Monitoring System for Patients with Cognitive Impairment Using Mobile Devices

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Abstract — **The identification, monitoring, tracking and locating of patients with cognitive impairment in healthcare institutions has always been a serious problem for these institutions. Most solutions adopted until today rely mainly on human resources and on very simple manual techniques, like, e.g., putting stickers on the patients' clothes. This paper addresses this problem describing a software solution based on the use of mobile devices, as smartphones, smartwatches, and identification tags all linked to an information system. This work was done in close collaboration with a national public rehabilitation hospital center to really understand the underlying problems, to identify the main requirements and challenges, and to help in the testing and validation process. The final prototype demonstrated the viability of the solution and that it could be deployed in a real set-up without significant effort.**

Keywords – technology-enabled health; monitoring; locating, mobile devices.

I. Introduction

In most healthcare institutions, the treatment of patients with cognitive impairment resulting from a stroke [1], traumatic brain injury (TBI) [2], mild traumatic brain injury (MTBI) [3], or any other kind of injury, allows them to move around freely: going to the cafeteria, walking in the garden, etc. Institutions, frequently post a sticker to the patients' clothing in order to identify them and quickly and easily provide some medical information, in case of necessity. For example, if the patients' want to buy something at the cafeteria, the employee can quickly see if they are diabetic and do not allow them to buy something with sugar. If the patients have some problem, when strolling in the garden, any staff member can help them quickly and more efficiently, looking for the information posted in the sticker. However, because of the sticker's size as well as its static and visible nature, the information to be posted must be very limited, as so its usefulness, and poses privacy issues since information can be seen by everyone. Another problem with this kind of patients, is their lack of sense of orientation and often they lose themselves in the institution domains and sometimes they even cross out its limits. In this case, the institution put its own security policies into action, but without any kind of system that can automatically locate the patients. This said, it would be very useful for the institution to have a minimally intrusive system connected to patients, that could quickly, easily, and maintaining privacy, show all kind of information about them in a ubiquitous way, as so as their location, mainly when they go out the facilities.

This paper presents a prototype software system, designed, developed and tested in cooperation with a well-known national rehabilitation hospital center, to assist the monitoring of their cognitive impaired patients, in a way as described above, with the additional requirement of being a low cost system, as long as the institution has scarce resources to spend in this type of equipment. It is organized as follows: section 2 is concerned with existing monitoring systems and technologies to develop them; section 3 describes the problems to solve, the requirements to comply with and a proposed solution; section 4 describes the development of the proposed solution; section 5 mention the tests carried out and the results achieved in testing scenarios in the hospital; and section 6 draws conclusions and presents ideas for future work.

II. State of the Art of Systems and Technologies

A. Identification Tag Systems

Identification tag systems allow to identify and track objects with tags attached. These tags can contain a variable amount of stored information. The simplest ones contain only an ID or a URI to identify the object in an information system or to connect the reader device directly to an information provider.

A mobile tag is an identification tag system and a way to provide data reading for displaying on mobile devices. They are usually encoded in two-dimensional barcodes and can be read by using the camera of a mobile phone as the reader device. The contents of the tag code is usually a URL for information resources accessible in the Web.

A good example of a mobile tag is the QR Code – Quick Response Code [4]. A QR code appears as a set of black squares organized in a square grid with white background. It can be scanned with a camera, and uses an error correction algorithm for processing and interpretation. The information is extracted from patterns that are present in both horizontal and vertical components of the image.

Another kind of mobile tags is RFID – Radio-Frequency Identification. RFID refers to a technology whereby digital data encoded in smart labels (RFID tags) is captured by a reader via radio waves. It's similar to QR Code in that data from a label is

captured by a device that accesses then the information in a database. The main advantage of using RFID tags is that they can be read outside the line-of-sight and the process is faster, in opposition to QR Codes that must be aligned with an optical scanner.

B. *Location Systems*

Real-Time Location Systems (RTLS) are local systems, based on radio frequency, for the identification and tracking of indoor location of assets and persons in real-time [5], usually in a facility or limited area. They do not allow for broad locating in open spaces, as GPS – Global Positioning System, for example.

This technology can be used to locate healthcare staff, patients and assets in large facilities [6]. It can be used to quickly locate staff members when patients summons assistance; to track the physical movement of patients to help ensure their safety; and to manage assets in a more effective way, avoiding the loss of expensive equipment and optimizing its use. Figure 1 illustrates the appliance of this technology.

Figure 1. Use of RTLS in a healtcare facility [7].

Borda Technology is a solution and product development company specializing in RFID Real Time Tracking and Security Systems to be used in healthcare indoor facilities that uses the RTLS approach [8].

Figure 2. Solutions for Healthcare by Borda Technology Company [8].

Their solutions are based in two different technologies, as illustrated in figure 2:

- Active RFID, to track all kind of actors in an hospital environment – personnel, patients, visitors, and mobile assets – with high accurate, room level resolution;
- Passive RFID, a battery free technology, to track non-mobile assets or assets that have less location-critical roles and therefore require less location resolution accuracy.

ActiveWave [9] is another company that uses RFID as the main technology to develop solutions and applications for tracking to be used in several different scenarios: Inventory Control, Parking Lot Access Control, Fleet Control, Hospital Resource Tracking, etc. In a Hospital scenario, their technology can be used to track patients, doctors and equipment in real time. RFID tags can be attached to the ID bracelets of all patients, or just patients requiring special attention, so their location can be tracked continuously. It can also provide an electronic link for wirelessly communicating patient data.

III. PROBLEMS, RQUIREMENTS AND SOLUTIONS

The research work started by having a first meeting in the hospital with the doctors to realize how the institution deals with the patients, the patients' limitations, and the must do tasks of staff members when they interact with the patients. This meeting was crucial to well understand what precisely the problems were, what the conditional requirements were and what solution could be proposed.

A. *The Problems*

Generally, these patients have a great freedom of action, circulating in and out of the buildings and using the available services, such as the cafeteria, for example. Currently, they have a sticker on clothing holding their identification, the unit to which they belong and the doctor in charge.

One problem relates to the information in the sticker. Even if it is useful, often it is insufficient, especially at times when it would be necessary to know more, such as: what are the patient's main health problems; substances to which they have allergy, if it's the case; what the recommended diet is; etc. This in order to be conveniently served with either going to the cafeteria or being rescued somewhere outside the ward.

Another problem relates to tracking the location of these patients. Inside the buildings it is not a problem, as they can be easily located. However, outside the buildings, it can easily become a serious problem, as the campus of the institution has several thousand square meters, without fences, and it already happened that some patients crossed its limits and lost themselves in the woods nearby.

B. *High Level Requirements*

To address the problems mentioned above, the first requirement putted by the hospital was the need to implement a solution that can comply with their low budget. Being a public institution it is a serious constraint, as it isn't easy to get money to spend in what is not considered absolute needed equipment.

Secondly, the solution must be the least intrusive possible from the point of view of the patients, staff members, and facilities. It must be easy for the patients to carry what kind of equipment is needed. Better, something that they even don't notice it. For the staff, it must be something that don't interfere with their daily tasks. And, from the facilities perspective, it

must not require any intervention on the building and/or spaces, inside and outside.

C. *The Proposed Solution*

The solutions, by ActiveWave and Borda Technology, are very expensive as they imply the installation throughout the hospital and its divisions of a vast set of equipment for the detection and reception of signals to locate people and assets holding the RFID devices. Also, they are good for indoor scenarios, but the main concern of the hospital is with the problems the patients can raise when they go outside the buildings. So these solutions aren't adequate approaches as they do not comply with any of the high level requirements placed by the hospital.

To address the first problem – the lack of information on the stickers – it was proposed that the patients could use a non-intrusive, very lightweight, silicone bracelet holding a sticker with a QR code or/and a passive RFID tag that could be read by any current smartphone and therefore linking the patient to a medical information system, in a loosely coupled way. This would allow a doctor, a nurse or any other staff member to identify the patients and have access to their information, according with a user profile.

Figure 3 shows an example of RFID silicone bracelets that can be used by smartphones capable to read RFID and allow to glue on it a QR code to be used also by smartphones without RFID reading capability.

Figure 3. A RFID silicone bracelet.

To address the second problem – the need for tracking and locating the patients outside the buildings – it was proposed the use, by the patients, of smartwatches, holding a GPS receiver and mobile internet data plan, in order for an information system to track in real-time their location. In this case, the smartphone itself can also display a QR code or hold NFC technology to address the first problem. This kind of device is also a very lightly intrusive solution.

IV. Solution Development

To be able to use the devices proposed before and develop the solution, an architecture using a set of free open source technologies and systems was designed, as shown in figure 4.

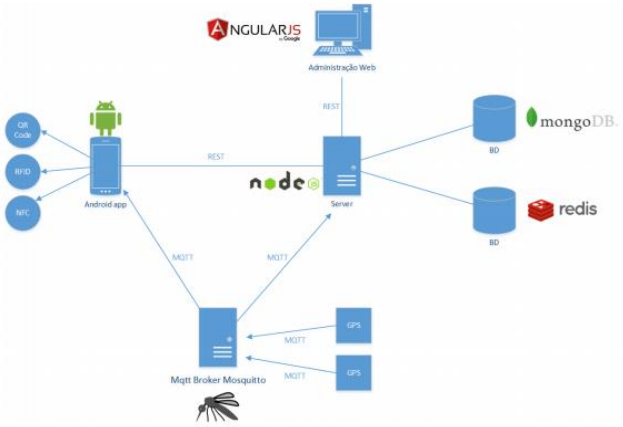

Figure 4. Architecture.

This architecture allows to implement three main components: the Manager Web Application; the Monitoring Mobile Application; and the GPS Transmitter Mobile Application.

A. *Manager Web Application*

This application is responsible by all the system management. It allows to: create users; add and see patients' information; generate QR codes for the patients; see the location of patients (figure 5); define geographical areas where the patients can walk and alerts for trespassing them (figure 6); and see the path taken by the patients when they walk outside the buildings (figure 7).

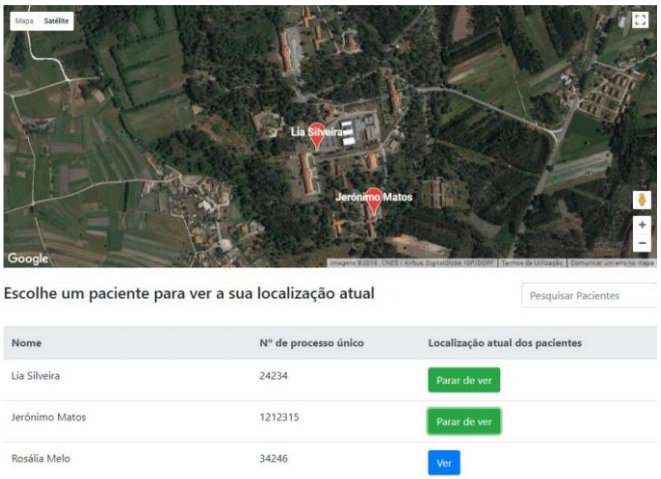

Figure 5. Manager Web App showing patients location.

Figure 6. Manager Web App defining walk areas and alerts.

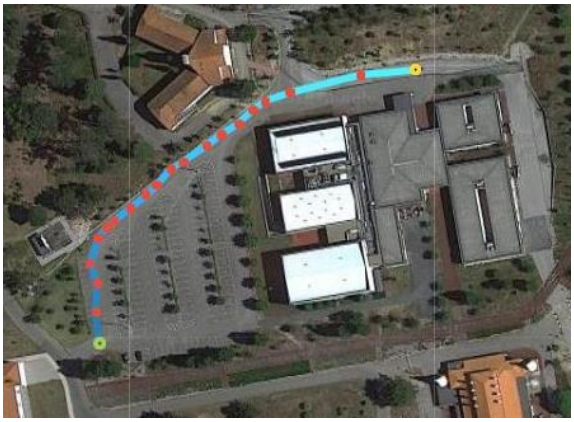

Figure 7. Manager Web App showing the path taken by a patient.

The patient's information that can be stored and viewed in this system is: name; birthday; patient number process; inpatient unit; doctor in charge; contacts from family members or caregivers; risk factors; and medication. This is a subset of all the patient's information, stored in the healthcare national database and until now the hospital finds it enough for this purpose. Figure 5 shows a web page from Manager where all this information can be viewed and edited.

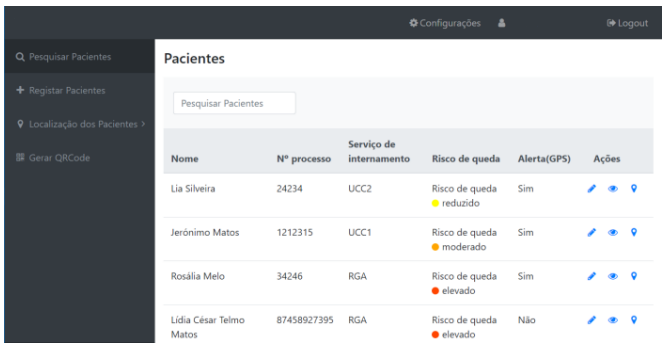

Figure 8. The Manager Web Application showing patient's information.

B. *Monitoring Mobile Application*

The Monitoring Mobile Application is an Android application and allows to show the patient's information, after reading the RFID device or QR code on the patient's bracelet. Besides the text information, it allows also to see the current patient's location and receive alerts if a patient crosses the area limits defined for him to walk outdoors. The application accesses all these information connecting to a REST API server and passing to it the patient's id found in the bracelet's RFID tag.

Figure 9 shows the Monitoring Mobile Application displaying a patient's risk factors. It is possible to see in it, that the patient is allergic to shrimp, is hypertensive, suffers from dysphagia, has high risk of falling, etc.

The monitoring mobile application allows also to: search by all users and see their information; edit information to allow the updating of variable data; assign RFID bracelets to patients, by writing the RFID tag.

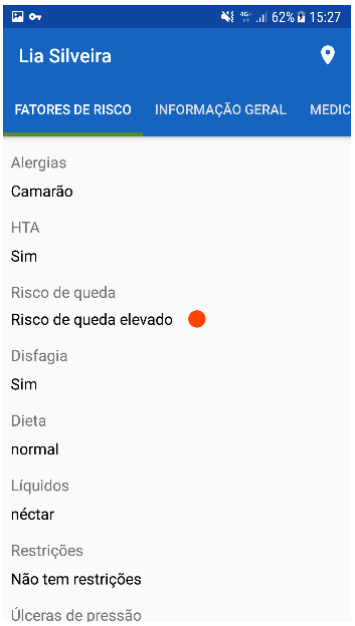

Figure 9. Monitoring Mobile Application showing risk factors.

C. *GPS Transmitter Mobile Application*

The GPS Transmitter Mobile Application was developed specifically to run on Android smartwatches and to send the GPS coordinates of the patients' location when they are outdoors to a specific server where all the coordinates are saved, allowing to reconstruct the path covered by the patient. Figure 10 shows the interface of this application.

Figure 10. The GPS Transmitter Mobile Application.

After some tests with the equipment and the installed application, it was decided to configure the application to send the location GPS coordinates at intervals of 30 seconds or when the displacement is of 10 meters. These factors and numbers were considered a good compromise to avoid high battery consumption and very high expenses with the use of mobile data.

After some reflection about how this application, running on a smartwatch, could turn itself even more useful, it was thought that this application could, in some way, incorporate some of the features present in the Monitoring Mobile Application, and for lighter situations, it could be used to access some patient's information more quickly. Figure 11 shows the interface of this more enabled application.

Figure 11. The enhanced GPS Transmitter Mobile Application.

V. Tests and Results

At the end of the solution's development it was arranged with the hospital to make some validation tests on site, using all the equipment and software needed and with the collaboration of voluntary staff people. The tests didn't include real patients, in this phase, because it's a sensitive matter and for a first testing iteration they can be easily replaced by other people.

The tests conducted using the Manager Web Application and the Monitoring Mobile Application revealed that they are of easy use by all staff members, they allow to manage and see all needed information about the patients and as so, the current scenario of using stickers on the patients' clothes could very well be replaced by the RFID/QR codes bracelets and to start using all the proposed technology.

The tests conducted using the GPS Transmitter Mobile Application with staff people simulating patients walking around the hospital campus demonstrated the effectiveness of this application, sending location information and allowing the Manager Web Application and the Monitoring Mobile Application, in a very effective way, to verify the patient's location, their walking route, and to receive alerts when they trespasses the area limits defined for them.

VI. Conclusion

This paper describes the development of a System to address the problem of monitoring and tracking patients with cognitive impairment in a healthcare institution. This was done in collaboration with a team of experts of a known national rehabilitation hospital center. The software system consists in an ecosystem of several applications and devices, each one responsible by a specific task but all communicating together to monitor several aspects of patients (e.g. medical information, diet restriction, location). The applications developed are a manager web application, running on a server, a monitoring mobile application, running in a smartphone, and a GPS transmitter mobile application, running in a smartwatch. The system relies on passive technologies to identify the patients, namely QR Codes and/or RFID tags located on silicone bracelets.

A test was performed at the healthcare institution demonstrating the viability of the system and that it could be deployed in a real set-up without significant effort.

As future work, it would be interesting to verify if it could be possible to completely substitute the QR Codes and RFID technologies by smartwatches running a mobile application with all integrated features from the GPS transmitter application to the monitoring application. If viable, it would have the advantage of being a less expensive system and speeding up the monitoring task by the staff members.

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