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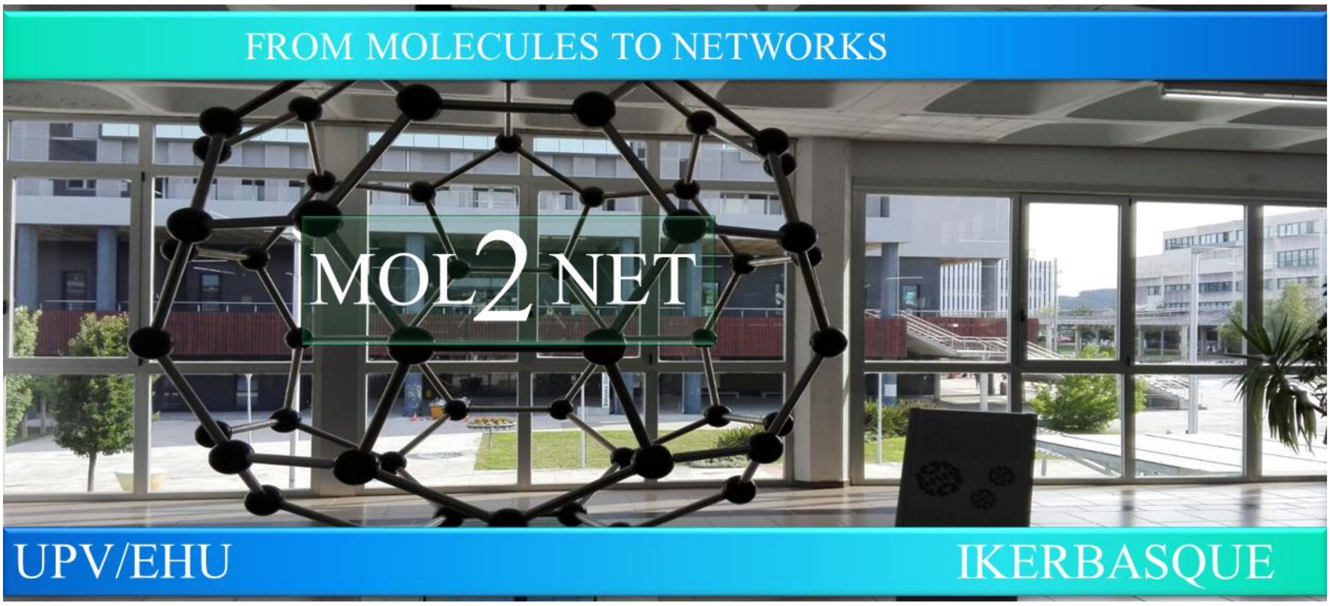

Integrated open-source heart rate and SpO2 monitoring system

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[a] *Department of Surveying and Geoinformatics Engineering, University of West Attica,* 28, Ag. Spyridonos Str., 12243 Egaleo, *Greece*

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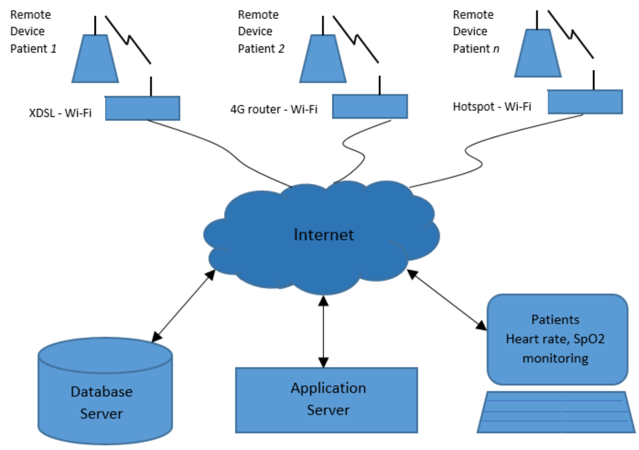
Graphical Abstract	Abstract.
	The application of new technologies in telemedicine shows increasing interest aiming at human health. In this work an integrated heart rate and SpO2 monitoring system is presented. A portable device was created with the aim of sending the measurement data, in real time, to a central information system, where the doctor will be able to monitor the measurements related to the patient's health. Low cost components were used for construction, while the entire system is based on open-source software. During the evaluation, the results of the measurements are satisfactory corresponding to the measurements from the commercial instruments that were used. **Keywords:** Patient monitoring, heart rate, SpO2, InfluxDb, sensor

Introduction

Nowadays, technology has changed the way of peoples' life. Technology is used every day in many human activities including the mobile phone, interactive television, video games, and smart home applications. Utilizing technology for health and patient care can achieve faster diagnosis of medical issues. Focusing on this goal, a simple heart pulse and blood oxygen monitoring device, known as an oximetry, will be the object of this work. Although there are many affordable solutions in the market, the development of both microcontrollers and sensors offers myriad possibilities for enterprise research activity. The research group [1] utilizes a combination of microcontroller and sensors to build an oximetry that sends the data through a Wi-Fi connection to an HTML page for online monitoring. Another research group [2] presents an oximetry which can also measure the patient's temperature while the data is transmitted through the GPRS network and is monitored through an Android device. Article [3] mentions the construction of an oximetry based on IoT technologies, where the data by two sensors are cloud based with the aim of improving clinical care for heart patients by providing early intervention and improved 24-hour monitoring. Paper [4] presents a similar low-cost wireless oximetry system for real-time monitoring, with the device being tested on 20 volunteers aged 18 to 24 years with satisfactory results. In another research work [5] the implementation of an affordable oximetry is presented which uses the Blynk application as a platform for data visualization. Also, another approach to detect arrhythmia and prolong the patient life is presented [6] with the use of a pulse oximeter and IoT technology, giving the possibility of monitoring the patient by a family member through the Blynk application, especially during the night hours. The important thing is that the system gives an alarm, in real time, when the patient is in a critical situation.

This work presents an integrated system for monitoring both heart rate and blood oxygen (SpO2). The innovation of the system is based on two parts: The first one is the measurement system, as it includes a rechargeable battery offering portability and a screen for the immediate visualization of the measurements of heart rate, SpO2 and battery status. Data transmission is conducted through a wireless network, while it can also be implemented through a LoRa network. This feature is provided as the development microcontroller boards contain both of the prementioned networking arrangements. The second part is the information system, in which the measurements are received, using a database specifically for time-series, as well as in the web-based software for visualizing the measurements on line. The curating doctor can view all of the historic record of the patient at any time with ease.

Materials and Methods

This work aims to implement an integrated monitoring system, for heart rate and blood oxygen content in a patient. The goal is to transmit the measurements from the patient home site in real time, to the doctor' site (home or hospital) or their mobile phone or computer, so that the doctor has immediate information about the measurements regarding the patient's health. For this reason, the presentation of the measuring device and the information system will take place in different sections.

Portable oximetry device

For the implementation of the measurement unit, affordable devices were exploited and specifically a microcontroller, a heart rate and blood oxygen (SpO2) measurement sensor, and a rechargeable battery. The microcontroller chosen is the TTGO@ESP32 [7] based on ESP32, which presents high processing speed, low energy consumption, while it has an integrated OLED technology screen, 25 port of I/O, supporting UART, I2C and SPI bus while implementing two communication technologies Wi-Fi and LoRa. In addition, the device includes a battery charging circuit. The heart rate and blood oxygen (SpO2) sensor used, was the GY-MAX30100 [8], which is based at optical technology as it combines two LEDs, in the infrared (880nm) and in the visible (660nm) spectrum, and a photodetector for the measurement process, presenting very small current consumption (600μA), while using I2C bus as communication protocol. Finally, an 18650 Li-Ion Lithium type battery with suitable characteristics was used charged buy the microcontroller's charging circuit, offering a duration of 10 hours of autonomous continuous operation. The implementation diagram of the construction is shown in Figure 1 and the final construction of the portable heart rate device and SpO2 show in Figure2.

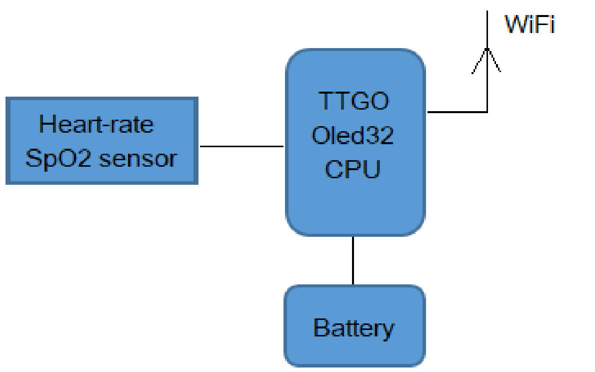


Figure 1. The implementation diagram of the portable heart-rate and SpO2 device.

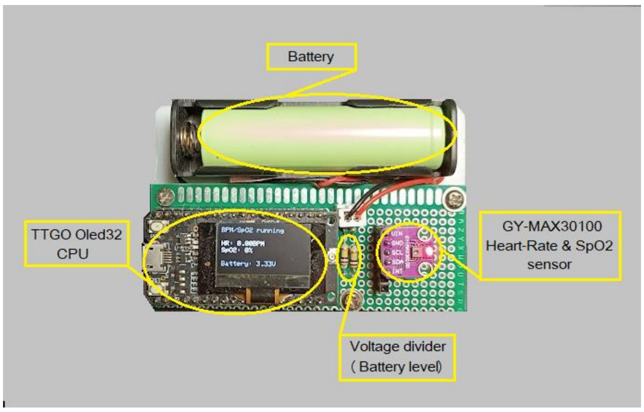


Figure 2. Final construction of the portable heart rate and SpO2 device.

The flow diagram of the measurement procedure of the device is shown in Figure 3.

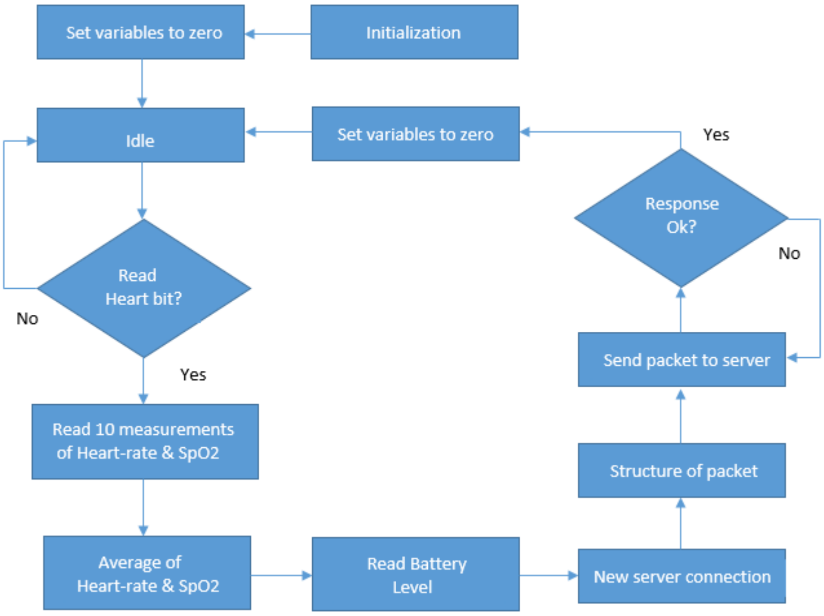


Figure 3. Flow diagram of the measurement procedure.

First, the system is initialized, then the measurement variables are set to zero and the system enters an idle state. As long as the sensor does not receive a heartbeat the system remains in idle state. If the sensor receives a heartbeat, then ten distinct heart rate and blood oxygen measurements are taken with the average value of the measurements of both, the heart rate and the oxygen in the blood (SpO2), being calculated while the battery voltage level is obtained. In the next step, a new connection is created with the database server, for data packet transmission. Depending on the response of the server, the outcome is as follows:

- The packet is received then the variables are set to zero and the system enters an idle state.
- The packet has not been received, the transmission is repeated.

Information system

The information system of the application relies on two servers with an open-source operating system (Linux based). The first server supports an open-source database, designed specifically for time series data, while the other server supports a web-based software for data visualization. The choice of using open-source programs is based on availability, but also because the source code can be adapted to the requirements of the implemented application, as well as for participation and contribution to the community. In our work the InfluxDB [9] as database was selected as it is designed strictly for time-series data. Although InfluxDB looks like an SQL database, it differs significantly in many ways. The comparative database is designed specifically for time-series data. Typical relational databases can handle time-series data, but InfluxDB is optimized for high time-series workloads. It is designed to store large volumes of time-series data and quickly perform real-time analysis. In InfluxDB, a timestamp identifies a single point in any given data series. This is like a SQL database table where the primary key is predefined by the system and is always time. InfluxDB also recognizes that the preferences of a database schema are likely to change over time so it is not necessary to define patterns in advance. Data points can have one of the fields in a metric, all the fields in a metric, or any number in between. It is possible to add new fields to a measurement simply by writing a point for that new field.

The visualization interface has been done under the Grafana lab [10] software. Grafana is an open-source solution for visualization and running data analytics with the help of customizable dashboards. Grafana may connect with different data source such as Graphite, Prometheus, Influx DB, MySQL, PostgreSQL etc. The open-source nature of the solution helps us alternatively write custom plugins to connect with any data source of our choice. Under Grafana environment user can both study, or analyze the data. In addition, they can monitor data over a period of time, technically called time-series analytics. Thus, it provides an easy interface management environment, for creating dashboards and editing them with various metric tools that are already included, making it user-friendly in terms of operation. In addition, the Grafana software offers authentication of users and allocation to roles, such as “administrator”, “operator”, and “viewer”, with specified rights of access/use, hence it controls which user has the ability to change the data, as well as the privacy of the data and their dissemination to third parties. Finally, it should be clarified that the connections for data transmission in all cases, including both the connection of the measuring device to the database and then to the visualization software, are achieved with a unique API key of each connection.

Results and Discussion

This section divided to two subsections: In the first subsection, the evaluation and accuracy of measurements from portable oximetry device are presented. Then in the second subsection the visualization of measurements under Grafana Lab environment are imprinted.

Portable oximetry device evaluation

For the purpose of evaluating the portable oximetry device, measurements were taken on three people. During the measurement process, two commercial oximeters were used simultaneously, to take reference measurements. The following models, model A, pulsossimetro c101a2 [11], and model B, Meditech Oxy Plus finger oximeter [12], are the commercial oximetry that are based on optical technology, utilized in this work. Table 1 shows the measurements of the portable oximetry device as well as the two commercial oximetry devices in three people, at the same time point.

Table 1. Measurements of the portable oximetry device as well as the two commercial oximetry devices in three people.

People	**Samples of measurement**	**Portable oximetry device**		**Model A commercial device**		**Model B commercial device**	
		Heat rate (BPM)	SpO2 (%)	Heat rate (BPM)	SpO2 (%)	Heat rate (BPM)	SpO2 (%)
	1	70	98	69	99	69	98
	2	75	98	74	99	74	99
1	3	73	98	74	99	74	99
	4	76	98	76	99	76	98
	5	77	97	77	99	77	98
	1	58	98	61	99	60	99
	2	63	98	63	99	61	99

2	3	59	97	60	99	60	99
	4	71	98	72	99	69	99
	5	58	97	64	99	63	99
	1	71	97	70	99	72	98
	2	74	97	72	99	72	99
3	3	76	98	74	99	74	98
	4	71	97	70	99	64	98
	5	72	98	70	99	71	98

The following figures show the time-series and correlations of the portable oximetry device in respect to each commercial oximeter, as well as the correlations between commercial oximeters. According to the measurements of the person 1, Figure 4 shows the time-series and scatter plots between portable oximetry device and commercial devices. Finally, Figure 5 show the time-series of SpO2 between portable oximetry device and commercial devices.

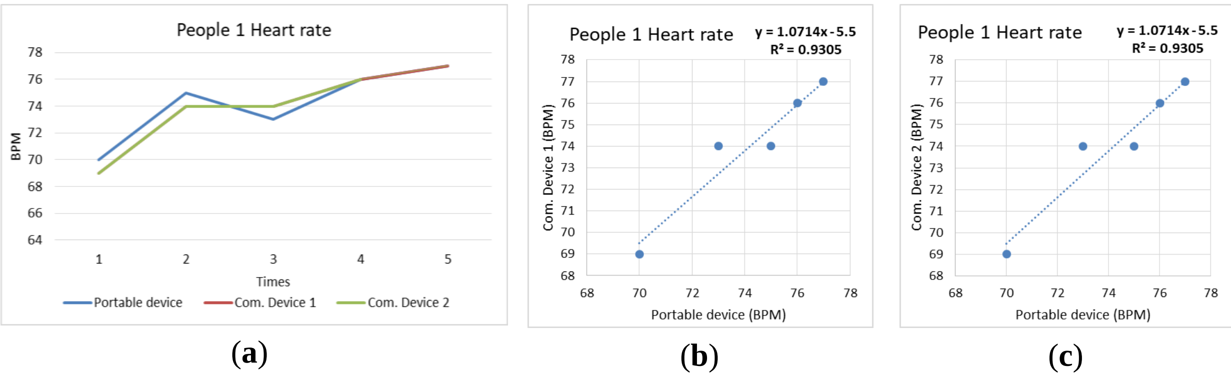


Figure 4. Time-series and scatter plots between portable oximetry device and commercial devices, of the person 1, (**a**) Time-series of heart rate between portable oximetry device and commercial devices, (**b**) Scatter plot between portable oximetry device and commercial device 1 (model A), (**c**) Scatter plot between portable oximetry device and commercial device 2 (model B).

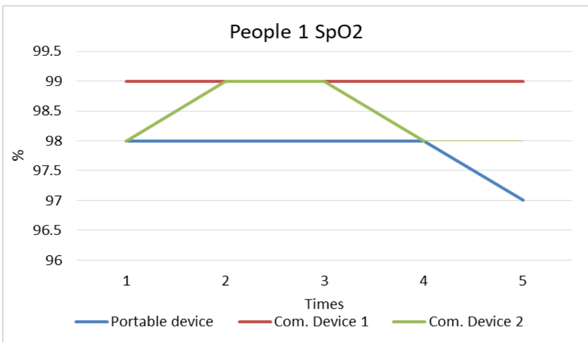
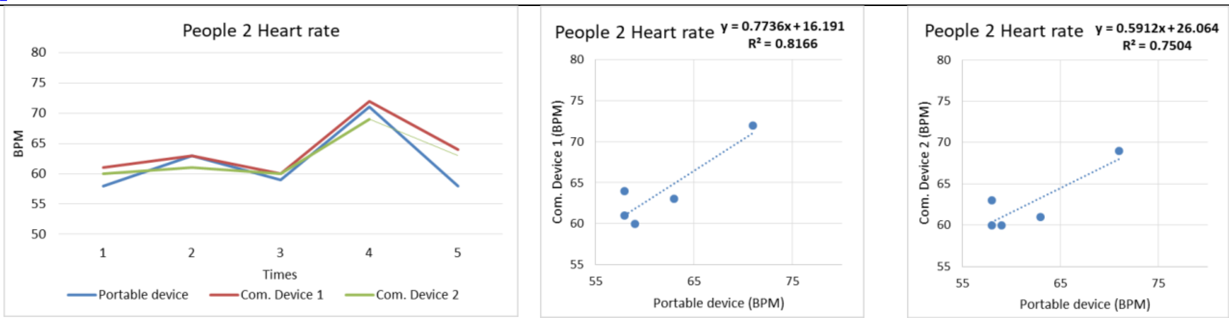


Figure 5. Time-series of SpO2 of person 1, between portable oximetry device and commercial devices.

According to the measurements of the second test, Figure 6 presents the time-series and scatter plots between portable oximetry device and commercial devices, Figure 7 depicts the time-series of SpO2 between portable oximetry device and commercial devices.



(a) (b) (c)

Figure 6. Time-series and scatter plots between portable oximetry device and commercial devices, of the person 2, (**a**) Time-series of heart rate between portable oximetry device and commercial devices, (**b**) Scatter plot between portable oximetry device and commercial device 1 (model A), (**c**) Scatter plot between portable oximetry device and commercial device 2 (model B).

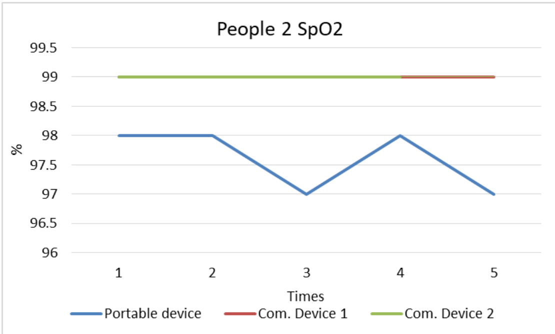
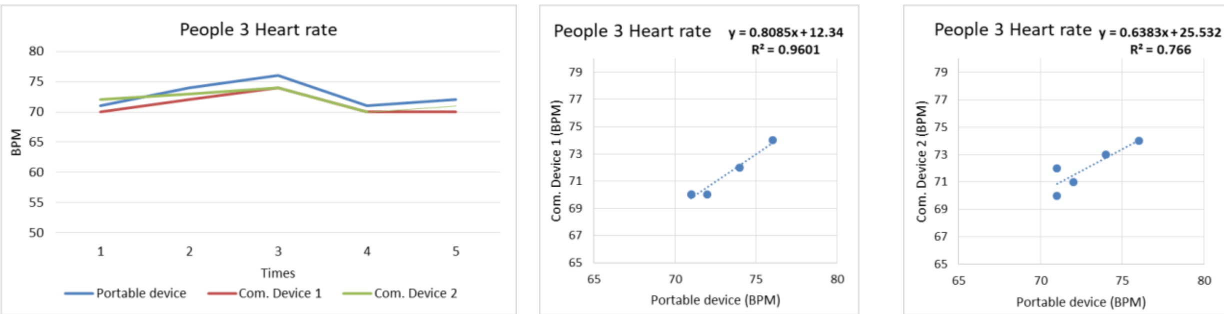


Figure 7. Time-series of SpO2 of person 2, between portable oximetry device and commercial devices,

For the third person, Figure 8 presents the time-series and scatter plots between portable oximetry device and commercial devices, Figure 9 indicates the time-series of SpO2 between portable oximetry device and commercial devices.



(a) (b) (c)

Figure 8. Time-series and scatter plots between portable oximetry device and commercial devices, of the person 3, (**a**) Time-series of heart rate between portable oximetry device and commercial devices, (**b**) Scatter plot between portable oximetry device and commercial device 1 (model A), (**c**) Scatter plot between portable oximetry device and commercial device 2 (model B).

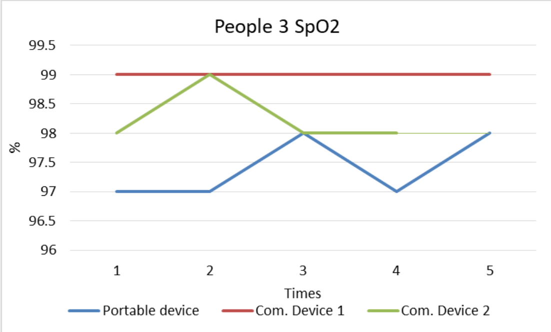


Figure 9. Time-series of SpO2 of person 3, between portable oximetry device and commercial devices.

Table 2 shows the average values errors of the measurements as well as the errors between the portable oximetry device and each commercial device (model A and model B) both of the heart rate (HR) and SpO2.

Table 2. Average values of the measurements and the error of the measurements, between the portable oximetry device and each commercial device.

	Portable device		**Commercial device 1 (model A)**				**Commercial device 2 (model B)**			
Persons	Average HR (BPM)	Average SpO2 (%)	Average HR (BPM)	HR Error (%)	Average SpO2 (%)	SpO2 Error (%)	Average HR (BPM)	HR Error (%)	Average SpO2 (%)	SpO2 Error (%)
1	74.2	97.8	74	0.3	99	1.2	74	0.3	98.4	0.6
2	61.8	97.6	64	3.4	99	1.4	62.6	1.3	99	1.4
3	72.8	97.4	71.2	2.2	99	1.6	72	1.1	98.2	0.8

Analyzing the data of the time-series, scatter plots and Table 2, it appears that the MAX30100 sensor achieves satisfying results in terms of heart rate measurements, as the correlation coefficient R^2 shows a degree from 0.75 to 0.96, and a maximum slide deviation of 3.4%, while for the SpO2 a maximum slide deviation of 1.4% is observed in relation to the commercial devices.

Visualization interface

The Grafana Lab, visualization environment is displayed in the figures below. A user, in this case the doctor, can see in real-time the measurements of heart rate and SpO2 of the patient, or patients, depending on the structure construction of the visualization dashboard. At the following figures, the visualization interface of Grafana is arrayed. Figure 10 exhibits the login interface, in which the user can insert their credentials to login to the system. Figure 11 shows the dashboards which user can select the dashboard of application (in our case the dashboard is "HeartRate - SpO2 Monitor"). Figure 12 demonstrates the dashboard of our application, the measurements of heart rate and SpO2 of two person are presented.

Figure 10. Grafana, login interface.

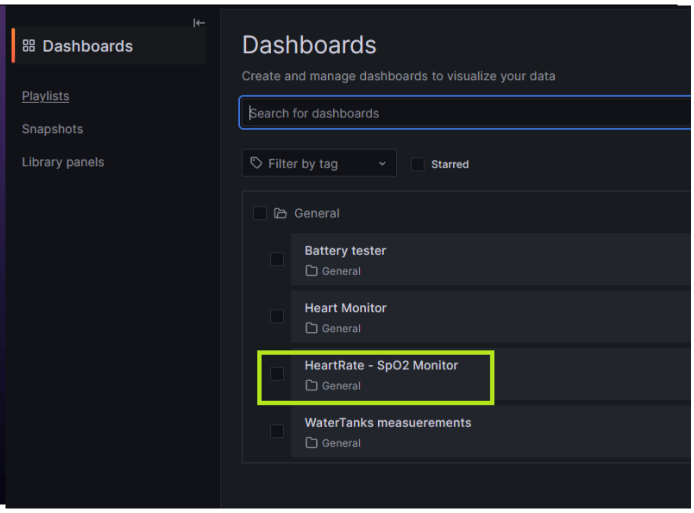


Figure 11. Grafana Dashboards.

Figure 12. Grafana, visualization of the measurements of heart rate and SpO2 for second test.

In the previous figure, the configuration of the dashboard for the presentation of this work is presented. Obviously, the configuration of the dashboard is at the user's preferences, by choosing the appropriate visualization points the user can configure an environment that better serves the needs of monitoring the health of patients.

Conclusions

Technological innovations are presented daily in the field of medical. IoT applications can be used for applications related to human health. In this work, an integrated, open source, heart rate and SpO2 monitoring system was presented. The system consisted of three parts, a portable heart rate and SpO2 device, the internet as a means of data transfer and an information system to visualize the data. The aim of this work is to show the feasibility of implementing accessible arrangements and integrated information systems, related to health. This application can be beneficial in a critical health situation as referenced to both the hardware and the software provided. The evaluation of the heart rate sensor and SpO2 showed satisfactory results in respect to commercial oximeters as the correlation coefficient (R^2) ranged from 0.75 to 0.93 and a maximum deviation of 3.4%, while SpO2 showed a sliding deviation of

1.4%. This information system is based on an open-source software while encouraging participation and contribution to the technical community. It consists of an InfluxDB database and a Grafana visualization application presenting particular interest, as the user of the application (in the case of our work, the doctor) can monitor the two distinct measurements, heart rate and SpO2, of the patient or patients in real-time to check or even address certain critical health situations. As health is the most important thing for all people, the use of applied technologies to health like the one proposed, is highly needed in the technological developments.

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[8] General Description Benefits and Features • Complete Pulse Oximeter and Heart-Rate Sensor Solution Simplifies Design • Integrated LEDs, Photo Sensor, and High-Performance Analog Front -End • Tiny 5.6mm X 2.8mm X 1.2mm 14-Pin Optically Enhanced System-In-Package • Ultra-Low-Power Operation Increases Battery Life for Wearable Devices • Programmable Sample Rate and LED Current for Power Savings • Ultra-Low Shutdown Current (0.7μA, Typ) • Advanced Functionality Improves Measurement Performance • High SNR Provides Robust Motion Artifact Resil- Ience • Integrated Ambient Light Cancellation • High Sample Rate Capability • Fast Data Output Capability MAX30100 Pulse Oximeter and Heart-Rate Sensor IC for Wearable Health System Block Diagram EVALUATION KIT AVAILABLE. https://www.analog.com/media/en/technical-documentation/data-sheets/max30100.pdf.

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