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IoT-Based Low-Cost Smart Health Monitoring System using Raspberry Pi Pico W and Blynk Application

Hala Jassim Mohammed

Department of Computer Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq
hala.jassim@coeng.uobaghdad.edu.iq

ABSTRACT

In recent years, the technological advent of the Internet of Things (IoT) and smart sensing devices have opened new trends and given practical solutions in various sectors of life. The IoT is a modern technology that interconnects networks of different things. Healthcare sectors have been improved based on IoT including the health monitoring system (HMS). Monitoring patient observation wirelessly at a low cost is considered a significant issue. This work is proposed especially for monitoring patient health parameters in real-time at a low price. It consists of smart sensors that measure different parameters which are: BPM (heart rate), body temperature, and SPO2 (Oxygen Saturation) for the patient, respectively. Patient status is displayed locally on the OLED and globally using the Blynk application. In this system, the Raspberry Pi Pico W board is used as a microcontroller with the concept of cloud computing. The results showed that patients' acquired data would be transmitted very quickly, and numerous patients could be screened remotely. The proposed HMS is compared to commercial devices in terms of accuracy, cost, and usability. The system shows an acceptable error percentage for the mentioned health parameters ranging between (-2 to 7 %), relatively low cost and flexible usage.

Keywords: Blynk application, Health monitoring system, Internet of things, Raspberry pi pico w, Sensors.

*Corresponding author
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نظام مراقبة الصحة الذكي منخفض التكلفة القائم على إنترنت الأشياء باستخدام Raspberry Pi Pico W و تطبيق Blynk

هالة جاسم محمد

قسم هندسة الحاسبات، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة

في السنوات الأخيرة، أدى التقدم التكنولوجي في إنترنت الأشياء (IoT) وأجهزة الاستشعار الذكية إلى فتح اتجاهات جديدة وإعطاء حلول عملية في مختلف قطاعات الحياة. يتم التعرف على إنترنت الأشياء كتنولوجيا حديثة تربط بين مختلف انواع الشبكات. في المجال الطبي تم تحسين قطاع الرعاية الصحية بناءً على هذه التكنولوجيا ومنها نظام مراقبة الصحة (HMS). تعتبر مراقبة المريض عن بعد لاسلكيًا وبتكلفة منخفضة أمرًا بالغ الأهمية في هذا المجال. في هذا العمل، تم اقتراح نظام مراقبة صحة المريض في الوقت الحقيقي وبتكلفة منخفضة. يتكون االنظام المقترح من عدد من أجهزة الاستشعار الذكية التي تقيس معلمات مختلفة وهي: عدد نبضات القلب بالدقيقة، درجة حرارة الجسم، وSPO2 (تشبع الأكسجين) للمريض على التوالي. يتم عرض حالة المريض اما على شاشة OLED اوباستخدام تطبيق Blynk. في هذا النظام تستخدم لوحة Raspberry Pi Pico W كوحدة تحكم دقيقة مع مفهوم الحوسبة السحابية. ان النتائج التي يتم الحصول عليها من المريض يتم نقلها بسرعة كبيرة ويمكن فحص العديد من المرضى عن بعد. تتم مقارنة نظام إدارة الصحة المقترح بالأجهزة التجارية من حيث الدقة والتكلفة وسهولة الاستخدام. يُظهر النظام نسبة خطأ مقبولة للمعايير الصحية المذكورة تتراوح بين (−2 إلى 7 %)، وتكلفة منخفضة نسبيًا ومرونة في الاستخدام.

الكلمات المفتاحية: نظام المراقبة الصحية، إنترنت الأشياء، أجهزة الاستشعار ، Raspberry Pi Pico W، تطبيق Blynk.

1. INTRODUCTION

The Internet of Things (IoT) represents the next important technological revolution and recently it has become a very important technology in people's lives. It connects different objects using different technologies that serve human beings with minimal intervention. The notion of IoT is the internetworking of various physical devices that are embedded with software, electronics, actuators, sensors, and network connectivity to give the connected objects the ability to collect and exchange information **(Younis et al., 2015; Kadhim and Hamad, 2023; Qadir and Hussan, 2023; Mahmood et al., 2023; Li et al., 2024)**. Physical things can share and collect data based on low-cost computing, cloud, big data, analytics, and mobile technologies **(Islam et al., 2020)**. IoT innovations have emerged as a new paradigm in using smart systems and intelligent devices to analyze data for various applications **(Ru et al., 2021)**. Examples of sectors that use IoT are Transportation, Environmental Monitoring, Manufacturing, Medical and health care, and home automation **(Khan et al., 2023).** A general overview of the IoT system (including proposed hardware components) is shown in **Fig. 1**, which includes the following key components: sensor communication, microcontrollers, actuators, and user interfaces **(Wu et al., 2020)**.

IoT falls into health monitoring fields, which is the most important branch that is in direct contact with human health. It provides health condition tracking facilities and can be applied to a diverse array of fields, including care for pediatric and elderly patients, the supervision of chronic diseases, and the management of private health and fitness **(Alattar and Mohsen, 2023)**. Recently, many people have been affected by chronic diseases such as mind stroke and heart attack. Therefore, it is required to undergo medical examinations to avoid any unexpected health conditions. In such systems, IoT links computers to the internet with the utilization of different sensors and networks to monitor the patient's health **(Hasan et al., 2019)** where the information is forwarded to distant locations using other devices such as handheld devices, or smartphones.

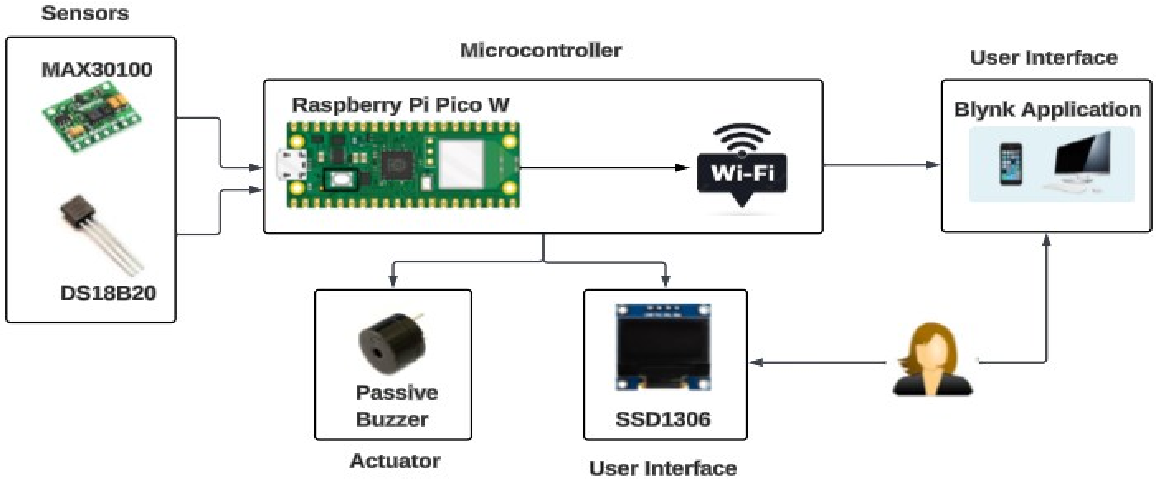

Figure1. A general overview of the IoT system (including proposed hardware components).

IoT-based healthcare monitoring systems are preferable over traditional healthcare systems since they are smart, fast, and efficient technologies that make human life simpler and easier **(Hegde et al., 2021)**. These systems are based basically on measuring patient signs. The physiological signs of the human body are different and can be electrical signs or biochemical signs. The vital signs of the human body are important and need to be measured and regularly observed to avoid remarkable inauspicious consequences. The most vital patient signs are Heart Rate, Electrocardiogram, Respiration Rate, Blood Oxygen Saturation, and Blood Pressure **(Elliott and Coventry, 2012)**. These signs are obtained from the sensor then they are transmitted through the network and then the caregivers can automatically know his/her health condition to provide the treatment based on the quick diagnostic **(Abdulmalek et al., 2022)**.

Embedded sensor systems are considered a key element of advanced medical devices because they enable the development of diagnostic and monitoring for patients in various environments such as home and hospital **(Arandia et al., 2022)**. In general, any embedded system is composed of Hardware, firmware, and software. Where the hardware component consists of the physical and electronic parts that are needed to implement the embedded system functionality. Usually, the main element of the hardware components is the processing unit (microcontroller, microprocessor, or Digital Signal Processor) that controls the integrated circuits. On the other hand, the software is the program (which is programmed in the specific processing unit) that responds to system functions. The firmware is the instructions implemented at the processing unit to control the electronic circuitry and it is considered the link between the hardware and software **(Arandia et al., 2022)**. Medical devices reduce costs and improve the outcomes of the patients. Such a system can capture and monitor the data of patients, and then transmit it electronically to specialists to aid in diagnosing and treating the patients based on their health conditions. There are different medical devices, diagnostics, sensors, and others that are considered a significant portion of IoT.

The estimation from the WHO (World Health Organization) states that between 2015 and 2050, the world's population over the age of 60 will increase from 12% to 22% **(World Health Organization, 2022)**. Moreover, it is noticeable that there is an increase in deaths among sick people, elderly people, and people suffering from chronic diseases due to the lack of adequate healthcare monitoring. In this context, the development of technologies going towards remote health monitoring in different environments is very important. Therefore, many researchers have changed their interest in the benefits of the Internet in health monitoring especially after the rapid development of the IoT **(Mostafa et al., 2020)**. In remote HMS, sensors can be used to check the activities of patient health by collecting data from them. Then these data are stored or transmitted to the specialized via the Internet by displaying the results on a web-based platform or special screen. The Multi-parameter monitoring devices are used in the applications of IoT to monitor human health based on the electrical activity, heartbeat, respiratory flow rate, and the temperature of the human body and some other signs **(Khan et al., 2022)** to monitor oxygen saturation level, heart rate, and temperature concurrently. HMS are simple, smart, scalable, efficient, and interoperable approaches for tracking and monitoring health issues **(Islam et al., 2020)**. One of the significant parameters that affect health issues of well-being in the human body is the heart rate. This indicator counts how many times the heart contracts or beats per minute **(Hegde et al., 2021)**.

Different factors change the speed of the heartbeat such as physical activities, continuous work, and security threats. This parameter is measured by heart beeps per minute (bpm) and it is commonly known as the pulse rate. It is used to measure the potential generated by the electrical signals that control the expansion and contraction of the heart **(Arandia et al., 2022)**, where the increase in the blood flow volume can be used by calculating the pulses **(Islam et al., 2020)**. The heart rate is stable for healthy people but not stable for patients with chronic diseases like heart disease, Chronic Obstructive Pulmonary Disease, asthma, and hypertension. For example, in the affected people with COVID-19-, the heart rate changes very quickly. Therefore, it is critical to watch these patients in real-time **(Khan et al., 2022)**. The second indicator is blood oxygen saturation level (SpO2). Oxygen saturation is considered an important factor in taking care of a patient's health. Hypoxemia can lead to many acute adverse effects on organ systems such as the brain, kidneys, and heart. Oxygen saturation is a measure of how much hemoglobin is currently bound to oxygen compared to how much hemoglobin remains unbound. The other important sign is the temperature of the human body which is a decisive essential indicator in the maintenance of homeostasis. It is the sum of heat radiated by the body, where the average person's body temperature relies on gender, ambient temperature, and eating habits **(Islam et al., 2020)**. Basically, fever is considered the typical indicator in most illnesses **(Santoso et al., 2015)**.

On the topic of HMS based on IoT, various studies have been proposed and implemented. These works provide a promising solution to healthcare services and match the real needs of human beings. In this realm, different systems have been proposed recently with common goals and properties. However, their main aim is to provide a smart environment that observes and assesses the health conditions of humans and gives the required services

(Mshali et al., 2018). Generally, these systems consist of microcontrollers and some biomedical sensors such as temperature sensors to measure body temperature and pulse oximeter sensors to measure SpO2 and heart rate. One of the common microcontrollers that is used widely in this field is the Arduino. Arduino is projected to collect the required parameters and explore the information acquired from sensory devices. To track the status of the body, sensors are linked to a microcontroller which is thus interfaced to an LCD screen. Moreover, remote associations exist which can send the information to the desired evaluation. Suppose the system finds any sudden changes in heartbeat or body temperature. In that case, the system alarms the specialist about the patient's status over IoT. Furthermore, it indicates subtle elements of the pulse and temperature of the patient live on the web and then an emergency case will be considered to provide the required treatment **(Li et al., 2024)**. Consequently, in HMS there is no need for medical personnel to be with patients to check their health condition periodically. HMS sends the health condition of sufferers in real time to doctors or professional persons to evaluate the status and provide the required solution quickly.

In health systems with Near Field Communication, Radio Frequency Identification has been used to observe life-threatening events. However, the cost of using an RFID reader is considered high, besides, an RFID reader is required to read the required information continuously **(Harshitha et al., 2018)**. On the other hand, in numerous existing systems, data is collected by sensors and then transmitted but the transmission is intermittent. If any critical parameter is recorded, an alert message is sent through the Global System for Mobile (GSM) technology to the registered caregiver. The disadvantage of such systems is that the patient's health cannot be monitored continuously. Moreover, the doctor may not conclude even if the patient is taken to the hospital in time without more information about the conditions of the patient causing delays in providing an appropriate treatment **(Harshitha et al., 2018)**. Therefore, HMS is moving towards integrating IoT and cloud computing into its architecture, which is the key technology in the recently developed body HMS **(Mohammed et al., 2014)**.

Basically, an IoT-based health monitoring system consists of microcontrollers and sensors. A microcontroller connects the worlds of software and hardware to allow interaction between the software with the physical world in the same deterministic, cycle-accurate manner as digital logic **(RP2040, 2021)**. Different approaches used Arduino Uno board as a microcontroller such as the works proposed by **(Gupta et al., 2016; Mostafa et al., 2020; Kumar and Kumar, 2022)**. This microcontroller is a small computer that can read information from various sensors and other electronic components, and it is an easy way to utilize it for equipment and programming. Other researchers used Raspberry Pi Pico as another type of microcontroller board because of its facilities since it is a low-cost, high-performance microcontroller board with flexible digital interfaces **(Raspberry Pi, 2021)**. This microcontroller is considered a popular platform that offers a complete Linux server in a tiny platform for a very low cost, and it allows different interfacing services. Therefore, it is used in different works such as **(Khan et al., 2023; Kamarozaman and Awang, 2021)**. The key difference between Raspberry Pi Pico and Raspberry Pi Pico W is represented by the wireless interface circuitry. This onboard Wi-Fi makes it a remarkable microcontroller that has Wi-Fi capabilities. Other important components of HMS are represented by the different types of sensors such as ultrasonic, heart rate, ECG, nasal/oral airflow, temperature, light sensor, and fall detection sensor. These sensors are used to check the biomedical signs of the patients and send the data to the microcontroller to process them as required which in turn sends them to the IoT cloud server.

In low- and middle-income countries, there is noticed an increasing burden of chronic illness that is driven by HIV, TB, diabetes, and cardiovascular disease. However, the number of health systems is considered low and cannot meet the requirements of chronically ill patients, especially those who need regular care and have limited resources **(Arandia et al., 2022)**. So, such countries often fail to mitigate the burdens of rising chronic diseases. HMS appears as a vital sector in human health life. Moreover, a real-time analysis based on IoT is required to achieve a low-cost requirement that makes most numbers of patients get the required services and maintain their independence **(Alsharif et al., 2023)**. Most of the existing works used Arduino as a key microcontroller in their work and others used Raspberry Pi. Based on our knowledge, there is no other work using Raspberry Pi Pico W as the main microcontroller in HAS.

The main disadvantage of the mentioned techniques is relying on relatively expensive components that lack chip integration. Contrastingly, the utilized microcontroller (Raspberry Pi Pico W) is equipped with integrated Wi-Fi. Replacing standalone components with integrated ones will lead to reduced cost and possible malfunction.

Thus, the main contribution of the proposed work is to develop a low-cost real-time HMS using Raspberry Pi Pico W that monitors the following patient vital signs: heart rate, SpO2, and body temperature records the patient status in different places and sends the information to the professional. The proposed system is to establish a low-cost HMS using Raspberry Pi Pico W microcontroller with different types of sensors to measure and collect the data from the patients in real-time. Raspberry Pi Pico W has been designed to be a low-cost yet flexible development platform for RP2040, with a 2.4 GHz wireless interface **(Raspberry Pi, 2021)**. The data is either sent to an LCD screen for presentation or sent to a mobile to alarm specialized healthcare professionals (such as nursing homes or doctors). Besides, the proposed module is wireless, therefore, there are no problems with mobility and the module may be freely moved from one place to another.

The proposed system is completely autonomous, and this will reduce the requirement for medical staff and physical accompanying. In comparison to commercial devices, the modern microcontroller Raspberry Pi Pico W is used in the proposed system. This microcontroller has built-in Wi-Fi which facilitates data i.e. vital signs transmission between system components such as OLED display. In addition, vital signs are displayed in different ways such as OLED display and Blynk application that allows remote monitoring of patients. Furthermore, using built-in components and remote monitoring leads to cost efficient system.

2. MATERIALS AND METHODS

The proposed IoT-based HMS has successive steps represented by system design, the installation of components, and finally the programming of the system that is performed to create a set of instructions and tell the microcontroller how to perform the desired task. The system consists of different software and hardware components. The most important hardware used in the proposed work is represented by the powerful and flexible Raspberry Pi Pico W microcontroller in addition to different sensor modules which are: SpO2 and heart rate sensor and body temperature sensor. All medical sensors are connected to the Raspberry Pi Pico W microcontroller that is equipped with appropriate power. Where Raspberry Pi Pico W microcontroller is considered the brain of the system. Sensors are the health-related parameters that monitor health conditions without disturbing the daily routine of the patients. They are placed on the human body and then communicated to physician's devices using long-range technologies. Raspberry Pi Pico W is connected to the results display devices (OLED and/or Cell phone). After the data is transferred, the information will be displayed to show the results in real-time through an IoT application to the caregiver to diagnose the conditions of the patient or can be displayed on the OLED. The proposed system is based on different hardware and software components, the description of all these components is elaborated in the following sections.

2.1 The Hardware Components

There are different hardware components connected to establish the proposed system. The most important are presented below.

2.1.1 Raspberry Pi Pico W Microcontroller

This work uses Raspberry Pi Pico W as the main Microcontroller of the proposed HMS which is considered the brain of it. Raspberry Pi Pico W microcontroller is a small computer that is built into a single integrated circuit to do a certain process with high quality, low cost, and high availability **(Raspberry Pi, 2021)**. This microcontroller board is based on the Raspberry Pi RP2040. It has a CPU, main memory, and input/output ports with onboard Wi-Fi capability. The final feature differentiates it from other prototypes and gives it new possibilities, such as Internet of Things (IoT) applications and devices that are automatically controlled. The details of the technical specifications of the Raspberry Pi Pico W development board can be seen in **(Raspberry Pi, 2021)**. Raspberry Pi Pico W provides a minimal yet flexible external circuitry to support the RP2040 chip: flash memory, a crystal, power supplies and decoupling, and a USB connector and it has an onboard 2.4GHz wireless interface **(Raspberry Pi, 2021)**. **Fig. 2** shows the Raspberry Pi Pico W microcontroller board based on the Raspberry Pi RP2040 microcontroller chip.

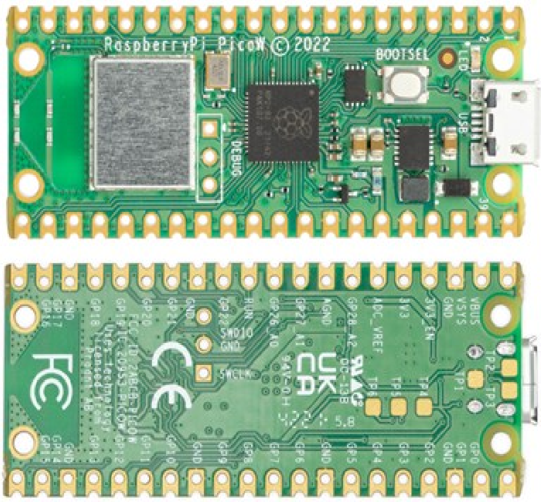

Figure 2. The Raspberry Pi Pico W Rev3 board **(Raspberry Pi, 2021)**.

2.1.2 Sensors

Medical indicators are vital in providing the body with information about the patient's current situation. Some key indicators such as SpO2, heart rate, and body temperature are used in determining the status of a patient in a medical circumstance. Therefore, the process of acquiring these data based on specific sensors is very beneficial. There are two sensors used in the proposed work which are described in the following sections. These electronic components are cost-efficient, and they are open-sourced. The proposed design due to the capabilities of IoT makes data acquiring process user-friendly and appropriate for the patients. This system is very easy to use for all patients and in different places such as home, office, and hospital. By plugging into a USB adapter/port with a 3.3 V electrical supply, the specialized within the network can view the individual's vital readings. In the proposed system, two types of sensors are used as mentioned previously. The first one is the Pulse Oximeter and Heart-Rate Sensor (MAX30100) and the second one is the temperature sensor (DS18B20). These two types are chosen based on their compatibility with the Raspberry Pi Pico W, appropriate size, appropriate cost, and reading accuracy.

2.1.3 MAX30100 Sensor (Pulse Oximeter and Heart Rate)

This sensor is an I2C-based low-power plug-and-play biometric sensor that is used to measure the level of oxygen in the blood and the heart rate in the human body for monitoring patient conditions portable with the assistance of other devices such as phones, wearable devices, and modern watches **(Gade, 2021; Ganesh et al., 2022)**. The pulse oximeter and heart rate sensor have two functions: Pulse Oximetry (to measure the blood's oxygen level) and Heart Rate Measurement. This sensor can successively reveal the oxygen saturation levels as well as the pulse rate. These signs are very vital and should be checked to show the health condition of the patients. The first function of MAX30100 is represented by a pulse oximeter. A pulse oximeter can undoubtedly distinguish little changes in oxygen by testing the actions of oxygen immersion level in patient blood by estimating changes of light ingestion in oxygenated or deoxygenated blood. It is easy. Therefore, it is considered a very important clinical estimation instrument **(Gade, 2021)**. The normal range of SpO2 must be between 95-100, if it is less, this indicates that there is a need for oxygen for the body, and if it further goes down the condition is serious and there is a need for quick treatment **(Abed and Hussein, 2021)**. The two main parts of this sensor consist of a pair of high-intensity LEDs (RED and IR, both of different wavelengths) and a photodetector. The finger must be held steadily, and then the light from the photodiode falls over this part of the body. The light is absorbed by oxygenated blood, and the remainder is reflected through the finger and falls over a detector. The output data of this detector is processed and then read by a microcontroller **(Gade, 2021)**. This method of pulse detection through light is called Photoplethysmogram (PPG) and the block diagram of the sensor's system and its board is shown in **Fig. 3 (Analog Devices, 2014; Gade, 2021)**.

(a) (b)

Figure 3. MAX30100 Sensor (a) The board of the sensor (b) The block diagram of the sensor.

The oxygen level in the blood is determined by measuring the ratio between the IR and RED light detected by the photodetector. The second function of MAX30100 is represented by measuring the heart rate. The oxygenated hemoglobin has the characteristic of absorbing IR light. When the hemoglobin is higher, the blood is redder, then more IR light is absorbed. For each heartbeat, blood is pumped through the finger. Therefore, the amount of reflected light will be changed which will lead to a change in the waveform at the output of the photodetector. By continuing to shine light and take the reading of the photodetector, the heartbeat pulse is quickly read **(Analog Devices, 2014)**.

2.1.4 DS18B20 Sensor (Body Temperature)

Body Temperature is one of the vital physiological parameters is body temperature which must be regularly observed by the caregiver for all types of patients. Therefore, a sensor of body temperature is required to determine the temperature as a primary signal which is measured using the sensor with a specific embedded system to process this signal **(Saha et al., 2021)**. In this work, the DS18B20 sensor has been used as an effective body temperature because of its high accuracy. This sensor provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with nonvolatile user-programmable upper and lower trigger points. It is commonly used in various environments such as humid places (including underwater) because it has a small size, anti-disturbance, and high accuracy. DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground), besides, it needs to be connected to a prototyping platform, such as Arduino and Raspberry Pi to start its work. In addition, DS18B20 eliminates the need for an external power supply because it derives power directly from the data line ("parasite power"). This sensor is a Waterproof sensor that operates in the range of temperature -55 °C to +125 °C with ± 0.5 °C error at -10 °C to + 85 °C **(Koestoer et al., 2019)**. The sensor used in the current work and its pin configuration are shown in **Fig. 4**.

(a) (b)

Figure 4. The used body temperature (a) The DS18B20 Sensor (b) The pin configuration **(Mohammed et al., 2014)**

The MAX30100 pulse oximeter and the DS18B20 temperature sensors do not have equations for directly converting their stimulus (light absorption and temperature respectively) into a voltage signal. The MAX30100 converts light absorption into digital counts to extract physiological data (SpO2 and heart rate), while DS18B20 transforms digital temperature into a voltage signal. Both sensors require further processing by a microcontroller (Raspberry Pi Pico W in the current work) using appropriate algorithms **(Analog Devices, 2014)**.

2.1.5 OLED (SSD1306) Display

In this work, an organic light-emitting diode (OLED) has been used to display the data as shown in **Fig. 5** OLED has been utilized because it is much smaller and lighter than Liquid Crystal Displays **(Gade, 2021)**. OLED produces light in response to an electric current and since its displays don't have a backlight, it can show deep black levels. It consists of 128 segments and 64 commons. OLED-SSD1306 is a more elaborate and beautiful screen than LCD, with more functions and high contrast, thus supporting a clear display. This IC is designed for a Common Cathode type OLED panel and embeds with contrast control, display RAM, and oscillator, which reduces the number of external components and power consumption **(Systech, 2008)**.

Figure 5. OLED 0.96 (SSD1306) display.

2.1.6 The Buzzer

A passive buzzer has been used in the proposed work since it is a cheap and simple DC component that can generate sound at different frequencies when activated with low-voltage currents. The passive buzzer is different from the active buzzer because it has an internal oscillator that can generate a "standard" sound by simply activating it with continuous triggers. Meanwhile, passive buzzers require square wave triggers (PWMs). A buzzer is a crucial part of basic alerts since it provides an audible alert, similar to how an LED may indicate the status of something. **Fig. 6** shows the passive and active buzzers **(Raghav et al., 2020)**.

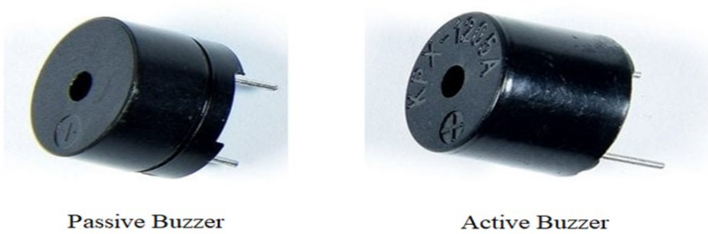

Figure 6. Passive and active buzzers.

The entire hardware is connected after checking and setting each one as required. **Fig. 7** shows the schematic diagram of the hardware connection to the proposed HMS system.

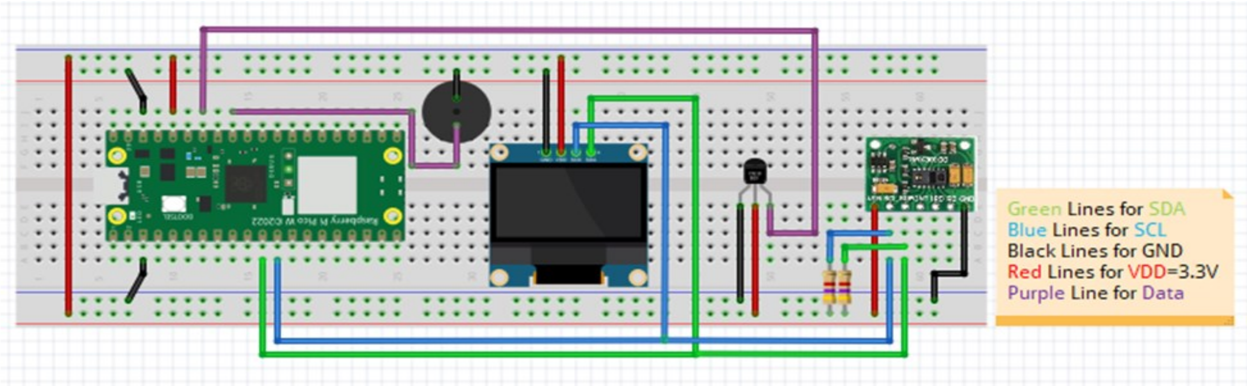

Figure 7. The schematic diagram of the hardware connection to the proposed HMS system.

2.2 Software Requirements

In the proposed monitoring system, in addition to the various hardware mentioned previously, there are multiple software used to verify the interface. In this section, the description of the interface of the hardware to the software is presented to show the way of the communication of the proposed system. Different software and Application Programming Interfaces are used, where these sets of instructions and programs are used to operate system components and execute the specific tasks of the monitoring system. The language used in programming Raspberry Pi Pico W is MicroPython. It is a version of the Python programming language for different microcontrollers. MicroPython uses Python knowledge to write code and interact with various electronic components. It is considered the easiest language compared to C and C++ and runs directly on embedded hardware. Raspberry Pi Pico W is programmed using MicroPython by installing it, then the used microcontroller is connected to the computer to drag and drop a UF2 bootloader file. An integrated development environment (IDE) is used for programming purposes and accessing the microcontroller from the computer. The easiest MicroPython IDE used in the proposed work is Thonny. Different libraries are used, the most important are Raspberry Pi Pico W, Max30100, DS18B20, and SSD1306. Moreover, the sensors are configured by using inter-integrated circuit (I2C) protocol which has mode functionality with various configurations .

3. THE METHODOLOGY OF THE PROPOSED HEALTH MONITORING SYSTEM

The proposed system is completely autonomous, and this will reduce the requirement for medical staff and physical accompanying. Besides, it can be used at home and the cost of the clinical staff is reduced. The proposed framework gives the results for three vital signs of patients based on the results of a body temperature sensor, heartbeat sensor, and SpO2 sensor. If any sudden changes are discovered from these results, the microcontroller sends an alarm message through the IoT to the caregivers, the information will be also displayed on an OLED display to be processed by the charge person and guardian. The complete flow work of the proposed system is shown in the flowchart of **Fig. 8**.

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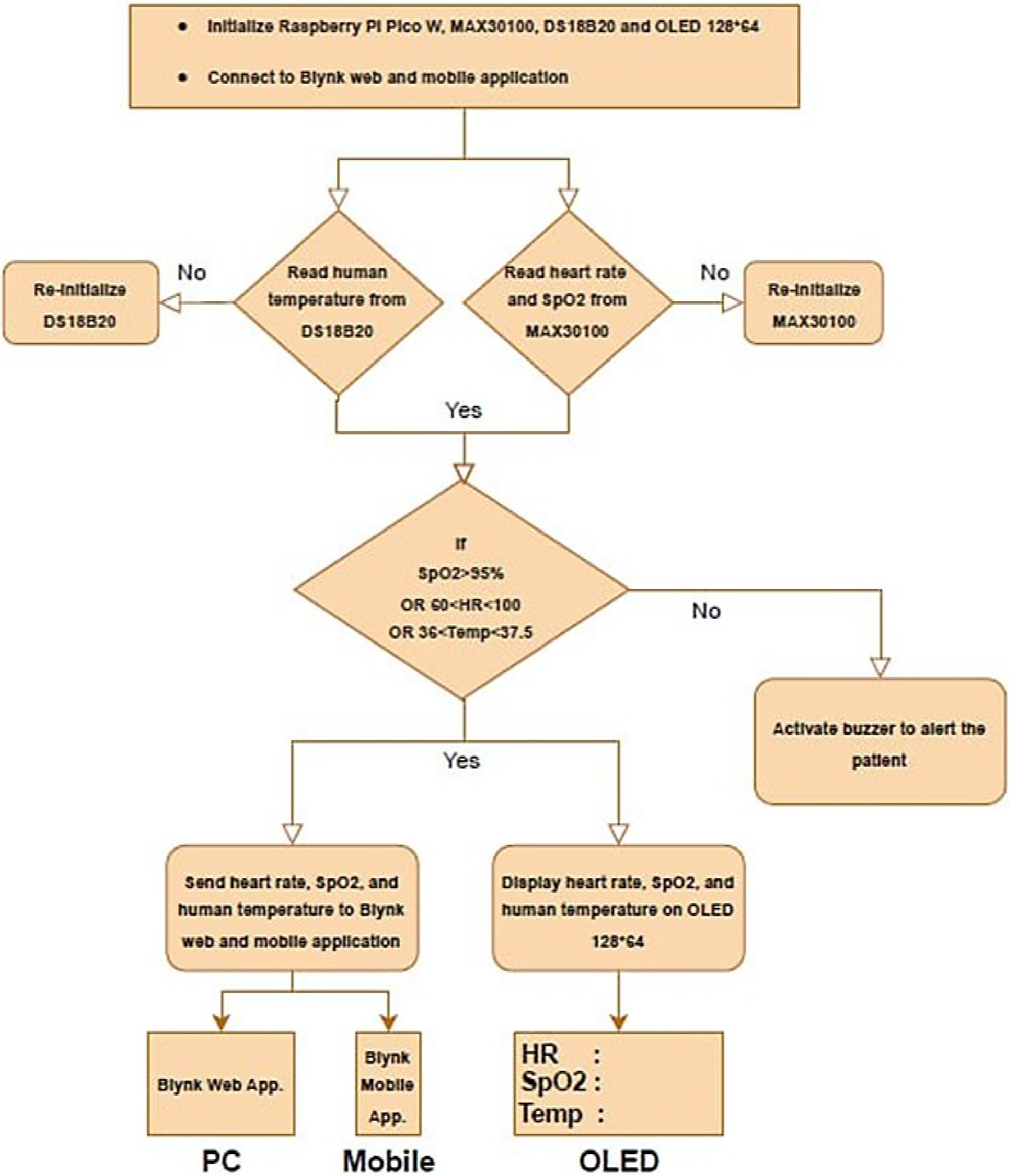

Figure 8. The flow chart of the proposed HMS.

The main benefit of using Raspberry Pi Pico W as a microcontroller is the cost. The total cost of the proposed system is shown in **Table 1**, which includes each component price used as well. It is obvious that Raspberry Pi Pico W has less cost since it is equipped with onboard Wi-Fi capability.

Table 1. The proposed system components cost (prices given in IQI)

Component	Item identifier	Quantity	Price (IQD)
Microcontroller	Raspberry Pi Pico W	1	14,000
Heart Rate & SpO2 Sensor	Max30100	1	6,000
Temperature Sensor	DS18B20	1	3,000
OLED	SSD1306	1	6,000
Wire set	-	-	2,000
Breadboard	-	1	2,000
Buzzer	-	1	500
Total			33,500

The first step as shown in the flow chart is to initialize Max30100, DS18B20, and SSD1306 devices through defined objects in MicroPython IDE (Thonny). The defined objects allow recalling read functions for Max30100 and DS18B20 to give back the readings of the vital signs (heartbeat rate, SpO2, and body temperature), respectively. If a vital sign reading is obtained, then data will be forwarded to the display devices. Otherwise, the sensors will be re-initialized. After obtaining vital sign readings, a decision will be made, if the values of these signs fall within the normal range, then they will be displayed directly where the normal range of vital signs is shown in **Table 2 (Forkan et al., 2015)**. To display body temperature, heartbeat rate, and SpO2 readings on the OLED, the display function from the object created for SSD1306 will be recalled for this purpose. Similarly, vital sign readings will be displayed via web and mobile Blynk applications which will be explained in detail in the following sections. In addition, values that fall outside the normal range will activate an alarm to allow healthcare givers to take the required actions quickly.

Table 2. The normal range for vital signs.

No.	Vital sign	Minimum	Maximum
1.	Heart Rate (BPM)	50	100
2.	SpO2 (%)	93	100
3.	Body Temperature (C°)	36.1^oC	37.9^oC

To post the MAX30100 and DS18B20 Data to Blynk using Raspberry Pi Pico W, a Blynk project needs to be created and a dashboard to be set up in both mobile and web applications. Firstly, an account has been made by visiting (blynk. cloud) on the Blynk website or signing in using a previously registered Email ID. Then pick on New Template and give a name to the Template such as "MAX30100 and DS18B20 with PICOW". Next, we selected the Hardware type and the Connection type, that is Wi-Fi. For the Description setting, we wrote "Healthcare System using Raspberry PI PICO W". After that, from "New DataStream" we selected "Virtual Pin" namely, V0, V1, V2 corresponding to HR, SpO2, and Temp, respectively. Therefore, the new Data stream was successfully created. To create a dashboard for graphical visualization purposes, we navigated to Web Dashboard, then dragged, and dropped three blank Gauges into the dashboard window. Then, the Gauges were set up by giving names for each one as follows (HR, SPO2, and Temp) and selected (V0, V1, V2), respectively which are the DataStream that was created earlier. To add devices to the visualization tool above, we have chosen a New Device from the Template and selected the Template previously created, and given a name to the device such as "PICOW". As a New Device is created its corresponding authentication token is also generated. The Authentication token can be copied, where it is required later in the code.

After setting up the Blynk dashboard, the programming of the Raspberry Pi Pico W board can proceed to enable the MAX30100 and DS18B20 to send data to the Blynk Dashboard. To visualize the MAX30100 and DS18B20 data on a mobile App or Mobile Dashboard, a Mobile Phone Dashboard needs to be set up. The processing of setup can be implemented by repeating the above procedure using the Blynk mobile app which is available on application stores (the Blynk IoT app available on Google Play Store is used in this work). **Figs. 9** and **10** illustrate the posting of MAX30100 and DS18B20 Data using Raspberry Pi Pico W on both Blynk web and mobile applications.

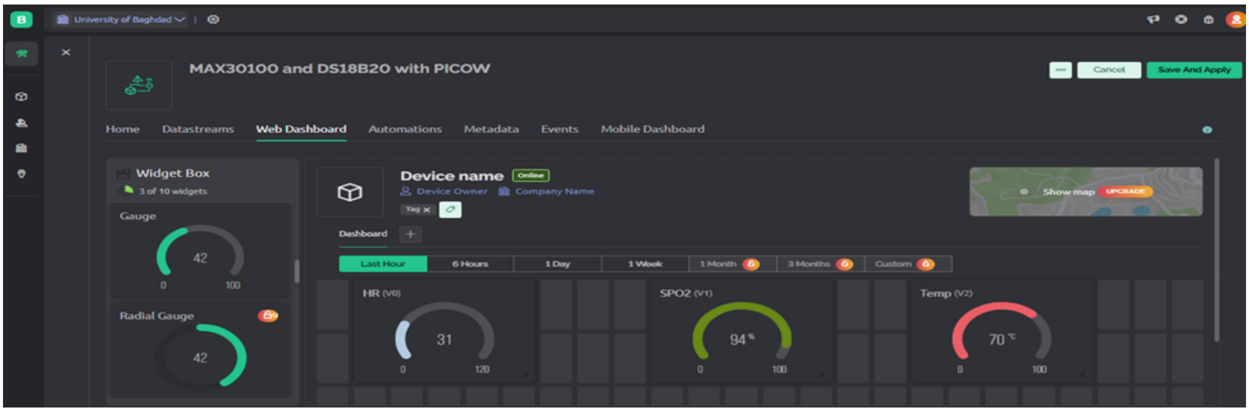

Figure 9. The Gages of HR, SPO2, and Temp streaming.

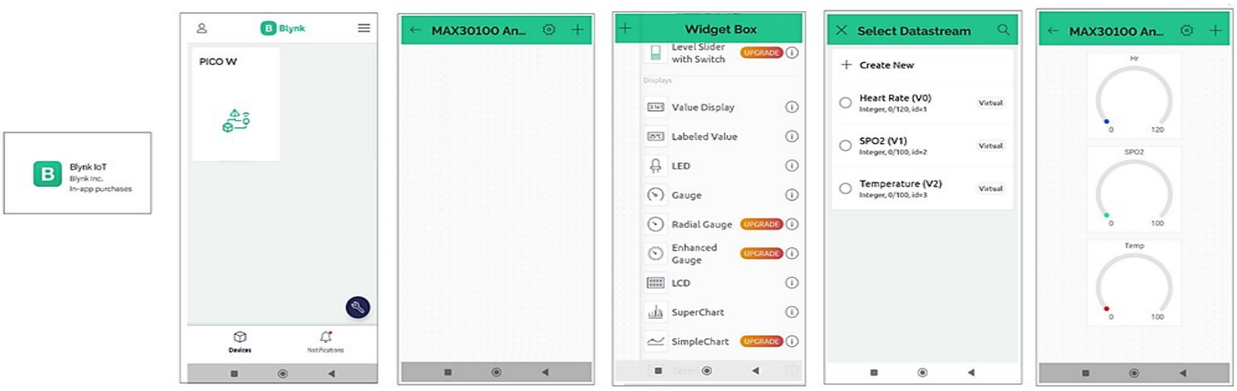

Figure 10. Blynk mobile application.

4. RESULTS AND DISCUSSION

By using the above-mentioned system and the dashboard, a test showed the gauge readings for heart rate, SpO2, and temperature that are presented on the Dashboard of Blynk Web Application as shown in **Fig. 11**, and the Dashboard of Blynk Mobile Application as shown in **Fig. 12**.

Figure 11. The Dashboard of the Blynk Web Application

Figure 12. The Dashboard of the Blynk Mobile Application

The complete circuit connection of the proposed HMS system is shown in **Fig. 13**, which shows the entire components connected. Once every part is configured properly concerning the hardware connection and programmatically, the accurate digital output of vital factors from the used sensor will be displayed.

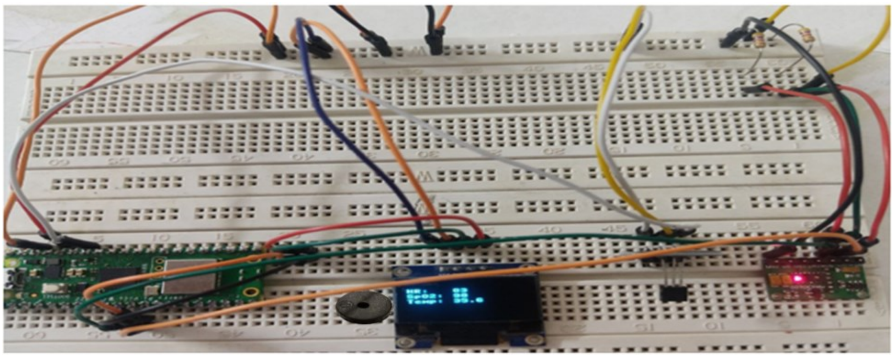

Figure 13. The complete circuit connection of the proposed HMS system

For evaluation purposes, an actual human test has been performed. The system's results are displayed after the observed temperature, heart rate, and SpO2 are measured on the OLED and in web and mobile Blynk applications. One of the important components of the proposed

system is the mobile application, where the data is transferred from the system to the specialized. Mobile Blynk application is crucial since it presents the primary outcomes of the system. For testing purposes, four persons, whose ages range from 5 to 40 years, measured their signs using both the proposed HMS and commercial devices. The measured signs fall within the normal range mentioned in Table 2 for both commercial and proposed system. The benefit of the proposed system is allowing users to access vital sign readings via a mobile application; as a result, the approach is considered simple and easy to use.
The measured values of heart rate, SpO2, and temperature for the four persons are listed in **Table 3**. It shows that tested individuals have SpO2 levels ranging from (95%-98%) with an error percentage ranging between (-1 to 0 %) in comparison to commercial devices measurements, while the temperature is around 36 C° with an error percentage do not exceed (1%). The measured values for the pulse rate by the proposed HMS range from (75-101 BPM) throughout the persons, and in comparison to commercial devices, an error percentage of (-2 to 7 %) is noticed. Comparing these measured values to those of other commercially available equipment, they were acceptable with minimal differences.

Table 3. A comparison based on vital sign readings between the proposed system and the commercial devices.

Persons	Age	Proposed System			Commercial devices			Error percentage		
		BPM	SpO2	Temp	BPM	SpO2	Temp	BPM	SpO2	Temp
Person-1	5	81	95	36.2	83	96	36.6	-2%	-1%	-1%
Person-2	10	101	97	36	99	98	36.4	2%	-1%	-1%
Person-3	36	75	99	36.3	70	99	36.1	7%	0%	1%
Person-4	40	88	98	36.2	89	98	36.2	-1%	0%	0%

To assess the proposed HMS, system accuracy, and usability are considered. The accuracy is expressed by error percentage for heart rate, SpO2, and temperature measurements in comparison to commercial devices as shown in Table 3 which gives an acceptable range for the parameters mentioned above (-2 to 7 %). In addition, the ease for users to interact with the system is an important factor, where health caregivers can interact with the system in different means including real-time monitoring via OLED display, web based Blynk dashboard, and Blynk mobile application. The mentioned means provide considerable flexibility, especially in certain circumstances such as limited human resources.

5. CONCLUSIONS

This paper aimed to propose low-cost HMS for patient vital signs observation wirelessly in real-time which is considered a very significant issue in the healthcare field. Raspberry Pi Pico W microcontroller is utilized for wireless data transmission based on IoT technique using the Blynk Application and numerous types of sensors are integrated into a wireless communication network to remotely collect patient vital signs which are: the BPM, body temperature, and SPO2 (Oxygen Saturation). The obtained signs are sent to the healthcare givers and will be presented by both the OLED and Blynk application. The proposed HMS is compared to existing commercial devices in terms of accuracy as error percentage, and usability. The error percentage for heart rate, SpO2, and temperature measurements show an acceptable range fall between (-2 to 7 %). The usage of the proposed HMS allows users to interact with the system in several means such as OLED display, web-based Blynk dashboard, and Blynk mobile application in real-time including an alarm informing abnormal vital signs instantly. The current HMS gives significant flexibility in low cost which plays a vital role in certain circumstances such as lack of human resources and remote interaction in comparison to physical interaction with patients which adds considerable cost and cannot be in real time.

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Credit Authorship Contribution Statement

The author carried out all work related to this paper including executing the experimental and numerical simulations and writing the manuscript.

Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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