Cardiovascular Monitoring Platform based on the Internet of Things

Plataforma de Monitoreo Cardiovascular basado en Internet de las Cosas

DOI: http://dx.doi.org/10.17981/cesta.04.01.2023.02

Scientific research article. Date of receipt: 02/11/2022. Date of acceptance: 27/02/2023.

Johan Mardini-Bovea
Universidad del Atlántico. Barranquilla (Colombia)
johanmardini@mail.uniatlantico.edu.co

Rosa Leticia Ibarra Martínez
Universidad Autónoma de Sinaloa. Sinaloa (México)
lety.ibarra@uas.edu.mx

Melissa Villa
Centro de Investigación Clínica Centro. Barranquilla (Colombia)
melissa.villa2019@gmail.com

Camilo Arteta
Centro de Investigación Clínica Centro. Barranquilla (Colombia)
camiloart0707@gmail.com

María Pulgar-Emiliani
Centro de Investigación Clínica Centro. Barranquilla (Colombia)
centrodeinvestigacionesclinicacentro@gmail.com

To cite:
J. Mardini-Bovea, R. Ibarra, M. Villa, C. Arteta y M. Pulgar-Emiliani, "Cardiovascular Monitoring Platform based on the Internet of Things", *J. Comput. Electron. Sci.: Theory Appl.*, vol. 4, no. 1, pp. 13–18, 2023. https://doi.org/10.17981/cesta.04.01.2023.02

Abstract

Introduction— The research area focused on health has led to the development of platforms for cardiovascular monitoring systems, considering the implementation of the Internet of Things as the central axis of technological innovation in medical environments, in turn, machine learning techniques and Language. Machine (ML) has proven their importance in the field of data analysis, efficiently extracting information for effective decision making in the field of precision medicine.

Objective— This article objective to present results of the design, test and evaluation of a prototype cardiovascular variables monitoring system, where they can be saved and displayed in real time in the cloud.

Methodology— For its development, non-invasive body sensors and low-cost embedded systems were used, which allow it to be implemented in medical environments.

Results— Consequently, the results of the implementation demonstrate to a large extent the feasibility of implementing this type of technology and systems without the need for the acquisition of high-cost technological devices.

Conclusions— The prototype allows health professionals not to have constant contact with patients who have this device installed on their body, but to obtain medical samples at any time under the implementation of this ICT tool.

Keywords— ESP8266; Internet of Things; Precision medicine; Cardiovascular monitoring; cloud monitoring

Resumen

Introducción— El área de investigación enfocado a la salud ha llevado al desarrollo de plataformas de sistemas de monitoreo cardiovascular teniendo en cuenta la implementación del internet de las cosas como eje central de la innovación tecnológica en ambientes médicos. A su vez, las técnicas de aprendizaje automático y Lenguaje Maquina (ML) han demostrado su importancia en el ámbito de análisis de datos, extrayendo de forma eficaz información para una toma de decisiones efectiva en el ámbito de la medicina de precisión.

Objetivo— Este articulo tiene como objetivo presentar resultados del diseño, prueba y evaluación de un prototipo de sistema de monitoreo de variables cardiovasculares, en donde pueden ser guardadas y mostradas en tiempo real en la nube.

Metodología— Para el desarrollo de esta se utilizaron sensores no invasivos corporales y sistemas embebidos de bajo costo, lo cual permiten ser implementados en ambientes médicos.

Resultados— Por consiguiente, los resultados de la implementación demuestran a gran medida la viabilidad de implementar este tipo de tecnología y sistemas sin necesidad de la adquisición de dispositivos tecnológicas de costo elevado.

Conclusiones— El prototipo permite a los profesionales de la salud no tener contacto constante con los pacientes que posean este dispositivo instalado en su cuerpo, pero obteniendo muestras medicas en cualquier momento bajo la implementación de esta herramienta TIC.

Palabras claves— ESP8266; Internet de las Cosas; medicina de precisión; monitoreo cardiovascular; monitoreo en la nube

© The author; licensee Universidad de la Costa - CUC.

I. Introduction

Cardiovascular Diseases (CVD) are a major global health problem, accounting for 42% of deaths from ischemic heart disease and 34% from cerebrovascular disease worldwide. In 2015, an estimated 17.7 million people succumbed to CVD, representing 31% of all recorded global deaths [1]. Reports from the WHO [2], the PAHO [3], and the ONS [4], indicate that cardiovascular diseases, along with cancer, diabetes and chronic lung diseases, are among the most rapidly increasing health challenges. They are among the leading causes of death globally, with CVD the most prominent, significantly outpacing cancer, diabetes mellitus, and chronic lung diseases.

In response to this health crisis, there is an increasing emphasis on the integration of technology into healthcare. Information and Communication Technologies (ICT) play a pivotal role in identifying heart-related diseases, thereby facilitating early detection of CVD. This early identification is crucial to improve patient quality of life. The technological advancements in this field are evident, with a growing number of evaluation features emerging that utilize both hardware and software. This progress is demonstrated in controlled clinical environments where medical examination data are efficiently captured [5]. The objectives of these ICTs, particularly in relation to Acute Coronary Syndrome (ACS) tests [6], include: 1) developing predictive models for the biclass identification of cardiovascular disease tendencies, 2) providing software-based tools for medical professionals to diagnose CVD, and 3) stratifying patient risk by combining validated risk scores.

Data collected from sensors in controlled environments are meticulously stored in data sets. These data sets encompass a variety of data, including laboratory tests, diagnostic tests, and clinical stress tests. To facilitate comprehensive data collection, various modalities have been proposed, such as biomarkers [12], clinical tests [13], biomedical sensors [14]-[16], and cardiovascular risk assessments [5]-[7].

The Internet of Things (IoT) plays a crucial role in the implementation of precision medicine, especially in the decision-making process. IoT effectively blends hardware with software for efficient data acquisition, collection, processing, and analysis. Furthermore, IoT techniques enable the transmission of data collected through biomedical sensors to the cloud. Once in the cloud, these data can be visualized through dashboards, offering graphical representations accessible from any device, be it mobile or desktop. This integration of technology significantly enhances the capacity for real-time monitoring and analysis in medical settings.

In summary, the technique discussed in this article involves measuring and integrating data from various parameters. This integration aims to support medical professionals in improving decision-making processes and identifying patients at risk of cardiac events before they occur.

The purpose of this article is to introduce the design, implementation, and evaluation of an IoT platform tailored for the measurement and analysis of cardiovascular variables. These variables are crucial in the realm of cardiovascular medicine.

Accordingly, the structure of this article is as follows: The second section delves into the proposed topic and its background. The third section explores the cardiovascular variables in question and their significance in the development of the proposed system. The fourth section introduces the model of the cardiovascular variable monitoring system. Following this, the fifth section discusses the results obtained from the system's implementation. The article ends with the sixth section, where we draw conclusions and outline potential avenues for future research.

II. Related works

In reviewing existing literature on this subject, it is noted that many reviews adopt a highly specific technological perspective. They explore aspects such as the use of biomedical equipment, the analysis of information capture, and the identification of potential cardiovascular risks. Other reviews, while not as comprehensive, focus mainly on evaluating methods to capture and optimize the evaluation of parameters in medical records of patients with cardiovascular disease [8].

However, there appears to be a gap in the literature regarding a novel model that specifically addresses the acquisition of medical variables for cardiovascular parameters using IoT-based methods and tools. A more detailed examination of some of these aforementioned studies is presented below:

At the UMH in Spain [9], researchers have implemented computer-aided techniques that offer fast and accurate tools for the identification of a patient's Electrocardiogram (ECG) signals. Their work involves summarizing and comparing various diagnostic techniques, including data preprocessing, feature engineering, classification, and practical application.

Similarly, studies conducted at the UNMSM in Peru [10], have focused on reviewing portable devices that allow users to monitor their cardiovascular status anytime, anywhere. These devices offer exciting new possibilities and pose unique challenges for the application of ECG algorithms.

III. Relevance of measurable variables

In the medical field, the monitoring and identification of diseases, especially in patients who show symptoms related to the circulatory system, requires the measurement of various parameters. These symptoms can be silent or manifest overtly. Accurately obtaining the correct levels of these measurement parameters in medical settings is a challenging task, necessitating the implementation of precision systems. The parameters that are commonly monitored in this context are listed below.

A. *Body Mass Index*

The Quetelet index, also known as the Body Mass Index (BMI), is a crucial anthropometric variable in medical evaluations. It plays an important role in the identification and stratification of obesity levels in adults. This index, which calculates body fat based on a specific formula (Formula for the calculation of body fat index = (1), has been emphasized in research conducted in Japan [11]. According to the Quetelet index, obesity levels are classified into four distinct classes: underweight, healthy weight, overweight, and obesity.

$$BMI = \frac{Weight\ (\mathrm{Kg})}{Height\ (\mathrm{m})^2} \tag{1}$$

Being overweight is a significant health problem, as it can lead to elevated total cholesterol and blood pressure, both of which are key risk factors for coronary artery disease. Furthermore, obesity markedly increases the likelihood of encountering other cardiovascular risk factors. These include, but are not limited to, high blood pressure, elevated cholesterol levels, and diabetes. The interaction between obesity and these conditions significantly increases the overall risk of cardiovascular diseases.

B. *Body Temperature*

Temperature is a measure that reflects the amount of heat in an object or entity. In the context of biology, the term "body" refers to the physical structure of a living being, which encompasses organs, apparatus, and systems. Therefore, body temperature is the heat level measured in the body of a person or an animal. This temperature can fluctuate according to the time of day and other factors. However, it is generally accepted that normal body temperature hovers around 37°C [12].

C. *Blood Pressure*

Blood pressure in humans is defined as the force exerted by blood against the walls of the arteries. When the heart beats, it pumps blood into these arteries. Blood pressure is measured in two components: Systolic (the higher number) and diastolic (the lower number). Systolic pressure represents the force when the heart contracts and pumps blood out, while diastolic pressure indicates the force when the heart is at rest between beats. Typically, the systolic number is written first or on top of the diastolic number. For example, a reading of 120/80 mmHg means a systolic pressure of 120 mmHg and a diastolic pressure of 80 mmHg [12].

D. *Oxygen saturation*

Oxygen saturation is the measure of the proportion of oxygen-saturated hemoglobin in the blood relative to total hemoglobin. Essentially, it indicates the amount of oxygen that is available in the blood. When the heart pumps blood, oxygen binds to hemoglobin in red blood cells and is transported throughout the body. Maintaining optimal oxygen saturation levels is crucial, as it ensures that an adequate amount of oxygen is delivered to the body's cells for their proper functioning and metabolic processes. Typically, healthy oxygen saturation levels range from 95% to 100% in most people [12].

II. Cardiovascular Variables Monitoring System Model

The development of the cardiovascular variable monitoring system is based on measurements obtained through the implementation of biomedical sensors. These sensors employ a noninvasive methodology which simplifies the process of medical sampling. In addition, the system incorporates a component that focuses on in situ samples. The specifics of this approach, including the parameters measured and the techniques used, are detailed in Table 1.

Table 1.
Medical data collection method.

Measure	Sensor Applied	Type of sample
BMI	Measuring tape	Insitu
Pulse	Pulse sensor	Non-invasive
Systolic	Digital blood pressure monitor	Non-invasive
Diastolic	Digital blood pressure monitor	Non-invasive
Height	Measuring tape	Insitu
Temperature	DS18B20	Non-invasive
Blood oxygen	MAX30101	Non-invasive

Source: Authors.

All sensors in the monitoring system are integrated with the ESP8266 hardware [17]. This hardware is responsible for processing the collected data and transmitting it to the cloud. Data transmission to the server occurs through a WiFi connection, utilizing the communication module embedded in the ESP8266 device[17].

Once in the cloud, the data are aggregated and displayed on a dashboard. This dashboard facilitates effective monitoring, enabled by the continuous interaction with the ESP8266 hardware [17], and its reliable WiFi connection. A comprehensive diagram illustrating the overall architecture and workflow of the proposed platform is presented in Fig. 1.

Fig. 1. Diagram of a prototype system for monitoring cardiovascular variables.
Source: Authors.

The programming of the ESP8266 module [17] was carried out using the Arduino Integrated Development Environment (IDE) software [18]. Within this programming environment, sensors were configured and the respective software for the monitoring system was developed. The Arduino IDE's console provided a robust platform for coding, testing, and debugging the software necessary to effectively operate the ESP8266 module in the context of cardiovascular variable monitoring [17].

III. Implementation results

The monitoring platform was successfully implemented at the Universidad de la Costa-CUC (Barranquilla, Colombia). This platform enables real-time monitoring of various health parameters, and it also provides access to historical medical data. The sampling process involved students from the Computer Science and Electronics department, specifically targeting those in the third and fourth semesters of the active systems engineering program.

In the visualization process, as shown in Fig. 2, pulse, Body Mass Index (BMI), and temperature sampling is demonstrated. Fig. 3 illustrates the relationship between systolic and diastolic blood pressure. Meanwhile, Fig. 4 displays the blood oxygenation levels of the analyzed patient. Each figure also specifically denotes the period of sample capture, which is crucial to developing a subsequent data analysis. It is important to note that during this phase, no alerts were generated as the model's scope was confined to the acquisition, transmission, and visualization of data on the described platform.

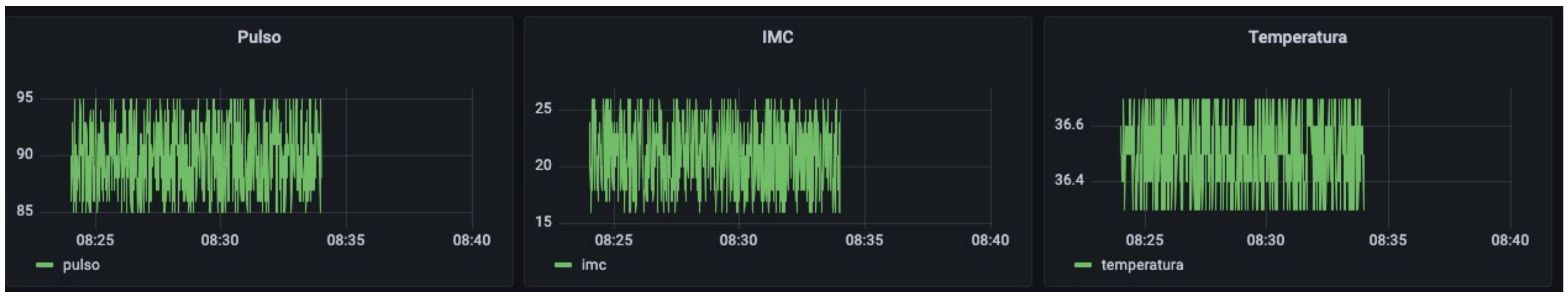

Fig. 2. Display of sample related to Pulse, BMI, and Temperature.
Source: Authors.

Fig. 3. Visualization and relationship between Systolic and Diastolic Pressure.
Source: Authors.

Fig. 4. Visualization of Blood Oxygenation.
Source: Authors.

IV. Conclusions

The Internet of Things (IoT) and its role in precision medicine are highly relevant in this post-pandemic era, particularly for monitoring vital signs and analyzing behavioral changes in patients who have recovered from SARS-CoV-2 (COVID-19). This article presents a clear demonstration of the design, implementation and deployment of an efficient prototype to monitor cardiovascular variables on a small scale, using IoT as a fundamental component of decision making. Furthermore, it enables systematic recording and storage of information in the cloud, facilitating the maintenance of an electronic health record for the patient under analysis.

A key feature of this system is that it allows healthcare professionals to monitor patients remotely, reducing the need for constant physical contact with individuals who have this device installed in their bodies. Medical samples can be obtained at any time using this ICT tool. However, some limitations were identified in this research, such as occasional delays when transmitting all data simultaneously.

As part of future work, it is proposed to extend the range of sensors and implement Bluetooth Low Energy (BLE) based technologies to improve the physical prototype. It should be noted that all connecting elements were initially implemented in a wired form.

Funding

This research was developed with own resources and the support of the Centro Clinic's Research Centre (Colombia).

Authors' contribution

The authors' contributions to this article are as follows:

Johan Mardini: Conceptualization, research, writing, review and editing.

Rosa Ibarra: Validation, review and editing.

Melissa Villa: Software, formal analysis, visualization and writing of the original draft.

Camilo Arteta: Methodology, software and validation.

María Pulgar: Conceptualization, formal analysis, research, supervision and data processing.

All authors participated in the review of the results and gave their approval to final version of the manuscript.

Conflict of interests

The authors hereby declare that there are no conflicts of interest pertaining to the reporting of this study. This declaration encompasses any potential financial, personal, or professional interests that could be construed as influencing the research process, its outcomes, or the interpretation of its findings.

References

[1] D. Nettleton, *Técnicas para el análisis de datos clínicos*. MAD, ES: Díaz de Santos. 2005.

[2] R. Whitmer, S. Sidney, J. Selby, S. Claiborne Johnston & K. Yaffe, "Midlife cardiovascular risk factors and risk of dementia in late life," *Neurol*, vol. 64, No. 2, pp. 277–281, Jan. 2005. https://doi.org/10.1212/01.WNL.0000149519.47454.F2

[3] O. Raitakari, M. Juonala, M. Kähönen, L. Taittonen, T. Laitinen, N. Mäki-Torkko, M. Järvisalo, M. Uhari, E. Jokinen, T. Rönnemaa, H. Åkerblom & J. Viikari, "Cardiovascular risk factors in childhood and carotid artery intima-media thickness in adulthood: the Cardiovascular Risk in Young Finns Study," *JAMA*, vol. 290, No. 17, pp. 2277–2283, Dec. 2003. https://doi.org/10.1001/jama.290.17.2277

[4] R. Poplin, A. Varadarajan, K. Blumer, Y. Liu, M. McConnell, G. Corrado, L. Peng & D. Webster, "Prediction of cardiovascular risk factors from retinal fundus photographs via deep learning," *Nat. Biomedical Eng*, vol. 2, No. 3, pp. 158–164. Jan. 2018. https://doi.org/10.1038/s41551-018-0195-0

[5] A. Rawshani, A. Rawshani, S. Franzén, N. Sattar, B. Eliasson, A. Svensson, B. Zethelius, M. Miftaraj, D. McGuire, A. Rosengren & S. Gudbjörnsdottir, "Risk factors, mortality, and cardiovascular outcomes in patients with type 2 diabetes," *NEJM*, Vol. 379, No. 7, pp. 633–644, Aug. 2018. https://doi.org/10.1056/NEJMoa1800256

[6] World Health Organikzation, "Cardiovascular diseases," 2019. [Online]. Available: https://www.who.int/health-topics/cardiovascular-diseases#tab=tab_1

[7] INS, "Boletin Observatorio Nacional de Salud," 2023. [Online]. Available: https://www.ins.gov.co/Direcciones/ONS/boletines-t%C3%A9cnicos

[8] S. Russell & P. Norvig, *Artificial intelligence: a modern approach*, 2 Ed., MAD, ES: Pearson. 2004.

[9] A. Bertomeu-Motos, S. Ezquerro, J. Barios, L. Lledó, F. Badesa y N. García-Aracil, "Predicción de actividades de la vida diaria en entornos inteligentes para personas con movilidad reducida", presented at *XXXVIII Jornadas de Automática*, CEA, GIJ, ES, 6-8 Sept. 2017. https://doi.org/10.17979/spudc.9788497497749.0251

[10] D. Utrilla, "Sistema de arquitectura multisensorial para supervisión y seguridad industrial aplicando tecnología de inteligencia artificial", *Tesis Grado*, Fac Ing Ind, UNMSM, LIM, PE, 2014. Available: https://hdl.handle.net/20.500.12672/3870

[11] K. Nakamura, H. Nakagawa, M. Sakurai, Y. Murakami, F. Irie, A. Fujiyoshi, T. Okamura, K. Miura, H. Ueshima & The EPOCH-JAPAN Research Group, "Influence of smoking combined with another risk factor on the risk of mortality from coronary heart disease and stroke: pooled analysis of 10 Japanese cohort studies," *Cerebrovasc Dis*, vol. 33, No. 5, pp. 480–491, Jan. 2012. https://doi.org/10.1159/000336764

[12] I. Kononenko, "Estimating attributes: Analysis and extensions of RELIEF", presented at *European Conference on Machine Learning*, ECML-94, CTN, IT, Apr. 6-8 1994. https://doi.org/10.1007/3-540-57868-4_57

[13] L. Breiman, J. Friedman, R. Olshen & C. Stone, *Classification and regresion trees*. BC RTN, FL, USA: Chapman & Hall/CRC, 1984.

[14] G. Li, R. Hu & X. Gu, "A close-up on COVID-19 and cardiovascular diseases," *NMCD*, vol. 30, No. 7, pp. 1057–1060, Apr. 2020. https://doi.org/10.1016/j.numecd.2020.04.001

[15] H. Liu, H. Motoda, R. Setiono & Z. Zhao, "Feature selection: An ever evolving frontier in data mining," presented at *Fourth International Workshop on Feature Selection in Data Mining*, JMLR, HYDB, IN, 21 June 2010. Available from http://proceedings.mlr.press/v10/liu10b/liu10b.pdf

[16] E. Hossain, S. Uddin & A. Khan, "Network analytics and machine learning for predictive risk modelling of cardiovascular disease in patients with type 2 diabetes," *Expert Syst Appl*, vol. 164, pp. 1–10, Feb. 2021. https://doi.org/10.1016/j.eswa.2020.113918

[17] *ESP8266*. (2014). Espressif Systems. Available: https://www.espressif.com/en/products/socs/esp8266

[18] *IDE*. (v. 2.0.4). Arduino LLC. Available: https://www.arduino.cc/en/software

Johan Mardini-Bovea. Electronic engineer. Specialist in convergent networks. Master's degree in systems and computer engineering. He is currently a full-time lecturer at the Universidad de la Costa (Colombia). Member of the research group GIECUC. His research interests are focused on the development of monitoring models focused on medical environments, models based on embedded systems, data mining and Big data. https://orcid.org/0000-0001-6609-1687

Rosa Leticia Ibarra Martínez. Computer Systems Engineer from the Autonomous University of Sinaloa-UAS (Mexico). Master in Education. PhD student in Education. She is currently a full-time lecturer in the Faculty of Computer Science at the Autonomous University of Sinaloa-UAS. His research interests are focused on the development of models based on IoT, data mining and educational models. https://orcid.org/0000-0002-0739-5768

Melissa Villa. Fifth semester student of Systems Engineering at the Universidad de la Costa (Colombia). https://orcid.org/0000-0001-7317-3840

Camilo Arteta. Fifth semester student of Systems Engineering at the Universidad de la Costa (Colombia). https://orcid.org/0000-0001-8277-7929

María Pulgar-Emiliani. Cardiologist at the Clínica Centro (Colombia). https://orcid.org/0000-0002-5318-286X