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The Promise of the Internet of Things in Healthcare: How Hard Is It to Keep?

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Abstract. Internet of Things is starting to be implemented in healthcare. An example is the automated monitoring systems that are currently being used to provide healthcare workers with feedback regarding their hand hygiene compliance. These solutions seem effective in promoting healthcare workers self-awareness and action regarding their hand hygiene performance, which is still far from desired. Underlying these systems, an indoor positioning component (following Internet of Things paradigm) is used to collect data from the ward regarding healthcare workers' position, which will be later used to make some assumptions about the usage of alcohol-based handrub dispensers and sinks. We found that building such a system under the scope of the healthcare field is not a trivial task and it must be subject to several considerations, which are presented, analyzed and discussed in this paper. The limitations of present Internet of Things technologies are not yet ready to address the demanding field of healthcare.

Keywords. Internet of things, hand hygiene compliance, automated monitoring system, indoor location, indoor positioning system

1. Introduction

Internet of Things (IoT) is a novel paradigm where several "things" [1] that consist on embedded systems (which, in turn, are the building blocks of IoT) are connected to the Internet [2]. Several projects following of IoT have been implemented in healthcare. It can enable proper management of operational issues like hand hygiene (HH).

Performing HH regularly and at specific times is an important measure that can save lives, but its adherence is still suboptimal among healthcare workers (HCWs) [3]. It is crucial to monitor HCWs' compliance with existing guidelines and provide them with feedback regarding their performance. An innovative, less costly and less time-consuming way of doing this (compared to the standard direct observation) is the usage of automated monitoring systems (AMS), which can electronically identify when an HCW uses a sink or an alcohol-based handrub (ABHR) dispenser. It provides exact quantitative results, which can be used to examine trends regarding the value of HH compliance over time [4].

An important component of AMSs is the indoor positioning system (IPS), which determines the current location of a target in an indoor space, following the IoT

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paradigm. There is no standard technology for indoor location (as we have GPS for outdoor location) [5] because this environment poses much more challenges, like its size limitation (thus, accuracy requirements are different) and signal attenuation due to buildings' construction materials [6]. Several technologies, methods and techniques are available, and they must be chosen depending on the system's requirements.

Aiming at providing HCWs with feedback, there was a need to develop and integrate with our solution an AMS to collect data from the ward in real time. So far, we went through two iterations of our work and developed two AMS using different approaches. From there, we were able to take some important conclusions regarding the design and development of IPSs to be used in the healthcare field.

We start this paper by defining the methods used to conduct the research, followed by the collected results and their discussion. We end with some conclusions.

2. Methods

A design science research methodology was adopted because of its iterative process, which allowed us to incrementally design, develop, test and evaluate a solution that is align with the organization and our end users' needs [7].

The goal was to build an IoT system that, without interfering with HCWs' regular practices, would automatic and continuously record real-time data regarding HH opportunities and actions. To achieve this, HCWs' proximity to strategic locations (beds, ABHR dispensers, sinks, etc.) is first collected using an IPS and this data is then analyzed with an algorithm that implements the business rules that state when HH compliance occurs (for example: "If the HCW gets close to the patient's bed, he/she shall perform HH"). These rules were structured in a model that represents different HH opportunities that may arise and how they are complied or not, following WHO's "My five moments for hand hygiene" framework. As an example, consider the case when a HCW enters a room more than 30 seconds after leaving another room. If he/she goes to an ABHR dispenser or a sink, the system registers a complied HH opportunity; otherwise the system registers a non-complied opportunity.

As already mentioned, two iterations were performed, whose design and development will be detailed in the following subsections.

2.1. First iteration

Because it was one of our least expensive alternatives and it promised accurate values, we build an IPS from scratch using Estimote beacons technology [8]. Beacons were to be placed in relevant places: one at entrance, two near each bed, one per ABHR dispenser and one per sink. These equipment use Bluetooth Low Energy technology to send signals, which are detected by an Android application installed on a mobile phone the HCW has to carry on the pocket. Using these signals, the application is able to detect if it is near the beacon or not. For example, if the application detects strong signals from a beacon placed in a sink, then it will know that the HCW is near that sink. This information is continuously processed using the already mentioned algorithm, and every time we detect and validate (or not) an HH moment.

The first step was to conduct some preliminary tests were on a pack of three beacons. An app provided by Estimote was used to calculate beacons' precision in estimating distances using a function called computeAccuracy (included in Estimote

SDK), which estimates a distance between a beacon and the device running the app. We also collected the correspondent Received Signal Strength Indication (RSSI) values received from the beacons, on which the calculated distance is based. For that, we used different scenarios, with several beacons' arrangements and number (Figure 1). After that, we develop a tool to collect, store and present information regarding beacons' RSSI values in the form of graphic, aiming at testing beacons' main functionality: detect proximity. Beacons were placed a few meters apart and, carrying the tablet, we started approaching one at a time to check if we could match our path in the graphic.

Figure 1. One configuration used to measure the estimated distance between Estimote beacons and a tablet

In the end, a simulation was performed to test the full system. Three beacons were placed on a lab (corresponding to the entrance of a ward, a bed and an ABHR dispenser) and the Android application installed on a tablet.

2.2. Second iteration

To the second prototype, we partnered with Sensefinity, a Portuguese startup developing "smart beacons" (Figure 2A) that use both Bluetooth and a proprietary protocol (also operating on the 2.4GHz frequency band) to communicate [9].

As in the first prototype, the system was built using a proximity based technique. Smart tags (Figure 2B) receive information from beacons and send a message to a gateway (communicating the tag ID, the detected beacon ID, the current time and the type of message – approaching or leaving) whenever they are approaching a beacon or walking away from it. In turn, gateways send these messages to the server using GSM technology. Analyzing the messages stored in the server, we are able to detect HCWs' position over time. Again, this information is processed using the already explained algorithm, and beacons were placed at the same positions, with only two variants: only one beacon was placed per bed and a "presence beacon" in a central point of the room (instead of a beacon placed near the entrance). Once a tag is detected approaching a "presence beacon", we assume that the tag is inside that room. Equally, when a tag starts walking away from it, we assume that it is leaving the room.

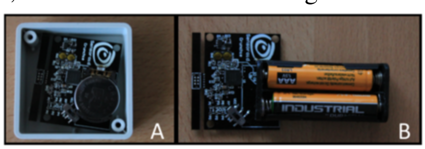

Figure 2. Sensefinity's A) Smart beacon B) Smart tag

26 beacons were deployed in a hospital's ward (composed by three rooms) in all the desired positions During a 4 days study, the IPS was tested, and in the end it was removed for further refinements. Four months later, a total of 12 beacons were deployed on only two rooms of the ward (one two-bed and one four-bed rooms) due to some restrictions Sensefinity had concerning the available equipment. To simulate the IPS usage, a nurse was handed a tag for her to carry during two hours.

3. Results

3.1. First iteration

In all arrangements used to test beacon's precision in estimating distances, either they were not detected inside the promised range or were detected without a suitable accuracy (the most accurate result presented an error of 1,9m). Results of proximity-based test are presented in Figure 3. Each line of different color represents one beacon. Though times are not totally accurate, we can identify in the graphic the sequence of movements performed (first the "green" beacon, then the "purple" one, etc.).

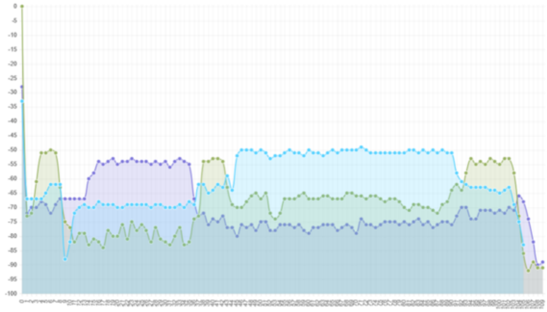

Figure 3. Graphic presenting proximity to Estimote Beacons.

Regarding the simulation, collected data was well processed but there were some problems in detecting the beacons. Sometimes we were placed right near a beacon and it was not being detected by the application, while other times (in the exactly same situation) its presence was detected. Also, the signal was much more unstable than it was right after beacons were purchased and the battery levels fell down very quickly.

3.2. Second iteration

During the first attempt, some hardware problems were spotted and solved, but in the end the system was still not functioning properly: it was sending way more messages than expected. Additionally, we noticed that hospital's GSM coverage is very weak, which could interfere with the correct IPS functioning.

In the second test, the nurse was most of the time in one room (approximately 1 hour and 45 minutes), and after that went to the nurses' room (where the IPS was not installed). Only three location messages were received, being one of them from a beacon placed in a room the nurse never entered. We believe this is due to problems in the hardware (during development phase it was frequently malfunctioning) and/or the bad GSM coverage in the ward. Besides, previous validation tests showed us that the signal was too unstable for us to extract positioning information (that means, we received far more messages that those expected – what was before pointed out as an issue, was now pointed as a technological limitation).

4. Discussion

In order to implement an IoT system to develop an AMS for HH, two innovative technologies were used.

Tests performed on Estimote beacons showed that the estimated distance values are unfeasible for our work, since they are not accurate at all. However, using a proximity-based technique it is possible, at least, to describe one's movements. But during the simulation it was observed that beacons did not present a stable behavior. Because their batteries level decreased very fast, their weak performance might be related to this. Despite the real reason, it is a fact that the numbers promised by Estimote regarding beacons' range and accuracy are far away from reality.

Concerning Sensefinity's solution, it either did not work at all (which could be due to the weak GSM coverage at the hospital) or did not work well, sending way more messages than expected, without any visible pattern that could be used to filter them.

Despite the promise of the vendors, the fact is that both systems are not reliable enough to cope with the healthcare settings demands.

5. Conclusions

IoT technologies have strongly evolved during the last few years and have been successfully applied in areas like retail. However, the main conclusion to retain from this work is that such technologies' precision is still far from desired for it to be applied in the healthcare field, where the areas of interest are much smaller (down to centimeters). The healthcare safety working processes demands more accuracy.

There is a need to test and improve indoor technologies. A new iteration is being prepared, with a partner startup that offers a location system using Ultrawide Band technology (which promises more precise values) combined with a trilateration technique to track HCWs inside the ward, but so far the results are not so good.

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