heart rate variability (HRV) is an accurate method to assess the autonomic nervous system (ANS) function. HRV is widely used by health and well-being professionals to objectively measure physiological and mental stress and recovery. In addition, HRV is a commonly used tool in the research of different cardiovascular and metabolic diseases and their risk factors [5].

The device detects the heart rate and its variability using 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 the light-emitting diodes (LEDs), absorbed by the tissues, and detected with photodiodes. The heart rate can be measured from the peaks of the alternating signal presenting the volumetric blood changes in the tissue [6].

HRV is the variation of the time intervals between heartbeats and it is measured in units of seconds, or more commonly, in milliseconds (ms). *Figure 1* visualizes heart HRV with R-R interval changes.

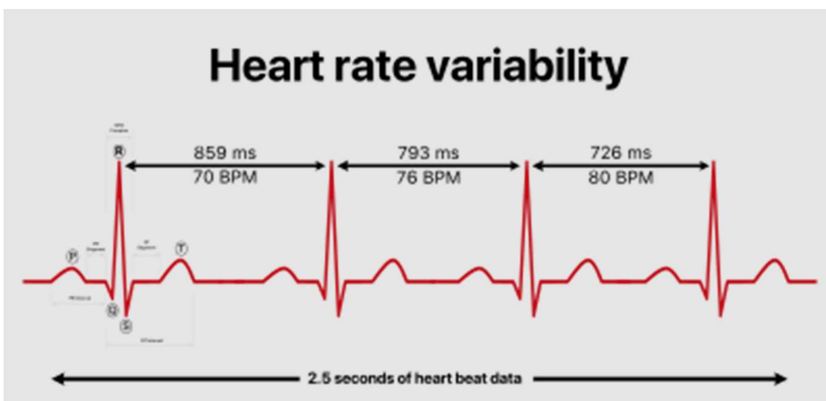


Figure 1. Heart rate variability (HRV) calculated from the R-R intervals (RRI)

After knowing HRV, BPM can be calculated using the formula:

$$BPM = \frac{60000}{\text{PPI}}$$

where PPI is peak-peak interval (timespan (ms) between 2 consecutive peaks)

The Crowtail - Pulse sensor is used to collect heart rate data. The analog data generated by the sensor is then converted to a digital signal which is in the range of 0 – 65355. While measuring heart rate, a min value is about 31000, and a max value is about 36000. This range might vary from person to person.

4 Implementation

4.1 End-to-End system

The overall system architecture is shown in Figure 3. The Raspberry Pi Pico is the heart of the system, which collects heart rate data from the sensor and then processes it according to the selected working mode. Besides calculating heart rate BPM, Pi Pico could analyze HRV data by itself or connects to the Kubios Cloud for analysis. The user’s heart rate BPM, beat line graph, and HRV analysis results are shown on the OLED display.

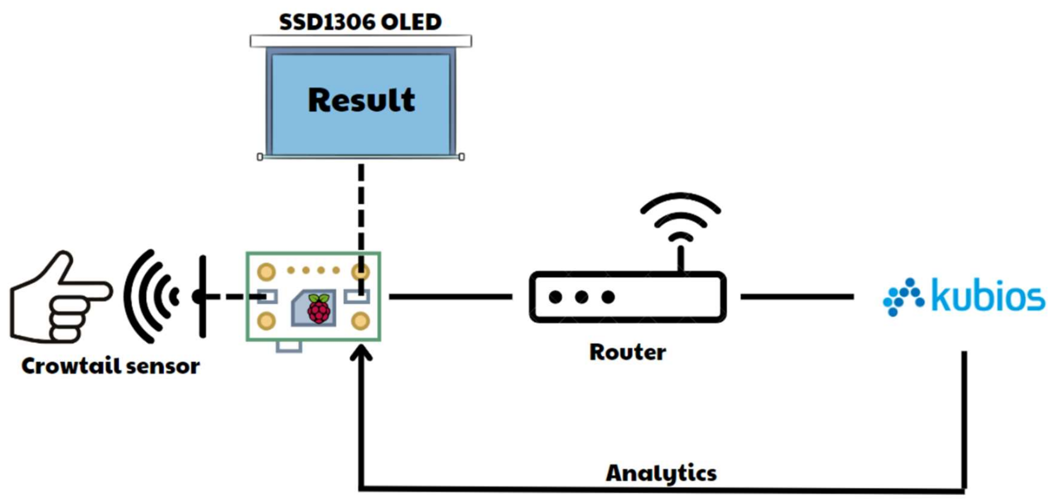


Figure 3: iPiStress system architecture

4.2 Collecting and processing heart rate data

The user’s heart rate data is collected through the Crowtail sensor, which is attached to the user’s fingertip. While collecting data, Pi Pico continued to detect heartbeats, which are used to determine BPM and analyze HRV. The inter-beat-interval (IBI) is processed according to the selected working mode:

- HR Measurement mode: in this mode, Pi Pico continues to collect heart rate data and IBI then calculates BPM without analyzing HRV.
- Offline Analysis mode: besides collecting IBI and calculating BPM, Pi Pico analyzes HRV data when collected enough twenty IBI (after about two minutes). The analysis results are then shown on the OLED with some basic information, such as mean PPI (mean peak-to-peak interval), mean HR (mean heart rate BPM), SDNN (standard deviation of RR (or PP) intervals), and RMSSD (Root mean square of successive differences)
- Online Analysis mode: after collecting enough twenty IBI, instead of analyzing HRV inside Pi Pico, data is sent to Kubios Cloud through a wifi connection and then gets analysis results back from Kubios Cloud. Similar to the Offline Analysis mode, mean PPI, mean HR, SDNN, and RMSSD is shown on the OLED display.

4.3 Software algorithm

The whole software of iPiStress is divided into some parts according to its functions: beat detection (Figure 4), BPM calculation (Figure 5), drawing OLED (Figure 6), offline HRV analysis (Figure 7), and online HRV analysis (Figure 8). The overall program algorithm is shown in Figure 9.

- Beat detection: heartbeat is detected using a slope detection method. With this method, a heartbeat is found if a sensor’s data value is greater than an upper threshold value but the beat flag is in **not found (False)** state. When a heartbeat is found, a current timestamp is stuck to this beat using the ticks_ms() function, and the beat flag is marked to **found (True)** state. The Pi Pico will do nothing with new heart rate data if the beat flag is in the **found** state. When a value of data is smaller than a lower threshold, the beat flag is reset to **False** to prepare for finding a new beat.

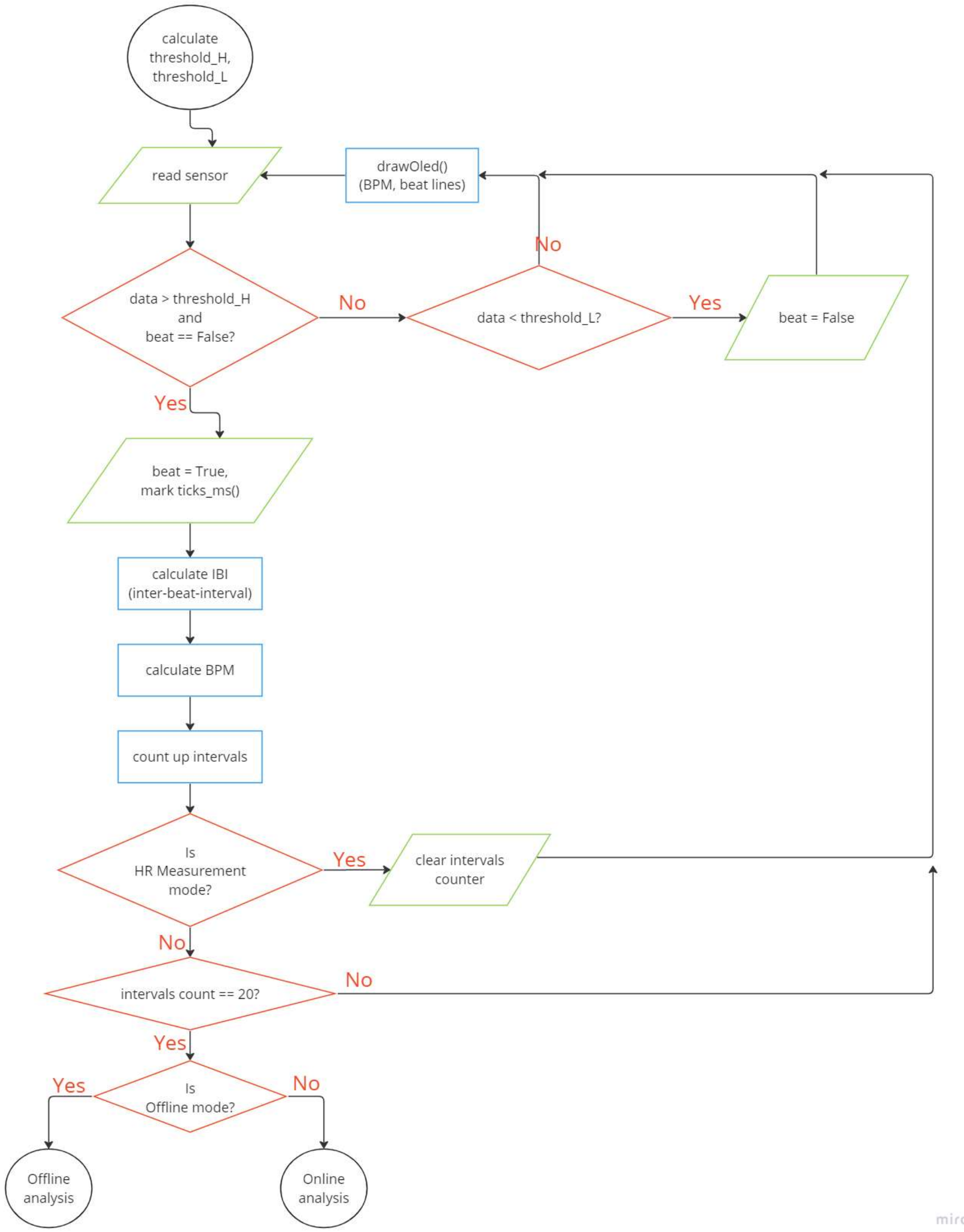


Figure 4: beat detection algorithm

- BPM calculation: every beat has its timestamp (in milliseconds). After finding a new beat, a new timestamp is stuck to this beat and then is appended to a list. A new interval (PPI or IBI) is calculated using the ticks_diff() function. This interval is a timespan between two consecutive beats (in ms). The heart rate BPM is then calculated based on this interval using the formula: BPM = 60000 / PPI. The algorithm for this function is shown in Figure 5

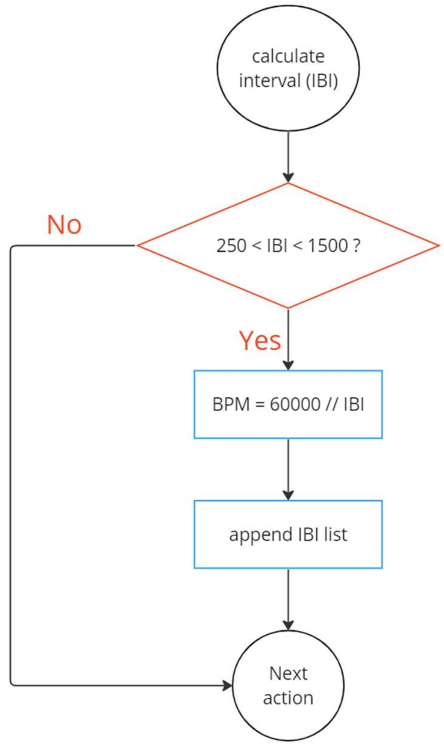


Figure 5: BPM calculation algorithm

- Drawing OLED: this function is used to display heart rate BPM and draw beat lines after every heart rate data. This function required four parameters: sensor's data, max value, min value, and bpm. Max and Min values are determined after every 200 samples getting from the sensor. The upper half of the OLED (32 pixels) is used to display BPM, and another half is used to draw beat lines. The algorithm of this function is shown in Figure 6

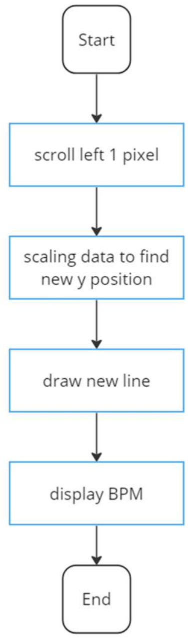


Figure 6: drawOled function algorithm

- Offline HRV Analysis: Pi Pico starts to analyze the HRV after collecting enough twenty intervals. Some basic calculations are executed using formulas provided by the Kubios website:

Mean PPI $(\overline{PPI}) = \frac{1}{N}\sum_{n=1}^{N} PPI_n$

Mean BPM $(\overline{BPM}) = \frac{60000}{\overline{PPI}}$

SDNN = $\sqrt{\frac{1}{N-1}\sum_{n=1}^{N}(PPI_n - \overline{PPI})^2}$

RMSSD = $\sqrt{\frac{1}{N-1}\sum_{n=1}^{N-1}(PPI_{n+1} - PPI_n)^2}$

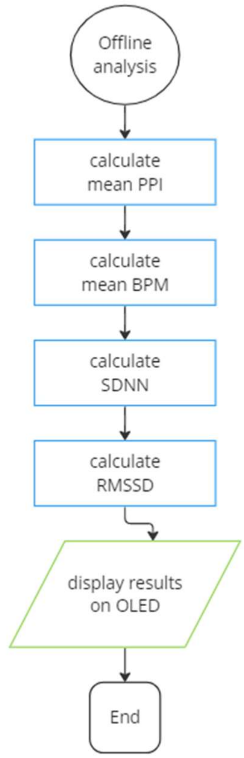


Figure 7: Offline HRV Analysis Algorithm

- Online HRV Analysis: Pi Pico first connects to a WiFi network, then processes to login to Kubios Cloud using an existing account's credential. After successfully logging in to the Kubios, Pi Pico sends a data set, which contains a list of twenty intervals using **requests.post** method. After getting back the analysis results from Kubios, Pi Pico shows this result on OLED. The Algorithm for this function is shown in Figure 8

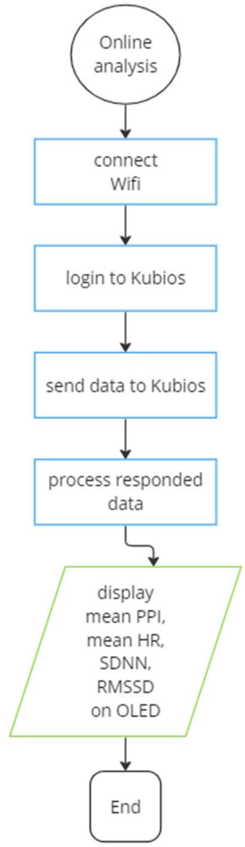


Figure 8: Online HRV Analysis Algorithm

- Figure 9 illustrates the overall program algorithm

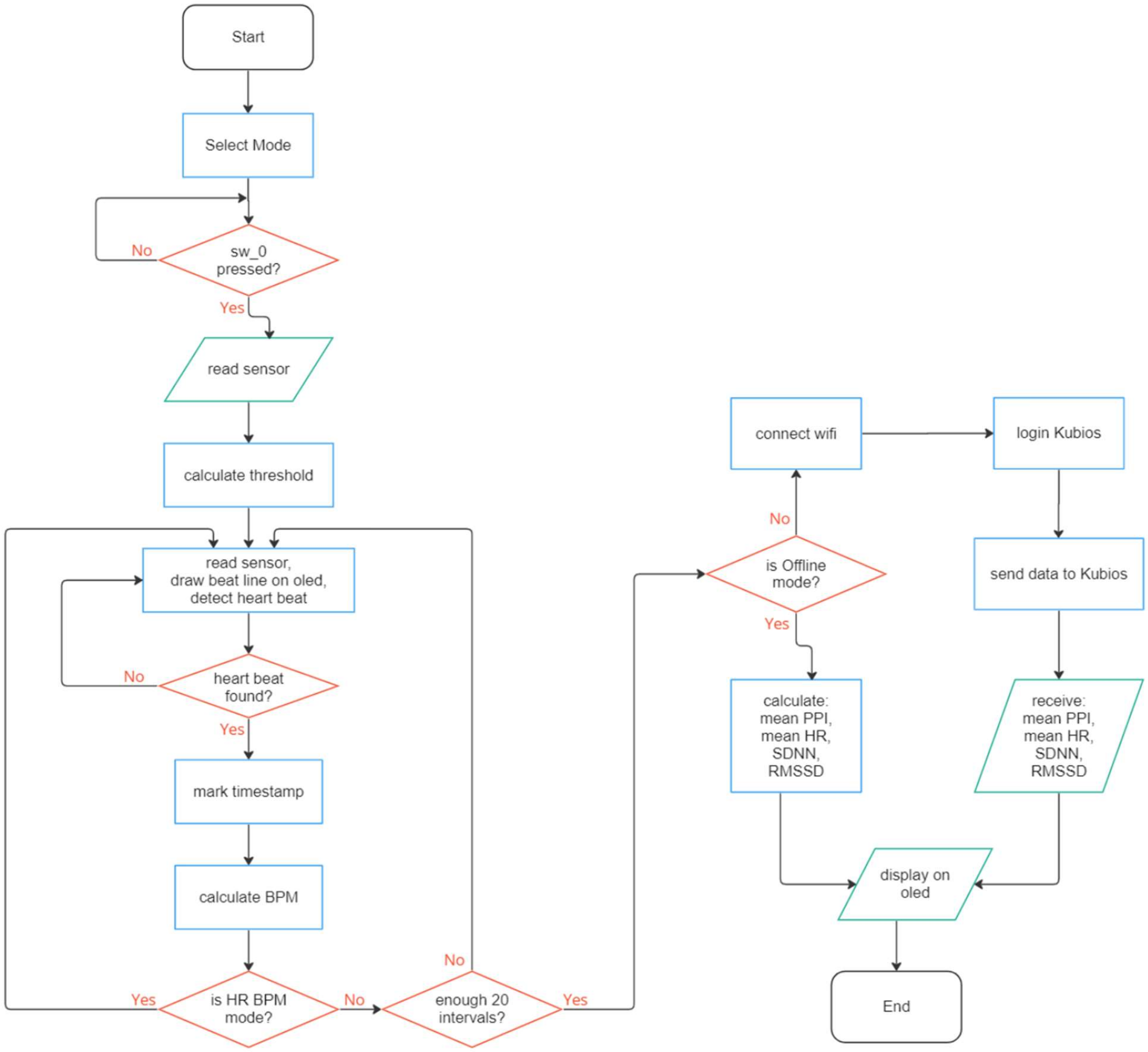


Figure 9: Overall program algorithm

5 Conclusions

Overall, the project was a success in achieving its goals of developing a Heart Rate Variability (HRV) measurement system using a Raspberry Pi Pico W and a Crowtail pulse sensor, and analyzing the HRV data using Kubios software. The prototype measurement system was able to accurately capture heart rate data and provide HRV metrics such as time and frequency domain analysis, which can provide valuable insights into cardiovascular health.

Throughout the project, some challenges were encountered, such as issues with sensor placement and heart rate data processing. However, these were overcome through careful troubleshooting and adjustments to the hardware and software configurations.

One limitation of the prototype measurement system is that it currently requires physical attachment of the pulse sensor to the body, which may not be suitable for all users or situations. Additionally, the current system is only able to measure HRV and does not include additional health metrics, such as blood pressure or oxygen saturation. To address this limitation, future iterations of the system could include additional sensors or integrate with other health monitoring devices to provide a more comprehensive view of the user's cardiovascular health.

To improve or continue the work in the future, several areas could be explored. For instance, alternative methods for wireless transmission of data could be investigated to improve the system's usability and portability. Additionally, incorporating additional health metrics beyond HRV, such as blood pressure or oxygen saturation, could enhance the usefulness of the system for monitoring overall cardiovascular health. Finally, user testing and feedback could be incorporated to refine and optimize the system for practical use by individuals and healthcare providers.

6 References

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