Automation System for Six-minute Walk Test Using RFID Technology

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***Abstract*—The main objective of this work was to develop a low-cost monitoring system based on radio frequency identification (RFID) to automatize six-minute walk tests (6MWT), an aerobic fitness test used in cardiopulmonary patients including those who have recovered from COVID-19. The advantages of RFID systems have been widely applied in the health area and in the field of physical fitness tests, reducing human errors often occurred due to the difficulty of tracking and monitoring continuously. We propose an automatic monitoring system based on RFID in which it is possible to perform the test on several patients simultaneously. The results demonstrate that the proposed system offers the ability to monitor multiple users simultaneously, accurately and quickly, in addition to reducing the manual work performed by test administrators.**

***Index Terms*—Automatic monitoring system, radio-frequency identification (RFID), six-minute walk test (6MWT)**

I. Introduction

The regular practice of systematized physical activities contributes to the improvement of health-related physical fitness, such as strength, muscular endurance, cardiorespiratory endurance and flexibility [1]. These activities favor the control of body adiposity and the maintenance of functional capacity, which facilitates performance in various daily activities and provides a better quality of life [2]. However, concerning clinical aspects, Heart Failure (HF) is one of the predominant problems in patients, which has become one of the main factors of hospitalization, in which about 50% of the South American population is part of these figures [3]. The analysis of DATA-SUS pictures the reality of the situation of hospitalizations for HF in Brazil. The data show that, only in 2012, there were about 26,600 deaths from HF in Brazil. In the same year, approximately 21% of hospitalizations for circulatory system diseases were due to heart failure [4]. Individuals with HF feel tired and (or) suffer from cardiac asthma while exercising or even at rest. Thus, the vast majority of patients with heart failure intentionally avoid the recommended treatment, destroying cardiac function and high readmission rate of the individual to the hospital [5]. With the constant advances in medicine and technology, it is possible to obtain pressure data, heart rate, among others, in real-time and following diagnoses that contribute to the recovery and treatment of the patient [6]. In this context, the six-minute walk test (6MWT) aims to measure the maximum distance that a person can walk for six minutes. This test comes from the modification of the twelve- minute walk test, initially developed by Kenneth Cooper in 1960, through a rapid aptitude test [7]. The 6MWT mainly measures the distance the patient is likely to cross back and forth on a flat surface lasting six minutes. During the test, the individual is allowed to rest or adjust the walking speed [11]. With the appearance of COVID-19, the 6MWT has been widely used. The 6MWT is commonly demanded due its simplicity, low cost, and suitable for evaluating respiratory function [8]. According to [9], the confirmed COVID-19 cases are classified as mild, severe and critical, with 81%, 14% and 5% respectively. Each requires a different level of medical care. In [10] it recommends the test to check the COVID-19 patient's actual need for hospitalization, optimizing the occupation of beds. Currently, test monitoring is performed through the monitoring of a health professional while the patient goes through a previously established trajectory. Calculations performed from the data collected manually by the professional informs the results [12]. The evaluation of functional exercise capacity has gained importance in the evaluation of patients with different diseases, contributing significantly to the diagnosis. Despite the vast usefulness of the 6MWT, the approached approach becomes inefficient and time-consuming due to manually performed procedures for data acquisition and analysis. Thus, it is necessary to develop a system capable of collecting the primary patient data remotely and accurately to automate the procedures, optimizing the results [13]. Given this, the present paper presents a six-minute walk

978-1-7281-5628-6/20/$31.00 © 2020 IEEE

test automation project, based on the study of radio frequency identification (RFID) technology, which emerges as a potential solution to make the test more accurate, faster and more efficient. With this technology, multiple patients can perform the test simultaneously, collecting data automatically. Section 2 comprises the exposition of the operation of the RFID system, explaining the performance of communications between reader and antenna, and the benefits of this technology. The following is an overview of the conventional six-minute walk test as well as its performance for disease diagnosis. In section 3, the model test will be proposed, analyzing the step- by-step operation of the test for the automation process. Section 4 brings a discussion on the procedures performed during the test automation, as well as the results found from data collected during the process. In section 5, the relevance of automating the six-minute walk test to the health area will be highlighted when compared to the traditional method.

II. Recent Research Progress

A. Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is a technology that uses electromagnetic waves to identify objects, people, and animals. It is composed basically of three components: reading device, transponder, and computer [14], and is schematically represented in Fig. 1.

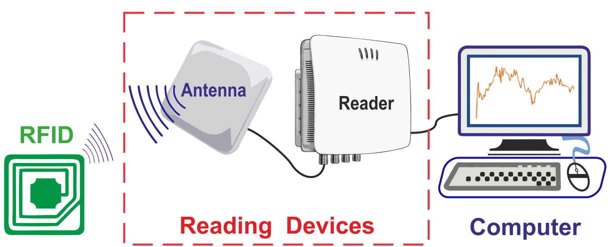

Fig. 1. RFID System Operation.

This technology is instrumental as it allows efficient tracking of people, animals, and objects. Also, this system introduces a new approach that tends to replace the bar code. The reading device emits an electromagnetic field that feeds the transponder, which is responsible for responding to the reading device with its memory content. The transponder contains the information and uses electronic devices (such as capacitor, inductor, resistor, etc.) to generate a signal [15] and [16]. The tag, is the component used for data storage. Each tag has its own integrated circuit, usually a chip and an antenna stored both in the component. The tag is attached to the object with a certain ID, the memory stores data about the manufacturer and other general information [17] and [18] . On the market, tags are available in different sizes and shapes. These are generally encapsulated in a credit card outline for restricted access card applications for example. Other applications of these are for the development of applications for tracking objects, and among other applications. Commercial devices are found thinner than a sheet of paper [19]. For the reader, all data stored is collected on the label. This component consists of a decoder with the purpose of decoding the information contained in the tag. In the reader, internally it has an antenna capable of transmitting and receiving electromagnetic waves and sending the tag data to the reader and vice versa. The RFID reader has the ability to read or write information for the tags, receiving the reading of nearest IDs and collecting the information. Therefore, the RFID reader has the characteristic of detecting and monitoring the existence of a certain object [20]. There are currently systems that connect the RFID system and wire sensor network (WSN), with applications in healthcare systems. In this application, communication is done through RFID tags and has an internal identification code. In that case, there are solutions using a range of WSN technologies, such as IEEE 802.15.4, ZigBee. The use of Wi-fi or even Bluetooth can be considered [21]. A software is used for data management and operations between reader and label. The details of the components existing in the operation are also stored. The collected information is forwarded to a host to ensure communication between the RFID system and other existing systems [18].

B. Application of RFID in the health area

The use of RFID in the health can considerably improve the risk control of a patient, through the identification and monitoring. RFID also allows allergies control, prevention of adverse events, like medications administration errors (patient, drug, time, dose and route) [22]. Therefore, technology offers means and tools to optimize patient care and control [23]. In this way, RFID allows a new technological advancement focused on health, enabling the construction of a new concept in health services [24]. Currently, intelligent systems migrated to hybrid systems, which are intelligent systems based on IoT. One of these is known as CUIDATS, a model that integrates or uses RFID and WSN in a single system, or which is the location and tracking of patients in real time, which has been successfully deployed and evaluated at the hospital in Asepeyo Sant Cugat de Valles in Spain [20]. CUIDATS can monitoring patient's vital signs and activate alarm signals in case of malfunctions. This system allows the control the patient located in the hospital, using a bracelet, several sensors and an RF transmitter inserted in the bracelet to collect data [26] [27]. Medical errors have become a leading cause of death on a global basis. It is found that medical errors are causing 250,000 deaths per year in the U.S. [33]. Specimen or medication misidentification is the leading cause of death due to medical errors [34]. To address this issue, hospitals and other institutions can apply RFID patient identification, tracking, monitoring and drug compliance systems [35]. According to a case study [33] [36], positive patient identification (PPI) systems allow the personnel to quickly obtain up to date information about the patients (including medication requirements), and prevents medical personnel from taking shortcuts when identifying patients and medication. This suggests that RFID enabled patient and medication identification systems does indeed reduce misidentification and non-compliance with medications, which thus improve patient safety.

C. Six-minute walk test (6MWT)

6MWT is a resistance test in which most patients with mild to moderate cardiopulmonary disease have a metabolic demand lower than the maximum obtained in an incremental test, and the maximum limits are not usually reached. However, for most patients, the 6MWT can be seen as an almost maximal test due to the near-maximal energy effort during the test [17]. The 6MWT allows an evaluation of the global and integrated response of all systems involved in exercise performance (pulmonary, cardiovascular, systemic and peripheral circulation, blood, neuromuscular unit, and muscle metabolism). It is advantageous in clinical practice to evaluate patients with various advanced cardiopulmonary clinical conditions [28]. In this context, the six-minute walk test is widely used to practically and inexpensively assess physical capacity in patients with a poor physical condition. Therefore, in recent years, this test has gained significant importance in both clinics and clinical research [29]. Among the 6MWT goals are the assessment of aerobic capacity for physical activity, the assessment of the functional status of the cardiovascular or respiratory system, the evaluation of prevention and rehabilitation programs, and the prescription of morbidity and mortality in transplant candidates [30]. The test can diagnose diseases such as heart failure (HF), chronic pulmonary obstruction (COPD), Alzheimer's, and Down Syndrome. In general, after the test, a medical team monitors the record of the distance traveled and performs the analysis of the patient's cardiac resistance [31]. The distance covered during the 6MWT is divided into four different levels so that the first level covers patients with a travel distance of over 450 meters; the second level comprises those that have traveled between 375 and 449.5 meters; the third level contains the individuals who moved between 300 and 374.9 meters; the fourth level covers those who have moved less than 300 meters. Thus, the higher the patient's level, the more severe heart problems identified [3].

III. DATA COLLECTION AND PROCESSING

The first step for data collection was to carry out extensive bibliographic research about the six-minute walk test, the test automation, and the components for prototype construction. It was based on national and foreign papers, as it is a recurrent topic, and there is similar research in other countries. Despite the wide application of the 6MWT, the approached method makes the data acquisition and analysis process somewhat inefficient due to manually performed procedures. Given this context, the present work seeks the automation of the test and the consequent reduction of human activity by replacing it with the microprocessor control. In the proposed test model, patients follow a 6-minute course. On this route, as the patient approaches the RFID module, data of time spent during a complete lap, total distance traveled at the end of the test, and number of complete turns will be transmitted to a computer where a healthcare professional will be responsible for patient diagnosis according to the data collected at the end of the test. The microcontroller and RFID module will be responsible for the timing, acquisition, and transmission of data, replacing the manual work previously done, improving the accuracy of the test, as illustrated in Fig. 2.

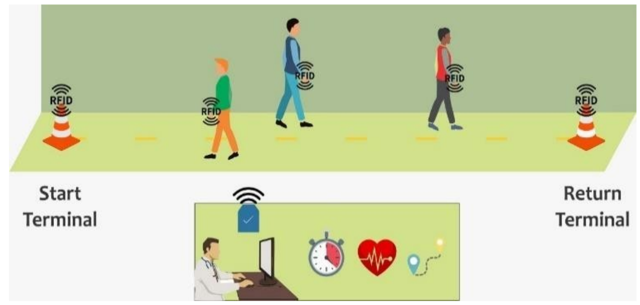

Fig. 2. Automated six-minute test scheme.

After the implementation of the RFID, its program verified the time it takes for the patient to travel the distance of one complete lap. Subsequently, it was necessary to evaluate the different methods for project application. The conduction of studies was key to find the best-proposed idea to fits in the prototype development, notably wireless communication devices. In this context, the best fit was XBee for wireless communication. The Fig. 3 shows how communication is proposed between the devices used in automating the test.

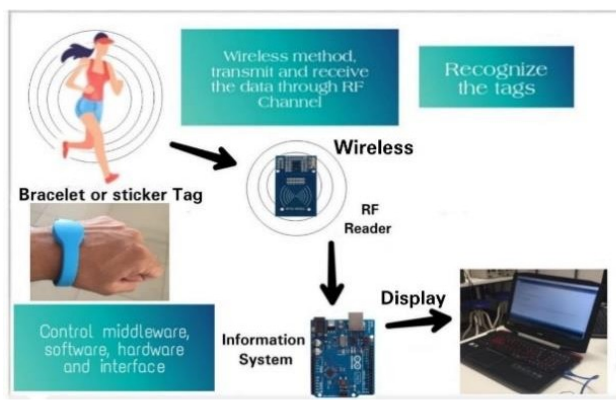

Fig. 3. Communication between the devices used in test automation.

XBee technology, sometimes referred to as Bluetooth Low Energy technology, is a smaller Power version of Bluetooth. XBee provides enhanced power performance by Bluetooth. XBee can be crucial in future medical sensors. In [32] proposed a time monitoring system for physiological signals using a wireless sensor network. The wireless sensor network (WSN) used to observe human physiological signals by XBee is equipped with lower power consumption, small volume, high expansion, stylization, and two-way transmission.

IV. RESULTS AND DISCUSSIONS

An Arduino and RFID circuit were assembled using the RFID Reader KIT MFRC522 / Tag (Keychain) / Tag (Card), as shown in Fig. 4. After assembly, the programming was performed in Arduino software, defining the reading and recognition of tags. Then, the system was programmed to perform a simulation similar to the proposed project, by counting the time when each tag was recognized when approximated the RFID.

Fig. 4. Arduino-RFID Link Representation.

That is, as one complete lap completes, the patient approaches the RFID reader's wristband, which reads the TAG, keeping track of the time it took the patient to complete each lap. The Fig. 5 shows the circuit simulation and tag recognition.

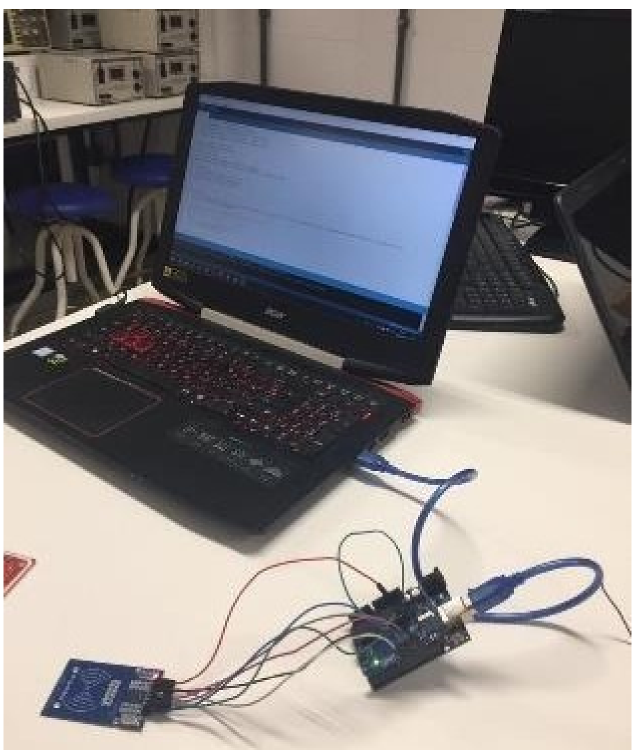

Fig. 5. Arduino-RFID Link Representation.

After the registration and recognition of the Tags, the simulation was performed by analogy to two patients who underwent the six-minute walk test. The test works on a course where the patient must perform for an established time of six minutes. During the simulation, the tag was attached to both students for data collection. Each time the participant approached the RFID device, time and variance data, distance traveled, and the number of turns completed was collected and transferred to a computer in real-time. On the computer, the program collected data extracted from each participant for analysis. Fig. 6 shows the time and number of turns obtained in the simulation of the two patients, where lap is the order of the lap traveled (lap 1 refers to the first lap).

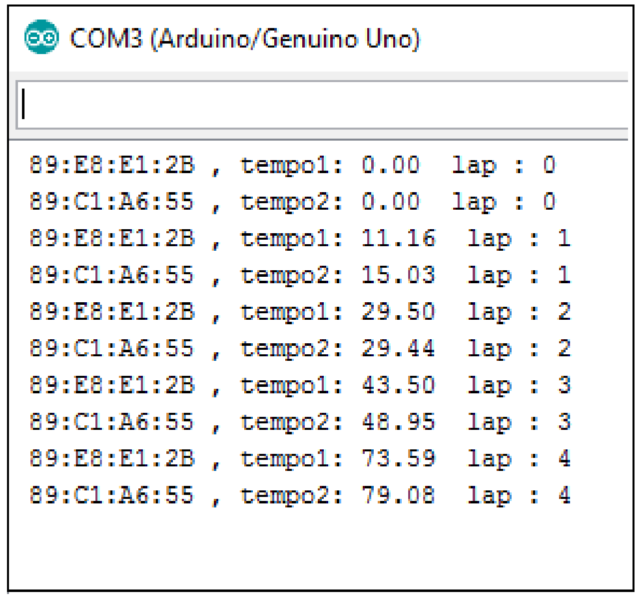

Fig. 6. Simulation with time and number of complete turns.

The Figure 6 shows the behavior of both patients during the simulation. Initially, both started with the checkpoint at 0.00 seconds. Soon after, defined as the number of laps (lap), patient 1 completed the first lap in 11.16 seconds, while patient 2 reached a relatively longer time to complete the first lap. At the end of the journey, on lap number 4, it is noted that patient 2 had more difficulty to perform the test, as the arrival time was longer than the time of the first patient. After the cardiac monitor tests, the collected data is transmitted remotely to a computer through a wireless sensor network (XBee). The cardiac monitor and XBee have already been obtained, as shown in Fig. 7.

The experiment also obtained and tested a patient identification bracelet that functions as the tag, as shown in Fig. 8.

With the experiments, the automation project was successfully developed using the bracelet, RFID and Xbee wireless communication technology. These devices were significant for the development of the research and for obtaining more efficient results than those obtained in the traditional test. In this way, the project is a door for the practical development of the automation of the TC6 in the near future.

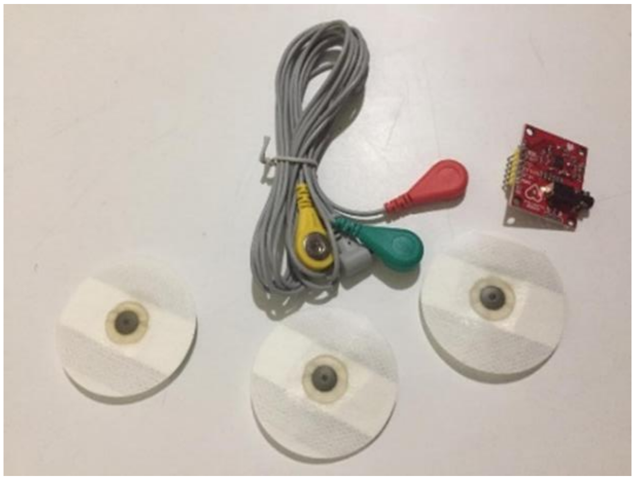

Fig. 7. Heart rate monitor.

Fig. 8. Patient ID Bracelet.

V. CONCLUSIONS

This work developped a low-cost system to automate the six-minute walk test based on RFID technology, ZigBee and Arduino to help health professionals to evaluate cardiopulmonary patients including COVID-19. The implementation of RFID in healthcare opens up many opportunities to improve patient safety and faster diagnostics. It attributes the use of RFID in identifying, tracking, monitoring and improving the patient's use of medication. Thus, with the implementation of RFID, medical and human errors in hospitals and other health services can also be reduced. The developed system allows simultaneous and accurate monitoring of several users and reduces the manual work performed in the traditional test. This paper is a step for health science and engineering, as it allows for improvement in tests that are very common in everyday life.

ACKNOWLEDGMENT

The authors would like to thank the Centro Universitário Santo Agostinho - UNIFSA, the Hospital Universitário do Piauí - EBSERH, the Universidade de Aveiro - UA, and the Instituto de Telecomunicações Aveiro.

REFERENCES

[1] BARROS, T. V.; MARTINS, A. M.; SOARES, M. M. V.; COSTA, H. S. et al. Avaliação da intensidade de um protocolo de exercício aeróbico utilizando a velocidade do teste de caminhada de seis minutos como parâmetro para prescrição de carga. Minas Gerais, 2019.

[2] A. Solanas, C. Patsakis, M. Conti, I. Vlachos, V. Ramos, F. Falcone, O. Postolache, P. Perez-Martinez, R. Pietro, D. Perrea, A. MartinezBalleste, Smart health: A context-aware health paradigm within smart cities, Communications Magazine, IEEE 52 (8) (2014) 74–81. doi:10. 1109/MCOM.2014.6871673.

[3] HSU, S.-J., Lin, S.-S., Pai, T.-W., Wang, C.-H., Liu, M.-H., and Lee, C.-H. Autonomous exercise rehabilitation for heart failure patients based on six-minute walk test through Internet-of-Thing devices. 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Canada, October 5-8, 2017.

[4] ALBUQUERQUE, D. C., NETO, J. D. S., BACAL, F. et al. I Registro Brasileiro de Insuficiência Cardíaca – Aspectos Clínicos, Qualidade Assistencial e Desfechos Hospitalares. Rio de Janeiro, 2015.

[5] G.A Haldeman, J.B Croft, W.H Giles, A Rashidee, "Hospitalization of patients with heart failure: National Hospital Discharge Survey, 1985 to 1995" 1999.

[6] Ong MK, Romano PS, Edgington S, et al. Effectiveness of remote patient monitoring after discharge of hospitalized patients with heart failure: the Better Effectiveness After Transition - Heart Failure (BEAT-HF) randomized clinical trial. JAMA Intern Med. 2016;176:310-18.

[7] COOPER, K. H. A means of assessing maximal oxygen uptake: correlation between field and treadmill testing. JAMA. 1968; 203:201– 204.

[8] MORALES-BLANHIR, Jaime Eduardo, et al. Six-minute walk test: a valuable tool for assessing pulmonary impairment. J Bras Pneumol, 2011, 37.1: 110-7.

[9] Mantha, Srinivas, et al. "Proposed Modifications in the 6-minutue Walk Test for Potential Application in Patients with mild Coronavirus Disease 2019 (COVID-19): A Step to Optimize Triage Guidelines." Anesthesia and Analgesia (2020).

[10] HALABCHI, Farzin; MAZAHERI, Reza. Six min Walk Test as a Criterion for going to the Hospital in Suspected COVID-19 Patients; Is it Practical, Safe and Scientifically Justified?. Advanced Journal of Emergency Medicine, 2020.

[11] D. A. Scalzitti, K. J. Harwood, J. R. Maring, S. J. Leach, E. A. Ruckert, and E. Costello, "Validation of the 2-Minute walk test with the 6-Minute Walk Test and Other Multiple Sclerosis," Int. J. MS Care, vol. 20, no. 4, pp. 158–163, 2018.

[12] ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six minute walk test. Am J Respir Crit Care Med 2002;166:111–7.

[13] Brooks D, Solway S, Gibbons WJ. ATS statement on six minute walk test. Am J Respir Crit Care Med 2003;167:1287.

[14] Seol, S., Lee, E.-K., Kim, W., 2017. Indoor mobile object tracking using RFID. Futur. Gener. Comput. Syst. 76, 443–451.

[15] Duroc, Y., Tedjini, S. (2018). RFID: A key technology for Humanity. Comptes Rendus Physique, 19(1–2), 64–71. doi.org/10.1016/j.crhy.2018.01.003.

[16] [13] Martínez Pérez, M., Dafonte, C., Gómez, Á. (2018). Traceability in Patient Healthcare through the Integration of RFID Technology in an ICU in a Hospital. Sensors, 18(5), 1627. doi.org/10.3390/s18051627.

[17] Kumari, L., Narsaiah, K., Grewal, M.K., Anurag, R.K., 2015. Application of RFID in agri-food sector. Trends Food Sci. Technol. 43 (2), 144-161.

[18] Seol, S., Lee, E.-K., Kim, W., 2017. Indoor mobile object tracking using RFID. Futur. Gener. Comput. Syst. 76, 443–451.

[19] Roberts, C.M., 2006. Radio frequency identification (RFID). Security 25 (1), 19-26.

[20] Adame, T., Bel, A., Carreras, A., Melià-Seguí, J., Oliver, M., Pous, R., 2018. CUIDATS: an RFID–WSN hybrid monitoring system for smart health care environments. Futur. Gener. Comput. Syst. 78, 602–615.

[21] Bouet, M., dos Santos, A.L., 2008. RFID tags: positioning principles and localization techniques. In: 1st IFIP Wireless Days, 24–27 November 2008, pp. 1–5.

[22] Bliven, B., Bragg, M., Long, B., 2016. Medical device connectivity case study. J. Clin. Eng. 41 (2), E1–E11.

[23] Ishida, K., Hirose, M., Fujiwara, K., Tsuruta, H., Ikeda, N., 2014. Analysis of medical equipment management in relation to the mandatory medical equipment safety manager (MESM) in Japan. J. Healthc. Eng. 5 (3), 329–346.
[24] Aboelmaged, M., Hashem, G., 2018. RFID application in patient and medical asset operations management: a technology, organizational and environmental (TOE) perspective into key enablers and impediments. Int. J. Med. Inform. 118, 58–64.
[25] Fosso Wamba, S., Anand, A., Carter, L., 2013. A literature review of RFIDenabled healthcare applications and issues. Int. J. Inf. Manag. 33 (5), 875–891.
[26] Papa, A., Mital, M., Pisano, P., Del Giudice, M., 2018. E-health and wellbeing monitoring using smart healthcare devices: an empirical investigation. Technol. Forecast. Soc. Chang. https://doi.org/10.1016/j.techfore.2018.02.018.
[27] Farahani, B., Firouzi, F., Chang, V., Badaroglu, M., Constant, N., Mankodiya, K., 2018. Towards fog-driven IoT eHealth: promises and challenges of IoT in medicine and healthcare. Futur. Gener. Comput. Syst. 78, 659–676.
[28] MANCUZO, E. V.; SOARES, M. R.; PEREIRA, C. A. C. Distância no teste de caminhada de seis minutos e sobrevida na fibrose pulmonar idiopática no Brasil. Minas Gerais, 2018.
[29] Swanson, C. W., Haigh, Z. J., Fling, B. W. (2019). Two-minute walk tests demonstrate similar age-related gait differences as a six-minute walk test. Gait and Posture 69 (2019) 36-39.
[30] CAHALIN, L. P. et al. The six-minute walk test predicts peak oxygen uptake and survival in patients with advanced heart failure. Chest, 1996.
[31] R.J. Butland, J. Pang, E.R. Gross, A.A. Woodcock, D.M. Geddes, Two-, six-, and 12- minute walking tests in respiratory disease, Br. Med. J. (Clin. Res. Ed.) 284 (1982) 1607–1608.
[32] FINKENZELLER, Klaus. RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, 2ª ed. John Wiley and Sons Ltd, Munich, Germany 2003, 427 p.
[33] Cha AE. Researchers: Medical errors now third leading cause of death in United States. The Washington Post. 2016.
[34] Mehrjerdi YZ. RFID Role in Efficient Management of Healthcare Systems: A System Thinking Perspective. International Journal of Industrial Engineering. 2015;26(1):45-61.
[35] Tzeng S-F, Chen W-H, Pai F-Y. Evaluating the business value of RFID: Evidence from five case studies. International Journal of Production Economics. 2008;112(2):601-13.
[36] Aguilar A, Van Der Putten W, Kirrane F, editors. Positive patient identification using RFID and wireless networks. HISI 11th Annual Conference and Scientific Symposium; 2006.
[37] Mehrjerdi YZ. RFID Role in Efficient Management of Healthcare Systems: A System Thinking Perspective. International Journal of Industrial Engineering. 2015;26(1):45-61.