Smart healthcare system for hospital monitoring during and post pandemic period

Safae El Abkari, Abdelilah Jilbab and Jamal El Mhamdi,
Ecole Normale Supérieure de l'Enseignement Technique, Mohamed V University, Rabat, Morocco

Summary
During this pandemic period, daily healthcare activities require a strict organization between members of healthcare professionals and important health measures when interacting with patients. Therefore, Smart hospitals come as a suitable solution to improve the medical and the clinical processes of covid-19. This paper proposes a design of a real-time monitoring system to support the wellbeing of patients and the healthcare workers now and in post covid-19 pandemic period. We introduce a prototype of an intelligent system that not only manages the interactions between patients and the medical professionals but also stores information data in an accessible database. We implemented an algorithm based on Received Signal Strength and test it using an ESP8266 module as a Wi-Fi device. Our proposed system proved its reliability and its flexibility by its self-configuration in case of emergencies in hospital.

Key words:
Locating, Wi-Fi, Fingerprinting, hospital, smart healthcare, covid-19

1. Introduction

Sensor based technologies are emerging rapidly in healthcare environment [1]. Recent advances such as smart hospital applications contributed to better optimization of the administration and the monitoring processes of healthcare structures [2]. In fact, with the spread of the severe respiratory syndrome of covid-19 [3], those applications could be the most effective in those complex structures where the real-time acquiring of the correct data information is critical to make the right decision at the right time.

Healthcare monitoring mainly consists in wireless technologies, with the deployment of systems that drives from the basic concept of complex context and computing in such environments, focuses on the wellbeing and the management of healthcare workers, the accessibility of healthcare application at any time and to anyone [4-5]. Various innovative applications have been developed, from the at-home monitoring of Alzheimer patients [6] to the intelligent consultations or smart hospitals [7].

The involving technologies and environment of the hospital are extremely complex. Therefore, collaboration between mobile healthcare workers is becoming very required to ensure the accomplishment of daily activities. In fact, the personalization and the accessibility of the healthcare applications have proved a noticeable improvement of service quality of doctors and nurses. Healthcare workers and patients can then benefit from the advantage of achieving a better medical or clinical process, in basic and emergency situation (pandemic…), linked to delivering real-time information data.

Moreover, it has been recently reported the necessity of tracking doctors and nurses in the hospital to better accomplish their daily activities and take care of emergency cases (covid-19...). For example, a nurse would constantly move throughout a hospital department looking for medicines or files or patients. Thus, if a nurse is interacting with a patient that tested covid-19 positive, her movements can dramatically cause a scale up of the virus spread in that space. This consequently lowers the quality of the clinical process and the implemented health measures. We expect then that by offering an appropriate monitoring, the medical professionals will be able to deliver a better care at any time and for everyone in the hospital.

However, healthcare applications require appropriate technologies depending on the specifications and features of the healthcare environment. [8] illustrates an example of a management system based on ultra-wide band technology that ensures real-time safety. [9] proposes a context-aware mobile prototype that supports the work tasks of healthcare workers in the hospital, it gives doctors and nurses their functions by recognizing their positions. Contrarily [10] aims to achieve a transparent integration of smart network without considering the special features.

Usually emerging real-time locating systems (RTLS) utilize locating techniques such as Angle of Arrival (AOA), Received Signal Strength (RSS), Time Of Arrival (TOA) and Time Difference Of Arrival (TDOA) in addition to the wireless technologies of indoor locating that have evolved rapidly over the last decade due to the limitations of satellites.

Radio Frequency IDentification (RFID) [11] is a low-cost wireless technology for indoor locating but has a low coverage, precision and accuracy. ZigBee technology [12] has a high coverage and a good precision that allow the ease of its deployment in adapted applications. Wi-Fi [13] has become very popular over last several years due to the popularity of its devices and its high coverage.

Manuscript received May 5, 2020
Manuscript revised May 20, 2020

In this paper, we introduce a smart system prototype for hospitals which provides a locating service to optimize the interactions between the healthcare workers and patients during and post the pandemic period, also an access to the mapping and the working plan in the database. The conception of this prototype drives from allowing a context aware access, flexibility, extendibility, self-reconfiguration and feasibility to the system. We mainly focus on the design of a locating service-based prototype that can easily interoperate with database and devices present in hospital. This system can be easily extended to integrate other devices or technologies.

This paper is organized as follows. Section 2 introduces the methodology of the locating system prototype. Section 3 describes the real-time monitoring system prototype. Finally, we conclude the paper in section 4.

2. Methodology of the proposed system prototype

2.1 Location calculation method

Real-time locating system is an emerging approach that uses physical, logical and geometrical position information data of a person or an asset. Among services offered by tracking technologies, people locating or tracking can be qualified as the most important. RFID, ZigBee or Wi-Fi represent the main technologies that suit the creation of sensor networks for real-time locating system. Table 1 shows a comparison of their advantages and disadvantages. Thus, the deployment of a locating network using these technologies mainly depends on the application specifications such as environment, accuracy, infrastructure… etc. Wi-Fi comes then as the most suitable technology for our application because of its low cost, availability of Wi-Fi infrastructure, flexibility and ease of use.

In this study, we consider two locating techniques:

- Trilateration [14] which uses at least three nearby references to determine the position/location.
- Fingerprinting [15] which uses statistical values to permit the calculation of the position/location.

Trilateration is commonly used for GPS and it is one of the most used techniques to determine locations. It consists of mapping RSS values in function of distance by considering three nearby references. Nevertheless, collected RSS signals are unstable in complex environment due to walls, floors, or interferences which complicates the accurate calculation of locations. Therefore, we abandoned this technique at an early stage of our study.

Fingerprinting includes signal fading and reflections when dealing with the calculation of location. It consists of two phases:

- The offline Phase wherein we construct a radio-map using collected RSS signals from the reference nodes fixed at known positions.
- The online Phase wherein the target node uses its collected RSS value and look up for matches in the stored database.

Table 1: Comparison of Wireless technologies used for locating

Technology	***ZigBee***	***Wi-Fi***	***RFID***
Advantages	Low price	Availability Ease of use	No battery (passive tags)
Disadvantages	Power consumption	Power consumption	Low precision
Data rate	High	High	Low to Medium
Accuracy	Good	Good	Good
Coverage	High	High	Low to Medium

K-NN [16] (K-Nearest Neighbor) is an algorithm that can be used when using RSS radio-map. A set of RSS data collected from reference nodes at different position permits the getting of an RSS signature-map at the computer memory level and achieve a high positioning process performance. The target tag collects real-time RSS values from reference nodes when it is present within the locating area. Then, our system looks for k-nearest matching data from those collected in the offline phase. For this purpose, we use the Euclidian distance [17] (1) to determine the target tag proximity.

$$de = \sqrt{\sum_{i=1}^{n} (RSSil - RSSreference)^2} \quad (1)$$

Where:

- RSSil is the RSS value collected from node i at location l.
- RSSreference is the RSS value collected from reference i at the target tag position.

Using the formula above, our system looks for the nearest location to the unknown location of the target tag once an RSS value is collected.

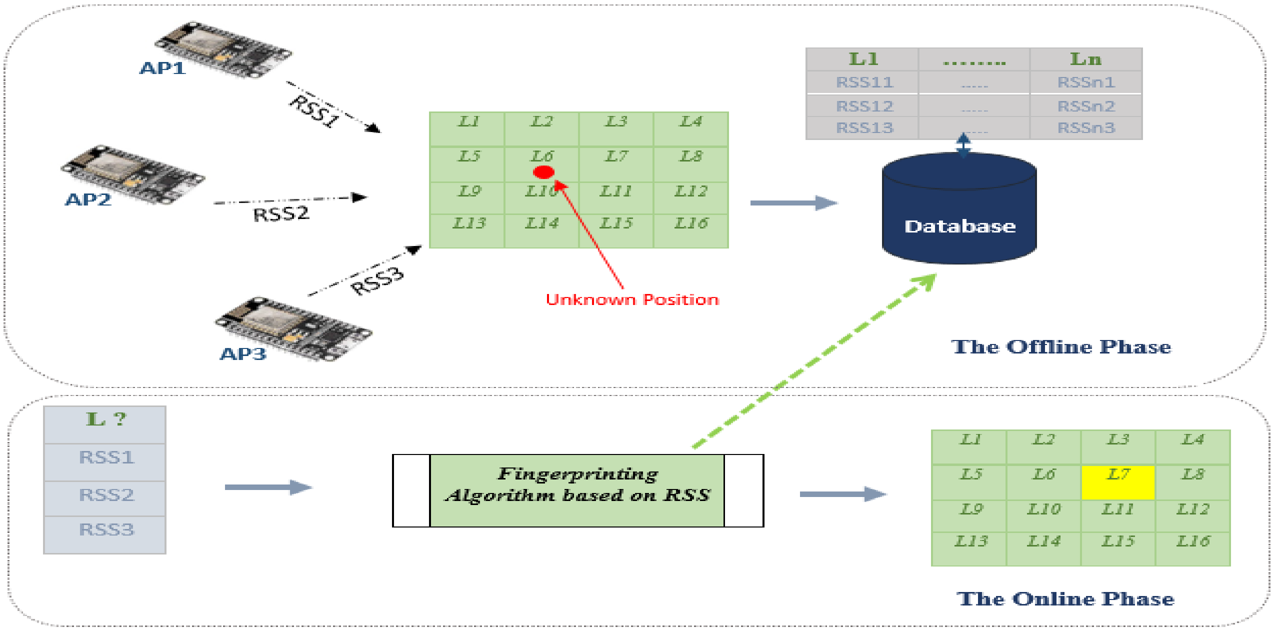


Fig. 1 Schematic of RSS fingerprinting system for the hospital

For locating in the hospital, the RSS fingerprinting method consists two phases as shown above:

- The offline Phase: wherein we constructed a radio-map (Fingerprinting database) using collected RSS values. We fixed the distance between two nearby refence nodes at 1 meter.
- The online Phase: wherein we determine location by matching the collected RSS to the RSS radio-map using Euclidian distance.

In order to optimize the storage of data during the locating process, we stored the collected data according to schematic below (Fig.2). Each detail of those data are presented in Table 2.

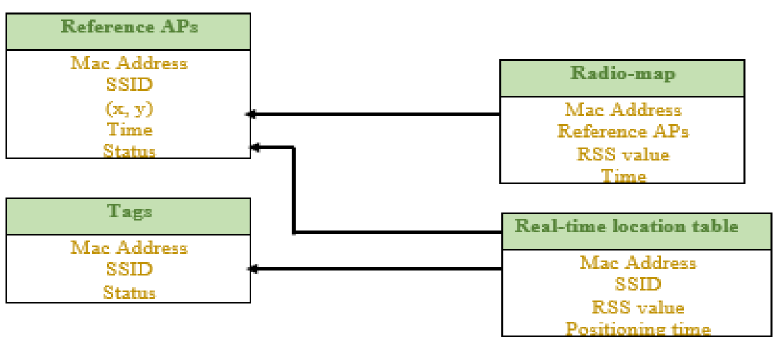


Fig. 2 Our proposed schematic of database stored in the computer

Table 2: Information data stored in the database

Tables	***Data***	***Notes***
Reference APs table	Mac Address SSID (x, y) Time Status	AP Mac Address Connected/ not Connected
Radio-map table	Mac Address Reference APs RSS value Time	Tag Mac Address AP Mac Address Reference AP RSS values
Tags table	Mac Address SSID	Tag Mac Address

	Status	Present in the network
Location table (in Real-time)	Mac Address SSID RSS value Positioning time	Tag Mac Address Reference AP's RSS value in real-time

2.2 Analysis of locations of healthcare workers

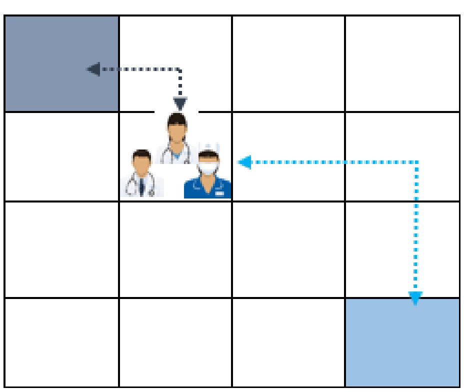
Not only the well use of locating and tracking technology contribute in the management of the medical workers but also the wellbeing of both the patients doctors and nurses. For this, a system must automatically analyze and self-reconfigure to adapt to hospital situation changes in order to be reliable and accurate.

For example, in Fig 3. doctor and nurses must be present at their expected positions Fig 3. (a), but the actual results are in Fig 3. (b). doctor and nurses are supposed to spend more time in the first location than the second one. This analysis of the placement of the healthcare workers permits to obtain a performance report as well as an amelioration of performances of healthcare workers in medical or clinical processes. the positions of doctors and nurses are analyzed using the following steps:

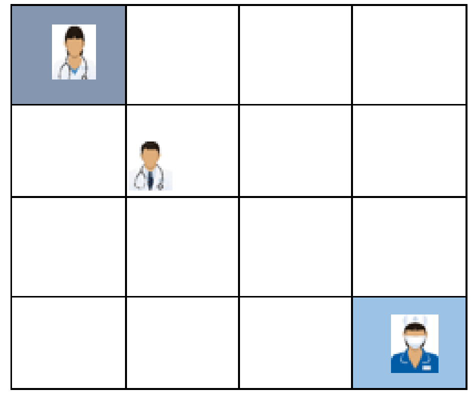
(1) Prepare a predefined table of locations: Each doctor and nurse follow a predefined procedure at a certain location in the hospital (Fig 3., Table 3). Those tasks can be updated at any time depending on the hospital status.

(2) Obtain location of healthcare workers and hospital status (presence of emergency…): collect position data of healthcare workers and hospital status.

(3) Analyze data and make a decision: we compare data of step 1 and data of step 2 by measuring the similarity degree between the two scenarios. Position is the main data used to measure this similarity.



(a) Expected person movement



(b) Actual person movement

Fig. 3 Predefined and actual locations of doctor and nurses within the hospital cell

Table 3: (a) doctor/nurses' expected position at its respective time (b) doctor/nurses' actual position at its respective time

(a)

Personnel	***Position***	***Date and Time***
Doctor1	L1	2020-03-10 11:33:10
Nurse 1	L6	2020-03-10 11:34:16
Nurse 3	L15	2020-03-10 11:53:21

(b)

Personnel	***Position***	***Date and Time***
Doctor 1	L2	2020-03-10 11:33:10
Nurse 1	L6	2020-03-10 11:34:16
Nurse 2	L14	2020-03-10 11:53:21

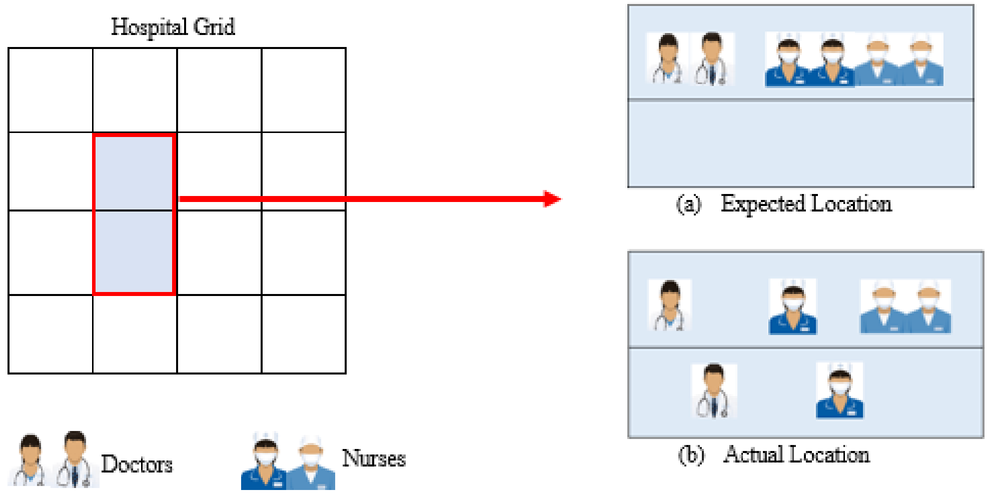


Fig 4. Analysis of position of doctors/nurses at a certain scenario

We define the similarity between two position data data1, data1' as:

$$d(data1, data1') = (data1 - data1') \qquad (2)$$

We can also use this method to compare performances of members of same team. In the present scenario team 1 and team 2 are supposed to work at the same place as shown in Fig 5.a. Actual scenario is that the team 1 and team 2 work at different locations Fig 5.b.

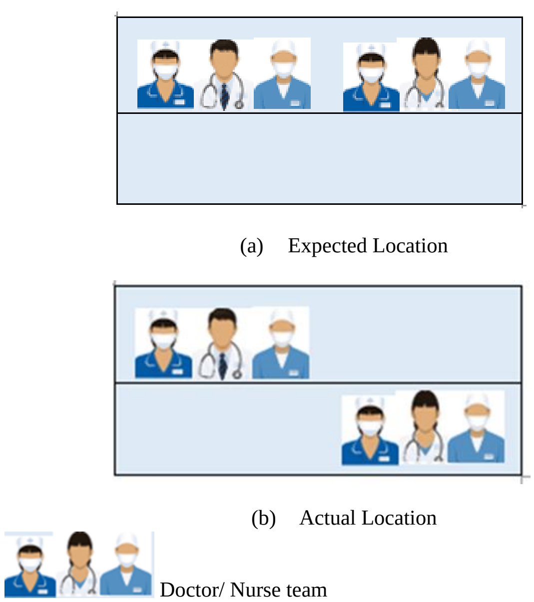


Fig 5. Analysis of the position of different doctors/nurses' teams

In order to improve quality control in the hospital, we set up three main hospital statuses (Table 4). The hospital status defines, at the computer level to, the real-time hospital situation and whether taking a real-time action or an update of the working plan is necessary.

Table 4: Hospital status type

Status	***Information***	***Messages of Information only***
S1	Emergency/ Alert	Immediate action should be taken + doctors/nurses are needed + urgent changes are undertaken in the working plan
S2	Warning	Warning situation is detected + doctors/nurses may be needed
S3	Notice	Normal functioning + changes to be consider in the working plan update

3. Description of the real-time monitoring system prototype

3.1 Overview of the proposed system prototype

Our system mainly focuses on the determination of the real-time locations of the healthcare workers. The analysis of this data permits an evaluation of the action characteristics in the hospital environment. Fig 6. Shows the schematic of the system from collection of data to position information data analysis and decision making.

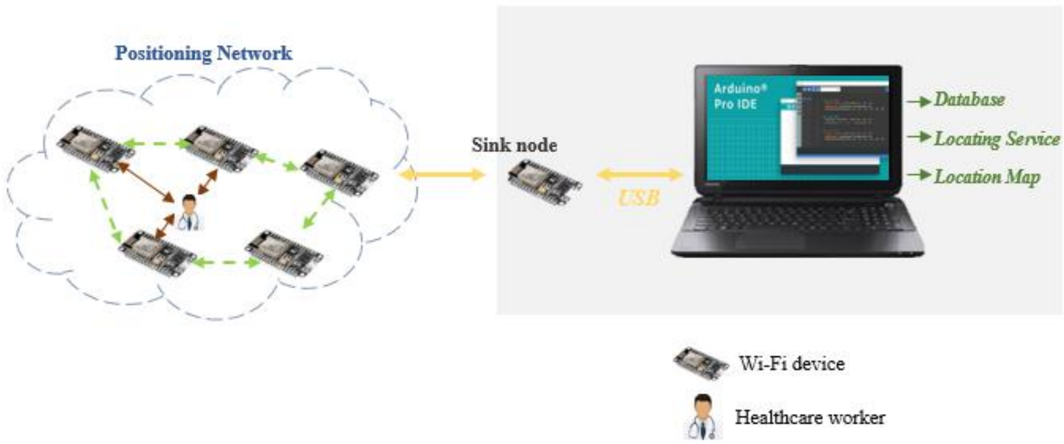


Fig 6. The locating system prototype components

Our proposed locating prototype is constituted of:

(1) Referee nodes (Wi-Fi based) based on ESP8266 [18] modules installed at known locations.
(2) A sink node (Wi-Fi) based on ESP8266 module connected to the computer with an USB cable.
(3) Computer in which we store the radio-map and, location database and the working plan.

3.2 The proposed locating prototype functions and features

Our proposed system constituted of features illustrated in the previous section using the basic concept of real-time monitoring with Wi-Fi hardware for tracking people (Fig 7). We initially suppose that the working plan including list of tasks, teams and hospital status data are stored in the database. The list of teams and tasks allow the real-time management of interventions of healthcare workers.

In case one of doctors or nurses is needed, they will receive a notification when LEDs of their respective tags start blinking.

- Red blinking LED means that doctor/nurse must be in emergency department.
- Green blinking LED means that doctor/nurse enters an unexpected location.

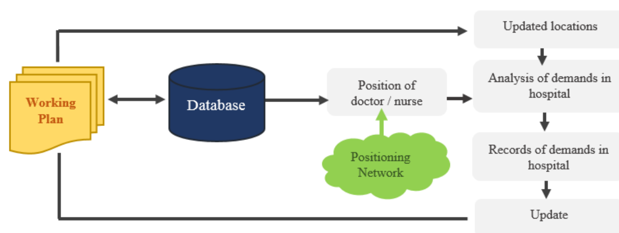


Fig 7. Locating system prototype working schematic

Our system records all positions of doctors and nurses in the hospital. This collected data is continuously used at the computer level to analyze the progress of the work and manage interventions in presence or absence of emergency cases. Our system adapts to the hospital needs, learns from previous experience and automatically creates new working plans based on the hospital current situation. Our system prototype can also be used in presence of interferences in the environment.

This system allows the main following functions:

(1) Doctors/ Nurses positioning: By using the collected signal proprieties, we determine positions and continuously store them at the computer level. Even when demand is too heavy, our system provides a quick response to the request.
(2)
(3) Information service: in critical situations (emergency…), the doctor or the nurse will be notified by a blinking red. it means that the needed medical professional is informed to go to the emergency department and issue the alarm by pressing tag button. When doctor/ nurse enters a

non-planned area, the system triggers a warning by a green led blinking.

3.3 Experiment

Fig 8. shows the installation of the system prototype when implementing RSS algorithm. There are three reference nodes (ESP8266 modules), a sink node, a target tag and a computer. After the set-up of the monitoring system, we start the experiment by collecting radio-signals (Fig 9.) and construct a radio-map in the offline phase.

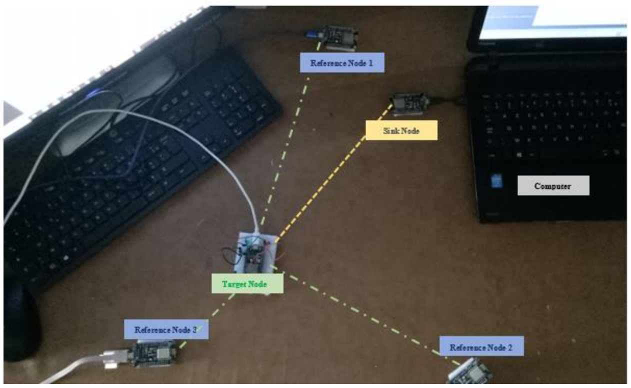


Fig 8 Installation of the system prototype

To reduce the RSS signal fluctuations at each collection, we calculate the mean value of series of 10 RSS measurements and calculate the distance at the reference nodes level. We then start real-time positioning in online phase.

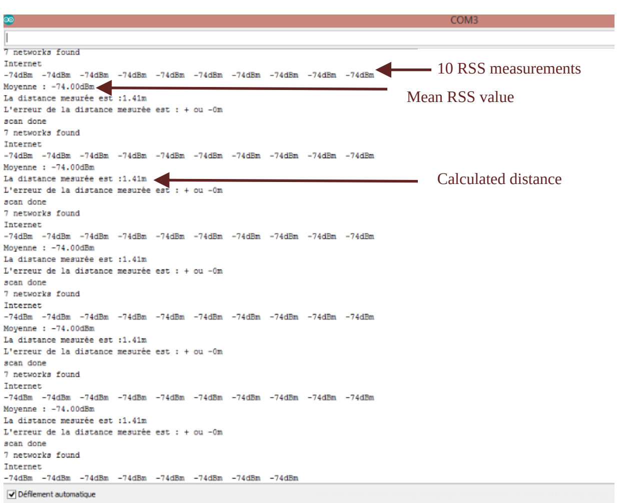
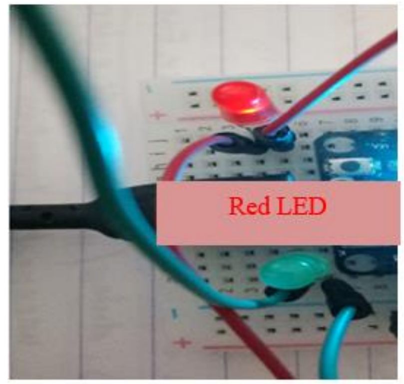
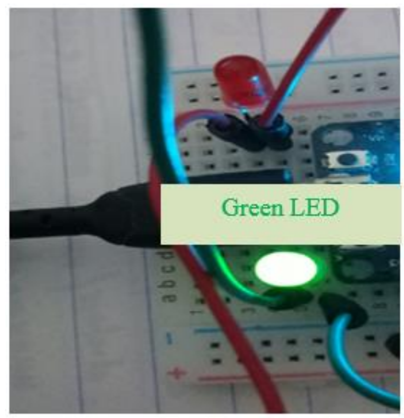


Fig. 9 Collection of positioning data in the offline phase*

Experiment test consists of checking if doctors and nurses are in their expected locations stored in the work plan at the computer level. In case of emergency, doctors and nurses receive emergency alerts as showed in Fig 10.



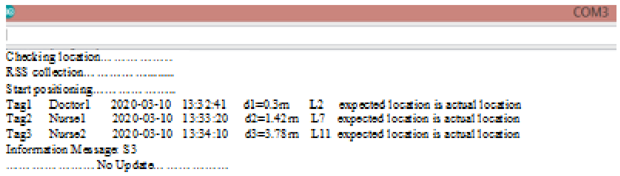
(a)



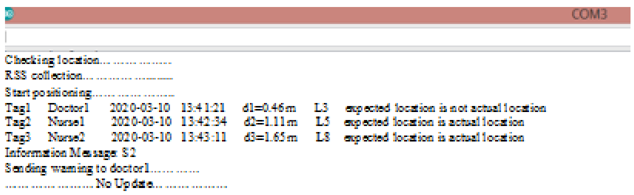
(b)

Fig 10. (a) Alert 1: doctors / nurses must be in emergency department
(b) Alert 2: doctors/ nurses are in an unexpected location

Fig 11. shows the locations of the doctor and nurses determined with the process of positioning of their tags at the computer level. Positioning data are then used for the analysis and self-reconfiguration of the system. Fig 11. (a) illustrates that the doctor and nurses are at their expected locations. Information message S3 shows that the hospital functions normally, and no update of the working plan is needed. Contrarily, Fig 11. (b) illustrates that the doctor and nurses are not in their expected locations, information message is changed to S2, a warning is then sent to doctor 1, and no update of the working plan is needed.



(a)



(b)

Fig 11 (a) positioning process with doctor/nurses at this expected locations (b) positioning process when doctor/nurses are not at their expected locations

In case of emergency (Fig 12.), information message is set up to S1. The system immediately automatically updates the working plan and sends an alert to the needed healthcare worker.

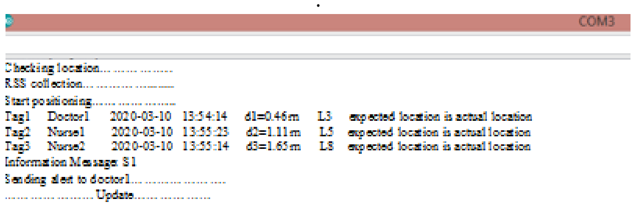


Fig 12 positioning process in emergency case

Based on tests on our system, the real-time monitoring system of healthcare workers permits to determine a location with a relative accuracy. It also proves that the RSS based locating method implemented by Wi-Fi devices (ESP8266 modules) is accurate enough and adapted to our application. The objective of this study, for healthcare environment such as hospitals, does not require a precise locating it estimates whether doctors/nurses are present in the expected locations. In another word, accurate locating is unneeded in our case. Therefore, we used Wi-Fi based technology as an approach because devices are available everywhere nowadays, reference nodes are small, target tags can easily be replaced by smart phones and finally the constructed sensor network is self-reconfigurable if the network is expanded with adding routers. Thus, our system prototype is flexible to any eventual changes and updates of the working plan.

4. Conclusion

While the existing limitations of the deployment of healthcare solution in hospital due to requirements of the healthcare applications and technological reality, a well-adapted smart hospital application can better support the medical or the clinical process during and post covid19 pandemic. Thus, a real-time healthcare monitoring system can be an efficient solution for the wellbeing of both patients and healthcare workers.

We propose a prototype of a system that aims to simplify access to resources (position map in the hospital, working plan) and guarantee extendibility and flexibility. For this purpose, our prototype primarily focuses on the ease of interoperating present database in hospitals and our system. A very simple square grid that represents the hospital environment was divided into twelve cells as a test bed of our network and positioning algorithm. Experimental test using ESP8266 modules carried on our prototype showed the reliability of RSS-based locating algorithm using fingerprinting, it achieves a real time, online and smart positioning, also includes many functions such as the ability to map positions in the hospital and automatically update the working plan of doctors and nurses by adapting it to the hospital needs. Finally, a scaled-up implementation of this =system with the addition of routers could be effective in a large hospital environment.

References

[1] SATYANARAYANAN, Mahadev. Pervasive computing: Vision and challenges. IEEE Personal communications, 2001, vol. 8, no 4, p. 10-17.

[2] BORRIELLO, Gaetano, STANFORD, Vince, NARAYANASWAMI, Chandra, et al. Guest editors' introduction: pervasive computing in healthcare. IEEE Pervasive Computing, 2007, vol. 6, no 1, p. 17-19.

[3] Cascella, M., Rajnik, M., Cuomo, A., Dulebohn, S. C., & Di Napoli, R. (2020). Features, evaluation and treatment coronavirus (COVID-19). In Statpearls [internet]. StatPearls Publishing

[4] FAVELA, Jesus, TENTORI, Monica, CASTRO, Luis A., et al.Activity recognition for context-aware hospital applications: issues and opportunities for the deployment of pervasive networks. Mobile Networks and Applications, 2007, vol. 12, no 2-3, p. 155-171.

[5] MHAMDI, Jamal et EL ABKARI, Safae. Contriving an RFID system for Alzheimer patients tracking. In : 2015 Third International Workshop on RFID And Adaptive Wireless Sensor Networks (RAWSN). IEEE, 2015. p. 23-28.

[6] GUINARD, Patrik Fuhrer Dominique. Building a smart hospital using RFID technologies. In : European Conference on eHealth 2006. Gesellschaft für Informatik eV, 2006.

[7] A.Carbonari, A. Giretti, and B. Naticchia, “A proactive system for real-time safety management in construction sites,”Automation in Construction, vol. 20, no. 6, pp. 686–698, 2011.

[8] SKOV, Mikael B. et HØEGH, Rune Th. Supporting information access in a hospital ward by a context-aware mobile electronic patient record. Personal and Ubiquitous Computing, 2006, vol. 10, no 4, p. 205-214.
[9] CASIMIRO, António, KAISER, Jörg, et VERISSIMO, Paulo. An architectural framework and a middleware for cooperating smart components. In : Proceedings of the 1st conference on Computing frontiers. 2004. p. 28-39.
[10] CORONATO, Antonio et ESPOSITO, Massimo. Towards an implementation of smart hospital: A localization system for mobile users and devices. In : 2008 Sixth Annual IEEE International Conference on Pervasive Computing and Communications (PerCom). IEEE, 2008. p. 715-719.
[11] S. El Abkari, A. Jilbab and J. El Mhamdi, "Real time positioning over WSN and RFID network integration," 2018 4th International Conference on Advanced Technologies for Signal and Image Processing (ATSIP), Sousse, 2018, pp. 1-5.
[12] GISLASON, Drew. Zigbee wireless networking. Newnes, 2008.
[13] J. Biswas and M. Veloso, "WiFi localization and navigation for autonomous indoor mobile robots," 2010 IEEE International Conference on Robotics and Automation, Anchorage, AK, 2010, pp. 4379-4384.
[14] THOMAS, Federico et ROS, Lluís. Revisiting trilateration for robot localization. IEEE Transactions on robotics, 2005, vol. 21, no 1, p. 93-101.
[15] YANG, Zheng, WU, Chenshu, et LIU, Yunhao. Locating in fingerprint space: wireless indoor localization with little human intervention. In : Proceedings of the 18th annual international conference on Mobile computing and networking. 2012. p. 269-280.
[16] GE, Xingbin et QU, Zhiyi. Optimization WIFI indoor positioning KNN algorithm location-based fingerprint. In : 2016 7th IEEE International Conference on Software Engineering and Service Science (ICSESS). IEEE, 2016. p. 135-137.
[17] DEW, Greg et HOLMLUND, Ken. Investigations of cross-correlation and euclidian distance target matching techniques in the mpef environment. In : 5th International Winds Workshop. Lorne, Australia. 2000.
[18] SAFAE, EL ABKARI et JAMAL, EL MHAMDI. Multiple Tags Positioning Algorithm using ESP8266 NODEMCU System. International Journal of Engineering Research and Advanced Technology-IJERAT (ISSN: 2454-6135), 2019, vol. 5, no 8, p. 33-39.