Three-Stage Power Supply System Model for a Wearable IoT Device for COVID-19 Patients

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***Abstract*—During the current crisis caused by the COVID-19 pandemic, Wearable IoT (WIoT) health devices have become essential resources for remote monitoring of the main physiological signs affected by this disease. As well as sensors, microprocessor, and wireless communication elements are widely studied, the power supply unit has the same importance for the WIoT technology, since the autonomy of the system between recharges is of great importance. This letter presents the design of the power supply system of a WIoT device capable of monitoring oxygen saturation and body temperature, sending the collected data to an IoT platform. The supply system is based on a three-stage block consisting of a rechargeable battery, battery charge controller, and dc voltage converter. The power supply system is designed and implemented as a prototype in order to test performance and efficiency. The results show that the designed block provides a stable supply voltage avoiding energy losses, which makes it an efficient and rapidly developing system.**

***Index Terms*—Battery charge controller, COVID-19 Wearable IoT (WIoT), embedded healthcare systems, lithium-ion (Li-ion) batteries, power supply system.**

I. INTRODUCTION

IN RECENT years, wearable devices have become a popular resource for health tracking due to the benefits and special features that these systems provide to monitor physiological and biomechanical signs. The wearable technology encompasses all devices with the ability to collect data from the body, perform basic preprocessing, data storage, and data transfer via wireless communication technologies [1].

The Internet of Things (IoT) support wearables in the task of achieving data communication toward a platform or data system through wireless communication protocols and standards. The IoT includes the different scenarios in which an interaction between objects and the Internet occurs [1]. A complete technological framework to receive data from wearables and mobile devices for computing and storage processes are provided by the IoT. This inexorable relationship between wearable technology and the IoT is known as Wearable IoT (WIoT) [1].

In December 2019 in Hubei, China, the first case of the COVID-19 disease was registered, becoming an international concern because this respiratory disease, generated by severe acute respiratory syndrome Coronavirus-2 (SARS-CoV-2), is rapidly spreading and mainly affects elderly and people with chronic diseases [2]. An effective alternative for this problem is the remote tracking of confirmed COVID-19 cases, since it is possible to monitor the main physiological signs and take early action when the patient's disease worsens [3]. However, there are factors that are recommended to include during the design of WIoT devices for medical applications [4]. The following factors are considered during the WIoT device design process presented in this letter: 1) portability; 2) scalability; 3) affordability; 4) connectivity; and 5) energy efficiency.

The contribution of this letter is the design of a power supply system model aimed at a WIoT device capable of monitoring patients with COVID-19. The proposed model is based on a comparison of the main alternatives of low-cost and reliability devices. Critical factors, such as output voltage signal and operating temperature are measured from the prototype implementation to achieve system effectiveness.

II. SYSTEM OVERVIEW

The proposed WIoT device model for COVID-19 patients mainly monitors blood oxygen saturation and body temperature. The method to measure these physiological signs is a noninvasive process in which sensors are placed in particular regions of the human body to provide measurements that are as accurate as possible. The complete health system includes wireless communication via the Wi-Fi technology, using MQTT communication protocol, to send data collected from the WIoT device to an IoT platform where patient information is displayed on a dashboard; additionally, alert management is implemented when critical values of oxygen saturation and body temperature are detected. To measure the patient's blood oxygen saturation and body temperature, MAX30100 and MAX30205 sensors are proposed. Espressif's ESP32 system on a chip (SoC) is proposed as the central microcontroller, which integrates technology and multiple modules for wireless communications in IoT applications, such as Wi-Fi, Bluetooth, and Bluetooth low energy (BLE).

The selected IoT platform is Ubidots, which allows mobile devices to communicate via MQTT. The WIoT device placement is proposed in accordance with World Health Organization (WHO) recommendations on the correct method for measuring oxygen saturation [5]. Therefore, the WIoT device is presented as a wristband with a clip for the index

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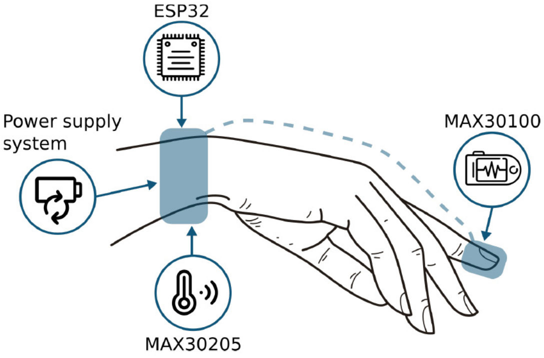

Fig. 1. Proposed system location based on oxygen saturation measurement recommendations.

finger connected by a cable to the central system for data communication and power supply. The temperature sensor, the ESP32 module, and the power supply system are embedded in the wrist, as shown in Fig. 1.

The proposed system is aimed at a medical research environment where multiple WIoT devices can be used on COVID-19 patients to record health data when different medical treatments are applied, or for different purposes. Furthermore, this device was designed with the intention that it be for personal use as well. This system allows free use of patient data for robust analysis or processing, with the benefit of remote wellness monitoring and the ability to change the time intervals for taking measurements.

Whether for personal use or for medical research purposes, the proposed WIoT device focuses on ambulatory cases, where the health status of the infected person does not indicate the need for specialized medical care directly in a hospital, but frequent wellness monitoring is recommended. The device operates in two different modes. In active mode, the device takes oxygen saturation and body temperature measurements, processes and sends the data to the IoT platform. When finished, the WIoT device enters deep sleep mode and the sensors and core processor are shutdown to reduce power consumption. Therefore, the active mode is proposed every hour, but this period can be modified if the patient requires it or if the health expert suggests it.

III. THREE-STAGE POWER SUPPLY SYSTEM DESCRIPTION

An essential layer of any WIoT device is the power supply system that provides the necessary energy to all components for proper operation. Generally, these systems are based on rechargeable batteries, and in recent cases, energy harvesting models have been proposed and developed for wearable technology [6]. Broadly, battery-based models are composed of three essential layers: 1) rechargeable batteries; 2) battery charge controller; and 3) dc voltage converter. In this section the supply system model and required components are presented.

A. Rechargeable Battery

In mobile technology, lithium batteries are increasingly common due to their low weight and high energy storage capacity, in addition, these batteries provide high safety and efficiency during the charging and discharging process [7].

Alkaline batteries are another popular alternative in mobile applications because they are easy to purchase and cheap. Compared to lithium-ion (Li-ion) batteries, alkaline batteries can provide long-term power, but the ability to store energy decreases over time; on the other hand, Li-ion batteries can store and provide more energy [7]. Another alternative is lithium iron phosphate (LiFePo4) batteries, which are used to power electric motors and mobile devices, because they are safer and can operate at higher temperatures [8]. However, they cannot store as much energy as Li-ion batteries and have the same dimensions [7].

Due to the advantages over other alternatives, Li-ion batteries are selected for this layer of the supply system. In terms of cost, LiFePo4 batteries are expensive and difficult to purchase. Alkaline batteries are cheaper compared to lithium batteries, but to obtain the minimum operating voltage for the core processor and sensors, a three AA battery pack is required, which increases the final cost. In addition to the energy storage capacity, Li-ion batteries represent a low-cost alternative. For the implementation of the prototype, a Li-ion 18 650 battery is used which provides 2600 mAh.

B. Battery Charge Controller

When using Li-ion batteries it is necessary to implement a circuit to control the charging process in order not to damage the battery. The recharging process for Li-ion batteries is standardized as a constant current-constant voltage (CC-CV) method. The recharging process must be carefully controlled since an overload in a Li-ion battery deteriorates the internal materials, inducing a decrease in electrochemical reactions when the battery is in operation [7]. Also, when an operating Li-ion battery drops its voltage more than the operating range it can be damaged. Therefore, the charge control circuit must perform at least three essential operations: 1) charge the battery with the standardized CC-CV method; 2) regulate the maximum charging voltage to 4.2 V and the minimum to 3.0 V; and 3) limit battery performance when its voltage drops below 3.0 V.

Some alternatives to build battery charge controller layers, such as BQ25798, LM3420A, or MAX3717, cost between U.S. \$6.00 and U.S. \$9.00 from official vendors, however, Nanjing Top Power ASIC Corporation's TP4056 IC is selected as its technical characteristics allow it to meet the three operations required for a Li-ion battery, protecting the battery when its voltage reaches 2.9 V; it is easy to buy with a cost of U.S. \$2.36, and the main benefit is the module version that integrates the IC, the required circuitry and a micro USB port, all on a small Printed Circuit Board (PCB).

C. dc Voltage Converter

Li-ion batteries provide a nominal voltage of 3.7 V and ESP32 module works typically at 3.3 V, but its voltage range is defined from 3 to 4.2 V; so much of the supplied voltage exceeds the allowable limit of the ESP32 module. Therefore, it is necessary to implement a voltage converter to adjust the supply voltage for the entire system.

Popular alternatives rely on low-dropout (LDO) converters that step down the input voltage and can provide ultralow

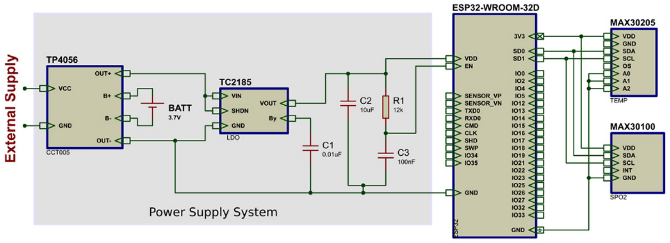

Fig. 2. Wiring diagram of the electrical circuit of the WIoT device.

quiescent current when the load is in standby mode; they have advanced packaging for reduced size and improved thermal performance [9]. However, at higher loads more energy is lost and dissipated as heat [10]. On the other hand, Buck converters are another alternative that improves efficiency and decreases heat during operation, achieving a stable reduced voltage [10]. Nevertheless, Buck converters can induce noise and do not optimize current consumption when the load is in shutdown mode.

For the WIoT device presented in this letter, an LDO converter is selected due to the ultralow quiescent current that optimizes battery life when the WIoT device enters sleep mode. The main alternatives studied for their costs, functionality, and reliability were the XC6210, TC2185, and LD59015. All three options meet the most important requirements, such as dropout voltage or output current. Hence, the selected LDO converter was the Microchip's TC2185-3.3, which steps down the voltage to a fixed value of 3.3 V, and draws 80 μA as supply current. This integrated circuit is the cheapest of the three, with a cost of U.S. $0.51.

For system calibration, the LDO converter requires recommended circuitry to function properly and generate the stable 3.3-V output voltage. This additional topology suggests specific capacitors at the Output and Bypass terminals; as recommended by the manufacturer.

IV. PROTOTYPE RESULTS

The block made up of sensors and microprocessor remains in active mode for approximately 29.97 s, taking readings and sending data through Wi-Fi and MQTT protocol. On average, in active mode the system consumes 134.9 mA; instead, in sleep mode the system consumes 9.823 mA. The circuit schematic of the entire WIoT device, including the additional circuitry of the LDO converter and the block to directly power the ESP32 module is presented in Fig. 2.

To obtain the total power consumed in 1 h, the mathematical model proposed in [6] is used, where the current consumption in active mode and in deep sleep mode, as well as the respective times in each mode, are analyzed.

For 1 h the entire WIoT device, whose prototype is shown in Fig. 3, consumes approximately 10.86 mA, when monitoring is performed once in 1 h. Since the selected battery provides 2600 mAh, to calculate the battery life between recharges when monitoring is performed once in an hour, the model proposed in [11] is used, in which the battery capacity is divided by the current consumption of the load. The results indicate that the battery can provide energy for about ten days, or 234 h.

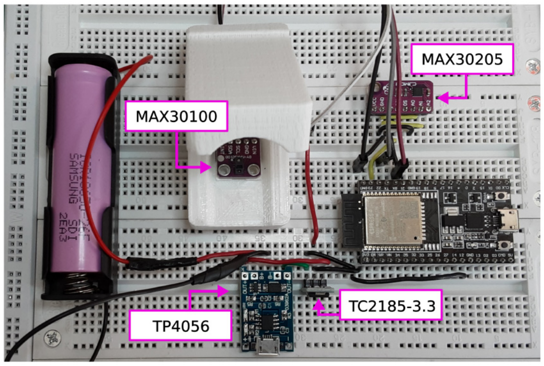

Fig. 3. Implementation of the WIoT prototype, with selected sensors, and the three-stage power supply system.

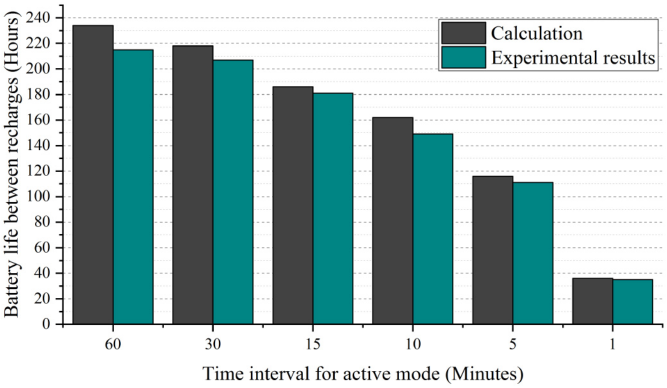

Fig. 4. Comparative graph between battery life calculation and experimental results.

On the other hand, as mentioned, the time period for complete monitoring can be modified, with six different periods available. Thus, from the mobile application, monitoring can be configured every 1, 5, 10, 15, 15, 30, and 60 min. For each option, the battery life was calculated using the same mathematical model and compared with the experimental results, as shown in Fig. 4.

From the results obtained, there is a slight difference between the experimental measurements and the theoretical values. This is because the calculation does not take into account the fact that the battery cannot provide the same voltage value during the run. When the battery is fully charged, it can provide 4.2 V, but this value starts to decrease slowly. For this reason, the ESP32 module and the sensors stop working.

The output voltage was measured, thus verifying that the signal is stable without noise; results are presented in Fig. 5. The supply system was put into operation for 5 h while temperature was measured periodically without getting significant changes. The measured values are presented in Fig. 6.

The portable technology may require various power levels from different power sources [12], depending on the design of the main layer. This can be studied in [13], where different power levels are provided from different dc voltage converters, using step-down and step-up converters that are not efficient when the load enters standby mode, leading to poor battery performance. When the central processor is well encapsulated with all its secondary modules, there is no need to provide different power levels, reducing size, and power consumption.

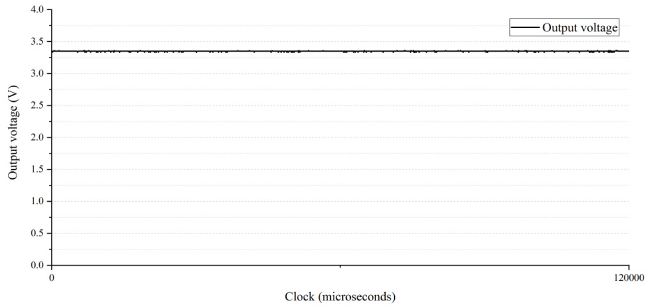

Fig. 5. LDO converter output voltage supplied by Li-ion battery (set of data obtained from oscilloscope measurements).

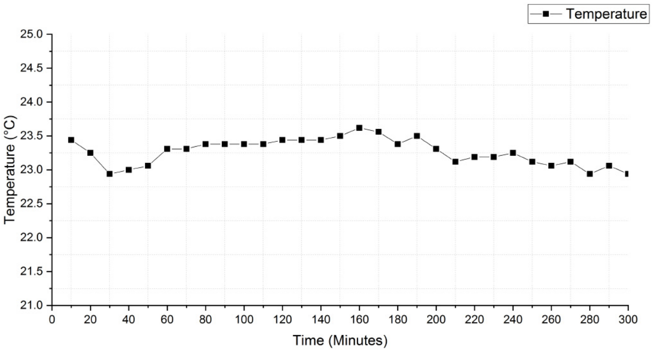

Fig. 6. LDO converter temperature measurements every 10 min and made with the DS18b20 sensor during 5 h of testing.

Regarding energy sources, wearables mainly use batteries, solar cells, and biofuel cells [12]; but in the last two cases a battery is necessary to store the collected energy. In [6] a hybrid power supply system using solar cells and a lithium battery is proposed. The main drawback of using solar cells is that they need light (preferably natural) [12], but a health device cannot always obtain this resource. That fact leads to low battery life. Additionally, hybrid systems are more complex in terms of materials, size, and require power management modules [12].

In order to improve battery charging, efficient alternatives based on radio-frequency designs for wireless chargers, such as the one presented in [14], are proposed. With such a wireless charging design, a battery can be fully charged in less time compared to the proposed cable-based model. However, these chargers require high radio frequency signals, are vulnerable to external electromagnetic interference, and the distance between the wearable device and the charger must be short [12]. In addition, noise during operation can be avoided with a cable-based charging system.

V. CONCLUSION

This letter presents the design of a power supply system aimed at the wearable technology, specifically for a WIoT health device for the current COVID-19 disease, which monitors oxygen saturation and body temperature. The power supply system is proposed as a three-stage block made up of a rechargeable battery, battery charge controller, and dc voltage converter. The design methodology was based on concrete research with the aim of selecting the optimal devices for a WIoT architecture and placing broad importance on the factors of affordability, portability, and energy efficiency, which are widely recommended in the design of the wearable technology. From the results obtained, the output voltage shows that the selected LDO converter avoids noise and ripples in the provided signal. Also, there is no power loss during voltage regulation because the operating temperature of the power supply system does not rise even when the ESP32 performs data transmission via Wi-Fi. With the selection of an LDO converter, which provides ultralow quiescent current, battery life is optimized during the sleep mode of the entire WIoT device. Due to the emergence of highly contagious diseases, the proposed model adopts a technological approach of a rapidly developing system, reliable in its autonomy and safe during battery operation, based on a low-cost and efficient architecture aimed at the development of new technologies for medical applications. As future work, the design of the WIoT device will be implemented including the power supply system presented in this work on a PCB.

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