Private Higher School of Engineering and Technology

Major: Electromechanical Engineering

Specialization: Mechatronics

Intelligent Medical Monitoring System for Preventive Patient Care

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General Introduction

Current technological evolution is radically transforming the healthcare sector. Beyond the simple digitization of records, we are witnessing a revolution in medical electronics driven by sensor miniaturization and IoT (Internet of Things) connectivity. These advancements now make it possible to design high-performance and accessible telemonitoring solutions.

Faced with an aging population and the increasing prevalence of chronic diseases, healthcare systems are under unprecedented pressure. The need for devices capable of monitoring patient health remotely, continuously, and non-invasively has become a priority to reduce avoidable hospitalizations and maintain independence at home.

This project is part of this connected medicine dynamic. The objective is to design and implement an integrated system for monitoring essential vital signs: heart rate, oxygen saturation (SpO_2), and body temperature.

Our approach is based on the integration of high-precision biomedical sensors (MAX30102 and MLX90614) controlled by an ESP32 microcontroller. Data is processed in real-time, displayed locally, and transmitted via a secure platform to enable rapid intervention in the event of an anomaly.

This report details the design of our prototype, from technological choices and programming challenges to the results obtained. It demonstrates how the fusion of electronics and computer science can significantly improve the quality of life for patients while optimizing medical resources.

Chapter 1: Project Description

1 Introduction

This chapter outlines the general context of our intelligent medical monitoring system. We begin by analyzing technological trends and current healthcare challenges, particularly within the Tunisian context. Next, we describe the objectives of our ESP32-based solution, specifying its utility for the target audience. Finally, a critique of existing systems highlights the innovation provided by our integrated architecture.

2 Current Technological and Medical Context

2.1 Evolution of Connected Medical Technologies

The Medical Internet of Things (mIoT) has fundamentally transformed patient monitoring. The miniaturization of sensors and improvements in wireless communication protocols now allow for the design of affordable, high-performance remote monitoring devices.

2.2 Demographics and Public Health in Tunisia

Tunisia faces a major healthcare challenge with its aging population. According to the National Institute of Statistics, nearly 12% of Tunisians are over the age of 65, a figure expected to reach 20% by 2035. This demographic transition necessitates the development of remote monitoring solutions to alleviate the pressure on saturated hospital facilities.

3 Project Presentation

3.1 Primary Objective

The goal is to design an integrated system for monitoring essential vital signs: **heart rate**, **oxygen saturation (SpO2)**, and **body temperature**. This system ensures the preventive detection of anomalies and provides immediate alerts to relatives or medical personnel.

3.2 Target Audience

- **Elderly patients living alone** requiring daily safety monitoring.
- **Convalescing patients** for post-operative follow-up at home.
- **Individuals with chronic diseases** (such as hypertension or heart conditions).
- **Family caregivers** seeking to reduce anxiety through real-time health tracking.

4 General System Architecture

To meet the requirements for reliability and simplicity, we have designed a centralized architecture around the ESP32 microcontroller. The diagram below illustrates the global organization of data flow between the user, the sensors, and the output interfaces.

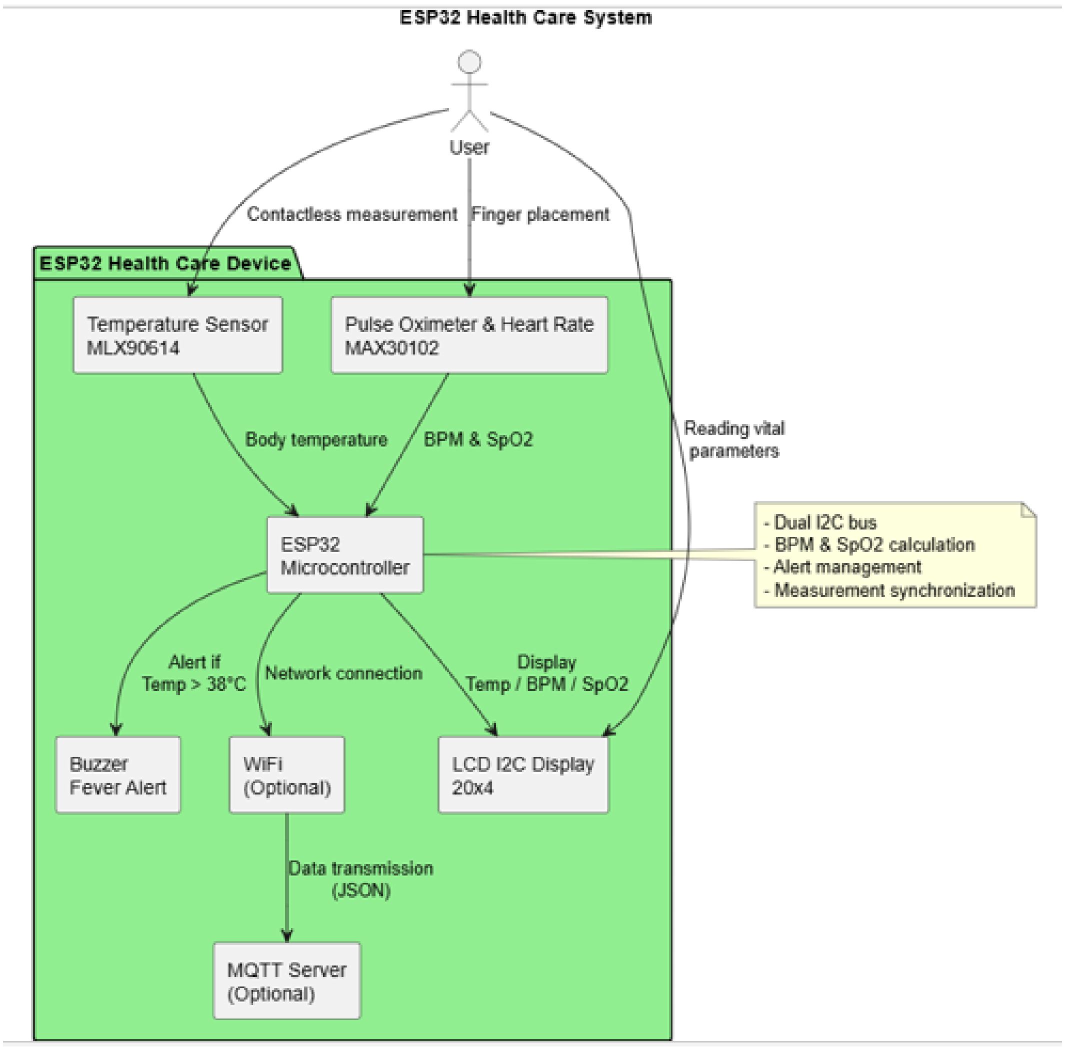

Figure I.1: General System Architecture

4.1 Technical Characteristics of the Solution

As illustrated in the architectural diagram (Figure I.2), the system is based on:

- **Precision Sensors**: Non-contact measurement (MLX90614) and contact measurement (MAX30102).
- **Intelligent Management**: Utilization of a dual I2C bus for sensor synchronization and SpO2 calculation.
- **Local Feedback**: A 20x4 LCD screen and a buzzer for immediate alerts (e.g., Fever > 38°C).
- **IoT Connectivity**: Data transmission in JSON format via the MQTT protocol for remote monitoring.

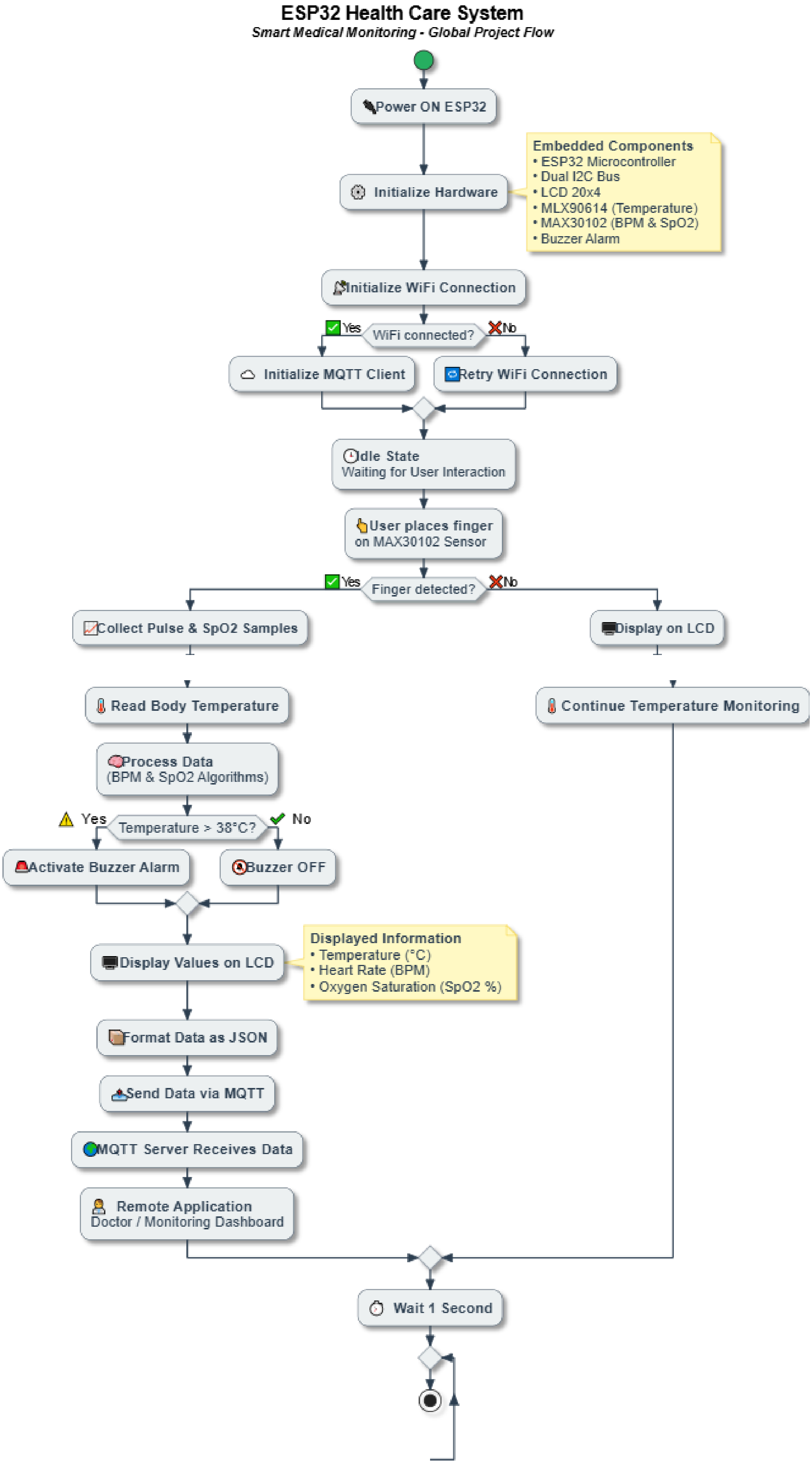

Figure I.2: Global Data Flow and Processing

5 Critique of Existing Solutions and Proposed Solution

5.1 Limitations of Current Solutions

Most current systems are fragmented (measuring only a single vital sign), complex for seniors to operate, or prohibitively expensive for home use.

5.2 Innovation of Our Solution

Our prototype distinguishes itself through an **integrated approach**: a single device manages three vital parameters. Innovation also lies in the accessibility of the hardware and real-time transmission, ensuring a potential reduction in emergency hospitalizations through early detection.

6 Conclusion

This chapter has established the foundation of our project by justifying its medical and technological utility. Based on the presented architecture, we propose a reliable and intuitive solution. The following chapter will detail the hardware implementation and software development required to bring this architecture to life.

Chapter 3: Implementation and Experimental Results

1 Introduction

This chapter details the physical realization of our Smart Health Monitoring System and analyzes the experimental results obtained. We transition from the theoretical design to the actual hardware prototype, demonstrating the system's ability to monitor vital signs in real-time and manage different health-status scenarios through an interactive IoT dashboard.

2 Hardware Prototype Realization

2.1 Physical Circuit Setup

The prototype was assembled using a breadboard for rapid testing and modularity. The central unit, an ESP32, manages the I2C communication bus connected to the MLX90614 and MAX30102 sensors.

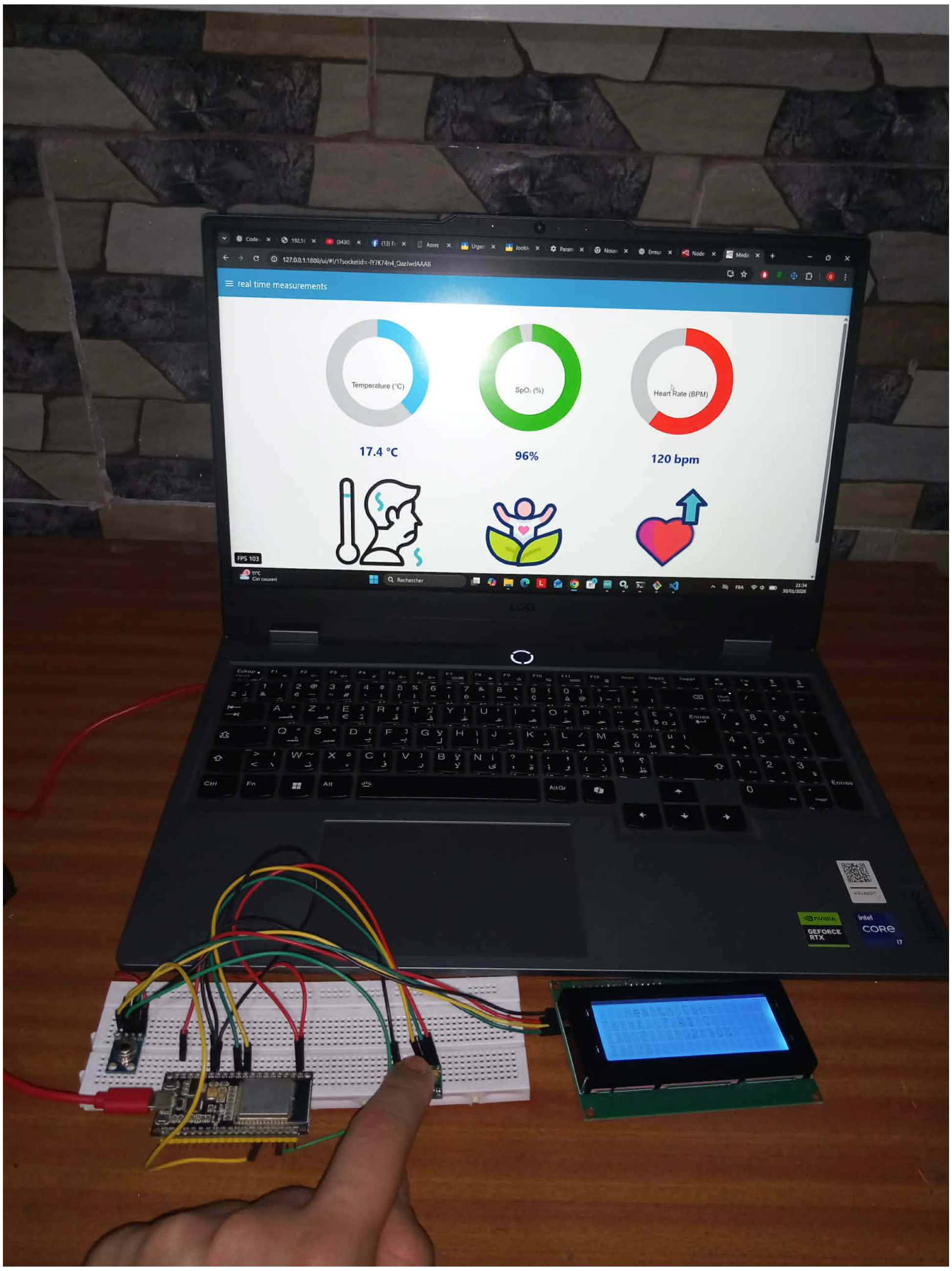

Figure III.3: Experimental Hardware Setup including ESP32, sensors, and 20x4 LCD display

As shown in Figure III.3, the system is powered via USB, providing a stable 5V for the LCD and 3.3V for the sensitive biomedical sensors. The wiring utilizes short-path connections to minimize I2C signal noise.

2.2 User Interface: Local and Remote

The local interface consists of a 20x4 I2C LCD that provides immediate feedback to the patient. Simultaneously, data is sent via WiFi to a custom web dashboard.

The dashboard (Figure III.4) displays the medical team in charge and serves as the gateway to real-time telemetry and historical data analysis.

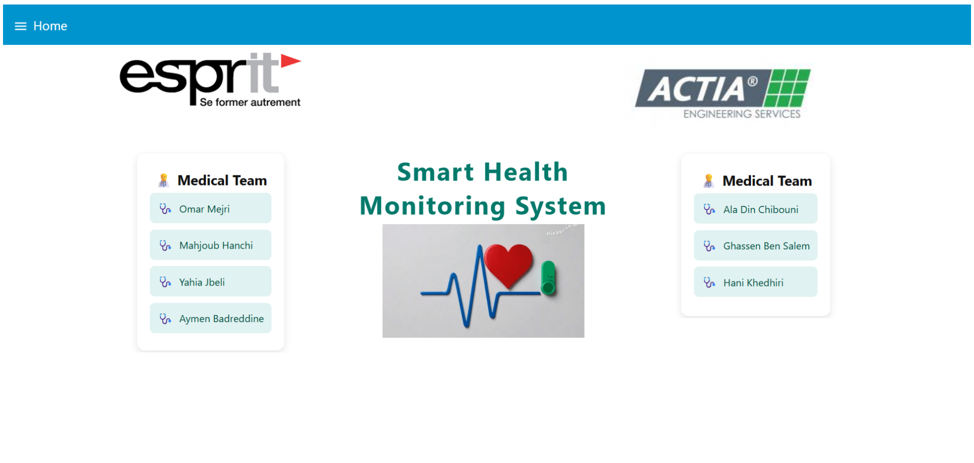

Figure III.4: IoT Dashboard Home Page and Medical Team Interface

3 Experimental Results and Case Studies

To validate the system, three primary physiological states were tested: Normal, Warning, and Critical.

3.1 Scenario 1: Normal Physiological State

In this scenario, the user's vitals are within standard ranges. As shown in Figure III.5, the dashboard displays green indicators.

- **Results:** Temperature: 36.8°C, SpO_2: 95%, Heart Rate: 72 bpm.
- **System Response:** No alerts triggered; the "Healthy" icon is displayed.

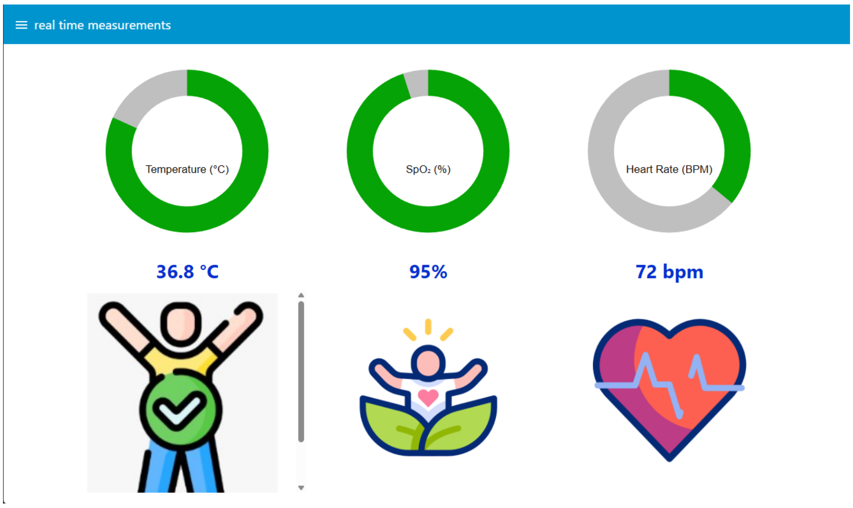

Figure III.5: Dashboard view for stable vital signs

3.2 Scenario 2: Warning State (Hypothermia/Hypoxia)

This test simulates a drop in vital signs. The system identifies a "Warning" state when parameters fall below the safety threshold.

- **Results:** Temperature: 34.5°C (Hypothermia), SpO_2: 88% (Mild Hypoxia).
- **System Response:** Indicators turn blue/orange to notify the caregiver of a potential issue.

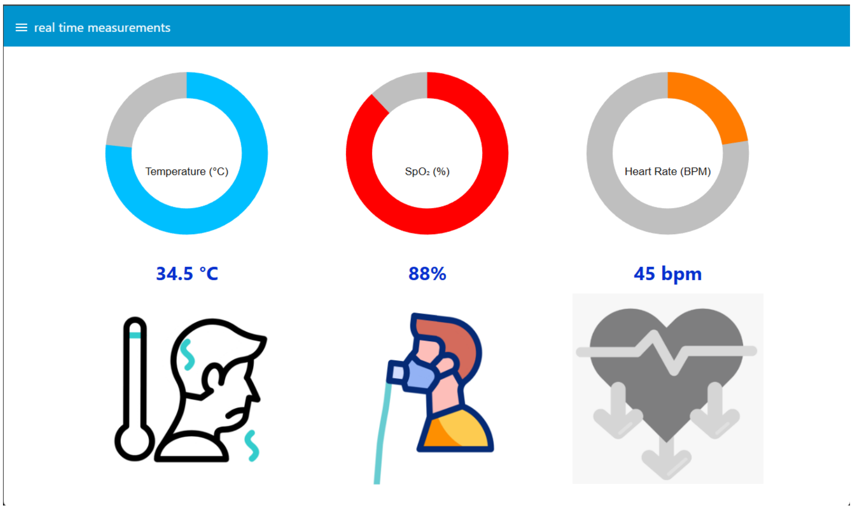

Figure III.6: Dashboard view for warning thresholds

3.3 Scenario 3: Critical State (Fever and Tachycardia)

The most severe state is the "Critical" alert, triggered by high fever or extreme heart rate variations.

- **Results:** Temperature: 39°C, SpO_2: 82%, Heart Rate: 130 bpm.
- **System Response:** Indicators turn red; icons update to show a patient in distress, and the local buzzer is continuously activated.

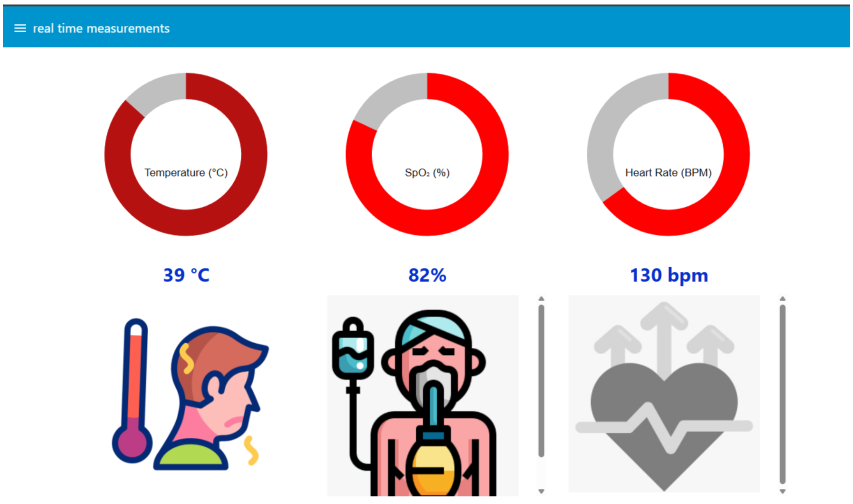

Figure III.7: Dashboard view for critical health alerts

4 Historical Data Analysis

The system stores telemetry data to allow doctors to observe trends over time. The "History" view provides line graphs for each vital sign, ensuring that temporary fluctuations are not confused with chronic issues.

Figure III.8: Historical trends for Temperature, Heart Rate, and SpO_2

As seen in Figure III.8, the system successfully logs data points every few seconds, providing a granular view of the patient's physiological progress.

5 Conclusion

The experimental phase confirms that the prototype is fully functional. The hardware successfully integrates multiple sensors without I2C conflicts, and the IoT dashboard provides clear, color-coded medical intelligence. This implementation effectively bridges the gap between low-level sensor acquisition and high-level medical supervision.

General Conclusion

This final year project enabled us to design and implement a complete medical telemonitoring system, combining embedded electronics with IoT technologies. This experience provided the opportunity to transform our theoretical knowledge into a concrete solution addressing the current challenges of connected healthcare.

The main objective has been successfully achieved: we developed a functional device capable of accurately measuring **body temperature (MLX90614)**, **heart rate**, and **oxygen saturation (MAX30102)**. The use of the ESP32 as the core of the system ensured not only rapid data processing but also a fluid transmission to the Cloud via the MQTT protocol.

From a technical standpoint, the major innovation lies in the system's ease of use and the responsiveness of its alerts. By integrating both local feedback (LCD and Buzzer) and remote monitoring, we provide a double-layer of security essential for the supervision of elderly or vulnerable individuals.

In conclusion, this work demonstrates that technology, when accessible and well-integrated, can significantly improve the quality of life for patients while optimizing medical follow-up. This project has not only trained us in the requirements of biomedical engineering but has also prepared us to meet the engineering challenges of tomorrow.

We would like to express our deep gratitude to our Professor, **Ms. Imen Saidi**, for her invaluable support, as well as to our institution for providing the resources necessary to complete this work.