HEROxS: Heart Rate and Oxygen Saturation Meter

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***Abstract*—Heart rate (HR) and oxygen saturation (SpO2) are two key indicators for evaluating the cardiovascular condition of a person and detecting potential health issues. Hence, there is a need for portable solutions that can provide daily and accurate monitoring of these signals, which later can be evaluated by a healthcare professional. This work presents the design of a device capable of HR and SpO2 monitoring, consisting of a 0.91-inch OLED display that shows real-time measured values, a MSP430G2553 microcontroller and a SEN-15219 sensor board. Experimental results show that the accuracy is very good (less than 2 % of absolute error) and the autonomy can be up to 15 days.**

***Index Terms*—photoplethysmography, PPG, vital signs monitoring, MAX30101, MAX32664**

I. Introduction

In Uruguay, the three leading causes of mortality between 2015 and 2020 were cardiovascular diseases, cancer, and respiratory diseases [1]. Generating information about an individual's health status during their daily activities, which can eventually be consulted by a healthcare professional, is crucial for the prevention, early diagnosis, and control of these conditions. Monitoring oxygen saturation (SpO2) and heart rate (HR) is particularly relevant as they provide a first approach to assessing a person's health status [2]. A commonly used technique to acquire these signals is Photoplethysmography (PPG). PPG use photo-diodes that capture light reflected from blood vessels (typically on the wrist or finger) after being illuminated by a LED [3].

Currently, there are several devices available in the market that utilize PPG, such as smartwatches like Apple Watch [4] or Samsung Galaxy Watch [5], as well pulse oximeter devices [6]. In our lab, we are developing our own device, and this work reports our second generation device [2], [7]. Then, this work presents the proof of concept of a portable device for HR and SpO2 acquisition and recording. The system offers two operating modes, an alarm to notify the detection of abnormal values, and the capability to transmit the recorded data to a personal computer (PC). Furthermore, the system features multi-language support for the device display and the PC.

II. Proposed solution

Fig. 1 shows the block diagram of the proposed solution. The user interacts with the device by pressing a button to start taking measurements, and through a PC terminal, to add/modify user data, to set the operating mode, and to download the recorded data.

The device is composed of the MSP430G2553 microcontroller, the SEN-15219 board, the OLED (Organic light-emitting diode) display with SSD1306 controller, and a button.

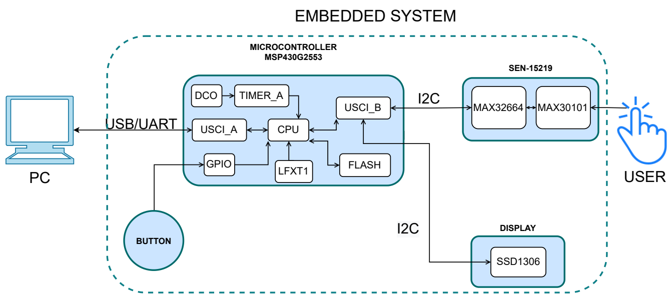

Fig. 1. Block diagram of the proposed system.

The MSP430G2553 is a low-power 16-bit microcontroller from Texas Instruments. It operates at speeds up to 16 MHz and has 16 kB of Flash memory and 512 bytes of RAM. It has built-in peripherals such as I2C (Inter-integrated circuit) and UART (Universal asynchronous receiver/transmitter).

The SEN-15219 board utilizes the MAX30101 SpO2 and HR sensor, along with the MAX32664 sensor-hub. The MAX30101 integrates an infra-red LED, a red LED, a photodetector, and analog signal conditioning circuitry. The MAX32664 controls the measurement process, performs the calculation of SpO2 and HR from the PPG signal, and provides the I2C communication interface.

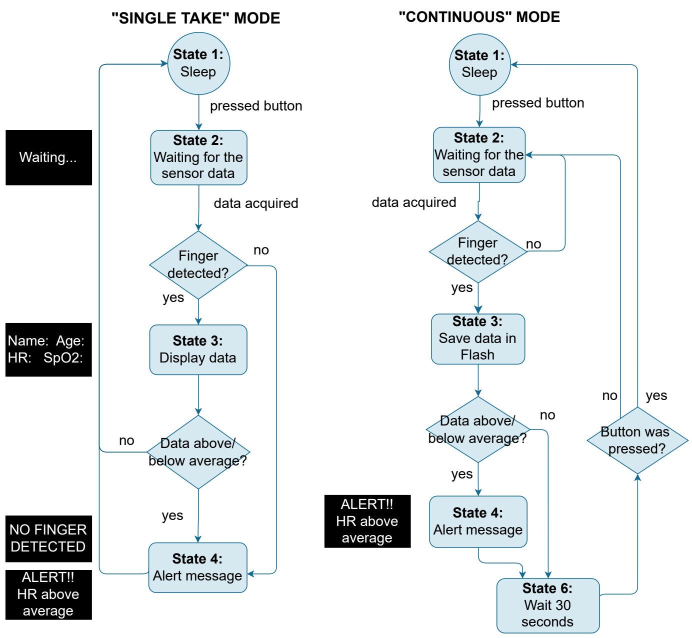

Fig. 2. Flow diagram of "single take" and "continuous" mode, some states are not shown for legibility. Display messages are depicted in black rectangles.

The device has two modes of operation (see Fig. 2). The “single take” mode is designed for occasional self-monitoring, while the “continuous” mode aims to monitor the user’s sleep cycle uninterrupted (approx. 8 hours). In both modes the device is in a low-power mode (sleep state) by default. In “single take” mode, when the user presses the button, the device takes a single measurement and shows the obtained data on the display, along with the user information. Then, the device returns to sleep. In “continuous” mode, the device takes periodic measurements and stores them in the flash memory until the button is pressed. Additionally, for both modes, an alarm message is presented on the display if the HR or SpO2 value is outside a pre-set range, or if the acquired data indicates that there was an error in the measurement (i.e. finger was not detected). For the “continuous” mode, an alarm was implemented to detect when the section of the flash memory reserved for data storage becomes full.

The embedded software architecture is Round-Robin with interruptions [8], where the task of the main program is to check the flags associated with the button’s and UART reception’s ISRs (Interrupt Service Routines) in a loop. When the associated flag is turned “on”, the corresponding handler is executed. In other case, the microcontroller is on low-power mode LPM3 until is woken up by an interruption.

The microcontroller’s internal peripheral data is handled by its ISRs. The USCI_A (Universal serial communication interface) and USCI_B peripherals were configured for UART and I2C protocols, respectively. UART was used for communication with the PC, while I2C was used for communication between the master (microcontroller) and the slaves (display and SEN-15219 board). Additionally, the Timer_A peripheral was used to implement the periodic sampling described in the “continuous mode” behavior. During this time, the device enters in low-power mode LPM0 to reduce power consumption until the next timer interruption.

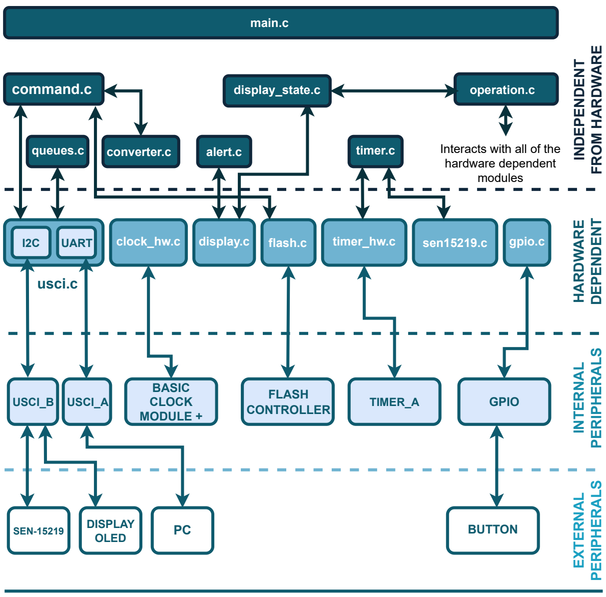

Fig. 3. Software modules.

Fig. 3 illustrates the interdependence of the software modules and their relationship with the hardware components. The modules include data acquisition and processing, communication, and user interface, among others, and work collaboratively to ensure the device’s proper operation.

III. Experimental Results

A. Current consumption and autonomy

Fig. 4 shows the experimental set-up, where the Power Profiler Kit 2 by Nordic was used to measure the current.

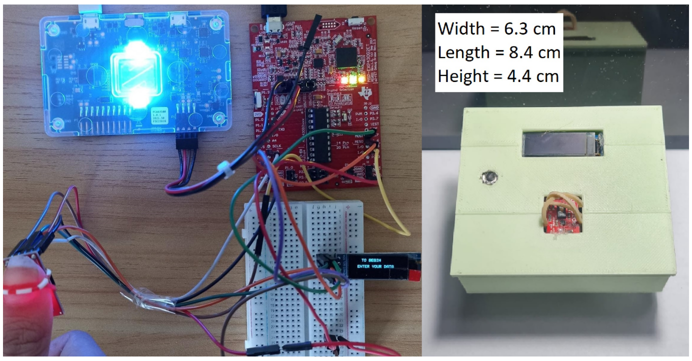

Fig. 4. Hardware experimental set-up (left) and the manufactured prototype (right)
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Table 1 shows the current consumption of each component of the system, categorized by different modes of operation. It was observed that the SEN-15219 board exhibited high current consumption in sleep mode, accounting for approximately 98.9 % of the total sleep current consumption. Additionally, significant current consumption was also observed in single take and continuous operating modes. Optimization strategies should be implemented in future work to reduce the current consumption of the SEN-15219 board in sleep mode and improve the overall energy efficiency of the system. This work focused on reducing current consumption at the microcontroller level, achieving an operating consumption of 360 μA and a sleep one of 88 μA.

TABLE I
Current Consumption of the Different Operating Modes

	Sleep	Single take	Continuous
Total	8.44 mA	18.12 mA	16.00 mA
Display	4 μA	2.71 mA	4 μA
Microcontroller	88 μA	360 μA	360 μA
SEN-15219	8.35 mA	15.50 mA	15.61 mA

Next, we estimate the device autonomy for different battery types, considering both modes of operation. In the single take mode, we considered that the user performs two measurements per day, while in the continuous mode, current was measured with the system at the steady state condition (taking measurements every 30 seconds). Table II shows the run time of different battery types for both modes of operation. It can be observed that in the continuous mode, the device is capable of lasting more than one complete sleep cycle.

TABLE II
EMBEDDED SYSTEM AUTONOMY FOR THE DIFFERENT OPERATING MODES

Mode	CR2032	2xAAA	2xAA
Single take	1d 4h 8m	11d 12h 38m	29d 22h 33m
Continuous	14h 41m	6d 22m	15d 15h

B. Memory

Memory usage was measured using *Code Composer Studio* from Texas Instruments. Table III shows these results.

TABLE III
MEMORY USAGE

	Flash (kB)	Flash (%)	RAM (B)	RAM (%)
Available	12.51	100	512	100
Used	6.40	51	486	94

C. Vital signs measurement

One hundred samples were taken to assess device accuracy. Measurements from a reference device were simultaneously obtained, using an ArgomTech smartwatch, model SkeiWatch S50 [9]. The test was conducted on a 21 year old healthy female, in an indoor space, and both our device and the reference device were placed in the right hand. Table IV outlines the statistical behavior of the acquired data, comparing results between HR and SpO2 measurements. The obtained values are consistent.

TABLE IV
STATISTICAL ERROR ANALYSIS

	Heart Rate (bpm)		SpO2 (%)	
	Abs. error	Rel. error	Abs. error	Rel. error
Mean	1.61	2.07%	1.48	1.50%
Std. deviation	1.20	-	0.94	-

Figs. 5 and 6 show the histograms which describe the absolute error behavior for HR an SpO2 measurements respectively.

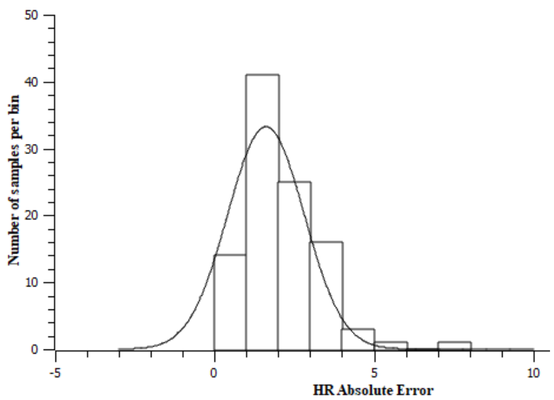

Fig. 5. HR absolute error.

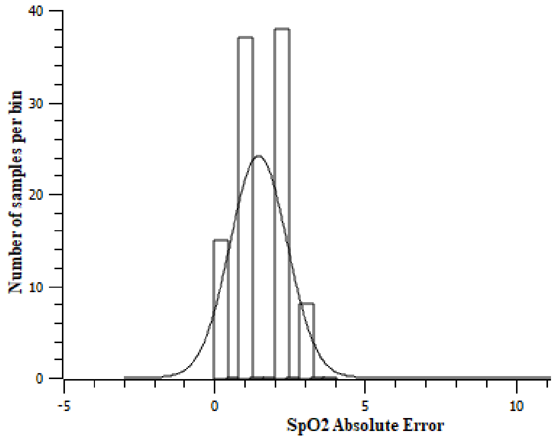

Fig. 6. SpO2 absolute error.

IV. CONCLUSIONS

We successfully developed a device capable of monitoring vital signs. The low-power techniques utilized in the microcontroller contributed to achieve the needed autonomy. However, optimization strategies need to be implemented to minimize the current consumption of the SEN-15219 board in sleep mode to further improve the device's energy efficiency. The system offers two operating modes, an alarm to notify the detection of abnormal values, and the capability to transmit the recorded data to a PC.

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