CAMACUA: Low Cost Real Time Risk Alert and Location System for Healthcare Environments

I. Decia[1], A. Farías[1], D. Szerman[2], L. Grundel[1], D. Briatore[2], M. Piñeyrúa[2], A.Villar[2] and F. Simini[1]

[1] Núcleo de Ingeniería Biomédica, Universidad de la República, Montevideo, URUGUAY
[2] Hospital Maciel, ASSE, Montevideo, URUGUAY

Abstract— **Medication error and other risky situations can lead to serious patient injuries or discomfort. We have designed a real time risk alert and location system to increase patient safety and to reduce medication administration errors. CAMACUA is based on barcode and passive RFID technology for real time location. First field test results show that 100% of patients, visitors and hospital assets are correctly located within hospital rooms or transitions > 1m. When closer than 1m from room entrance, 30% of objects need additional data to determine their location.**

Keywords— **Medication error, Patient safety, Radio frequency identification, Real time location system.**

I. Introduction

Medication error refers, as stated by the National Coordinating Council for Medication Error Reporting and Prevention, to "any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer. Such events may be related to professional practice, health care products, procedures, and systems, including prescribing, order communication, product labeling, packaging, and nomenclature, compounding, dispensing, distribution, administration, education, monitoring, and use" [1].

When administering medication to a patient, the following aspects must be considered:

- The medication must belong to the patient.
- The medication, dose and route must be that of the prescription.
- The dose must be administered in due time.

A study conducted in 2008 in US hospitals concluded that 34% of the medication error occurred at the administration phase, and only 2% are intercepted (near misses). An additional 10% occurs while the prescription is transcribed and medication dispensed [2]. Some of the errors could be life-threatening [3]. These reports [2], [3] conclude that bar-code technology can help mitigate the risk of medication error. Despite the efforts to prevent medication errors, they are still reported in 2016 [4].

Other risk situations are related to patients and visitors wandering within hospital corridors or non-authorized zones. In some occasions wrong patients can even be operated on [5].

The goals of CAMACUA were defined as (1) to reduce medication error, (2) to notify when someone is in an unauthorized zone and (3) the system should be flexible enough to define new risk situations.

II. Real time location systems in healthcare environments

State-of-the-art real time location systems (RTLS) were tested by Clarke in a seminal publication [6] where the most relevant basic functions of such systems are identified, along with their error rate.

Wi-Fi: Based on a proprietary protocol over 802.11b/g [7], the system consists, at the physical level, of wearable devices called tags, and Wi-Fi access points (AP). Each tag periodically sends a “probe request” to the APs, which send in turn the received signal strength indication (RSSI) and tag identification to a central server (CS). Based on the gathered information, the CS computes each (x,y) tag coordinates. The most remarkable functionalities are: real time assets location in 2D coordinates, location history logging and alerts on location and state of tags [8].

Ultrasound: The hardware layer consists of ultrasound (US) mobile emitter tags and fixed receivers. Each tag sends a pulse containing its identification. The receiver demodulates each US pulse, extracting the tag identifier. Since US cannot go through walls [9], it is fair to assume that the identifier corresponds to a tag in the same zone as the receiver. The main functionalities are: real time assets location at zone level, alerts about tags locations, patient fall detection, hands hygiene compliance control [10].

Radio frequency and infrared: It relies on a proprietary protocol based on radio frequency (RF) and infrared (IR). Among the vendor declared functionalities, the most relevant are: real time assets location at zone level, alerts on tags locations, hands hygiene compliance control [11].

Ultra wide band: This system provides only real time location functionality. It consists of emitter tags and fixed receivers, communicating with each other in the ultra wide band (UWB) radio frequency spectrum (6 – 7 GHz). It can locate a tag with 15 cm accuracy [12].

Active radio frequency identification: Consists of self-powered radio frequency identification (RFID) tags emitting signals periodically to readers. They differ from passive RFID systems, where tags are remotely powered. The system main functionalities are: real time assets location at zone level; search assets by location and alerts if some asset exits an assigned zone [13].

Coordinate level active RFID location: This system is also based on active RFID technology, but the vendor claims it can locate an asset with (x,y) coordinate accuracy. The most remarkable functionalities are: real time assets location; medication near miss or error alerts; notify medical personnel if a patient enters an operating room (OR) and automatic bed management [14].

Table 1 shows some of the results by Clarke [6]. The "n/a" stands for "no test could be made", either due to system limitations or because it was not deployed in all the rooms. The experimental scenario consisted of two ORs separated by scrub, wet storage and autoclave areas. Each system was separately implemented, several tags placed in different locations and situations (i.e. covered by other object, over an instrumental tray, etc.) and the reported locations where compared with the real ones. Further description of the experiment can be found in [6].

Table 1 Error rates for commercial RTLSs

System	Error rates per zone (%)			
	OR1	Wet storage	Scrub	OR2
Wi-Fi	24.7	0.0	22.2	6.7
Ultrasound	2.9	62.9	78.5	70.1
RF + IR	1.3	100.0	100.0	2.5
UWB	n/a	n/a	n/a	14.9
Active RFID (zone)	5.7	95.0	85.1	41.4
Active RFID (x,y)	1.3	42.4	64.1	12.0

Table extracted from Clarke [6]

III. System specification

In order to detect risk situations, our design -which we called CAMACUA- must identify and track hospital entities (staff, patients, visitors, unit-doses, medicines and physical objects). For this, our system combines barcode and RFID technology.

RFID tags and barcodes are attached to entities to be tracked. Upon admission, patients are also provided with an ID barcode wristband. Fixed RFID readers are mounted in room entrances and corridors for receiving signals generated by passing tags. Each employee carries a mobile device, equipped with barcode reader, used to check entities. Visitors are given cards with passive RFID.

If a person or object is identified (by a sensor or employee) in a forbidden zone, the system sends and alert to the security staff, notifying the event. Zones can be rooms, OR, beds or hospital main entrances.

In order to prevent medication administration errors, some mobile function of CAMACUA should request the nurse to scan the patient barcode and unit-dose QR code. The application should check if the unit-dose matches the patient and if it is being administered at the right time. Should a mismatch occur, a warning message is displayed. Detailed information of medicines and patient should also be shown at the bedside, including patient photo, observations and dosages. Leftover medicines are notified to pharmacy in order to prevent waste and unauthorized use.

Patients and objects should also be located using a mobile application, with reports created from the "last seen" zone. CAMACUA should be freely configurable - using a flexible event specification language - to alert in case of entities and locations matches, which include drug mis-administration risks.

IV. System design

A. *Software architecture*

Main system components are (1) the back-end application, (2) mobile application, (3) web client and (4) RFID sensor middleware. The back-end application is the key component, which executes all the event processing logic and notifies when a risk situation has been detected. It is composed of the event engine and the alert system, and provides a lightweight interface, used by client side components. Web client for administrative staff manages such functions as entity registration and zone permission assignment. The mobile application runs on devices carried by medical and security staff. It is used for entity identification and to display notifications according to predefined priorities. Nursing staff use it as an assistant for unit-dose administration to prevent errors. Finally, the

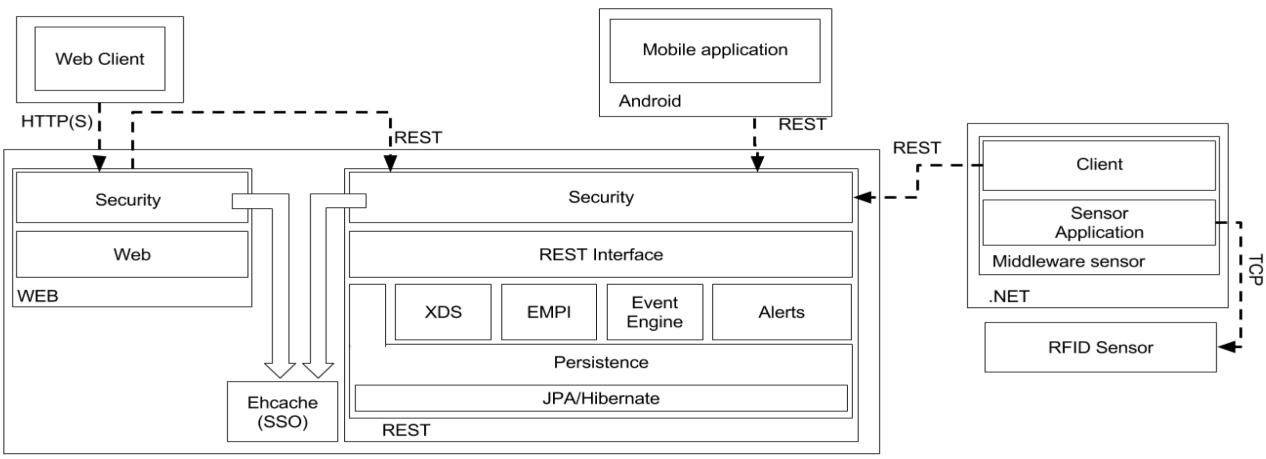

Fig 1: CAMACUA arquitecture. Main components are the back-end application, the mobile application, web client and RFID sensor middleware

sensor middleware is responsible for receiving and filtering raw data from RFID sensors.

B. Hardware components

Hardware components include readers, antennas, tags and barcodes. We selected passive UHF RFID as location technology. As stated by Weis [15], it provides reading ranges up to 10m, doesn't require “line of sight” and it is supported by well known standards (EPC UHF Gen2). Furthermore, passive tags do not need power supply and are available in a variety of materials and shapes. Sensors are connected to circular polarized antennas which send and receive signals from/to tags. Finally, we use barcodes which provide an inexpensive way to identify entities.

C. Event specification

Events are classified as primitive or complex. Primitive events are generated by external actors and constitute the main input data. They can represent, for example, the following situations: a patient, unit-dose or object is identified; a unit-dose is packaged; there are unused medicines or a log-out. All triggered primitive events are persisted in an event log for further analysis and traceability. On the other hand, complex events are combinations of primitive events according to a set of operators applied to both primitive and complex events. In this paper we consider the following basic operators, based on the work of Wang et al. [16]:

a) Logical operators
- *AND* ($E_1 \wedge E_2$): occurs when both E_1 and E_2 occur irrespective of their order.
- *OR* ($E_1 \vee E_2$): occurs when either E_1 or E_2 occurs.
- *NOT* ($\neg E$): occurs if no instance of E occurs.

b) Temporal operators
- *SEQ* (E_1; E_2): if E_2 occurs given that E_1 has occurred.
- *WITHIN (E, t)*: if E occurs within an interval ≤ *t*.

The syntax for defining events and actions is as follows:

ON event ; IF condition ; DO action

where *action* is executed iff *condition* is true when *event* occurs.

Next we show two examples of complex events that are freely defined by the administrator of CAMACUA. Let be *P*, *U* denote the following primitive events:
P: A patient is identified. *P.patientID* is the patient identifier, *P.zoneID* is the zone where the patient was detected and *P.userID* is the user who identified him/her.
U: A unit-dose is identified. *U.unit-doseID* is the unit-dose identifier, *U.patientID* is the patient whom the unit-dose belongs to & *U.userID* is the user who identified it.

(I) Patients in unauthorized zone:
ON *P*
IF is_in_unauthorized_zone(*P.patientID*, *P.zoneID*)
DO notify_security_staff();

(II) Wrong unit-dose-patient correspondence:
ON WITHIN(*P* ; *U* , 2 min)
IF (*P.userID*==*U.userID*) && (*U.patientID*!=*P.patientID*)
DO display_message(“Wrong unit-dose for Patient!”);

By launching these two safety rules the administrator is putting in place an error risk reduction functionality.

V. System evaluation

Several test where conducted to evaluate the system capability to locate a tag within a zone.

Given a certain tag, it is said the system locates it correctly if only a sensor in the same zone as the tag detects it.

Figure 2 shows the RFID sensors placement schematics. One of them was installed in the room above the door (RS), and the other, in the corridor (CR). The tested scenarios are:

1. Person in corridor > 1m from door. Closed door.
2. Same as scenario 1, Open door.
3. Person in corridor < 1m from door. Closed door.
4. Same as scenario 3. Open door.
5. Person in room > 1m from door. Closed door.
6. Same as scenario 5. Open door.
7. Person in room < 1m from door. Closed door.
8. Same as scenario 7. Open door.

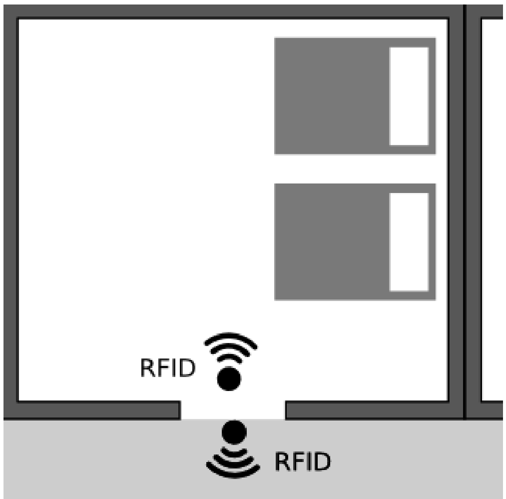

Fig 2: Experimental set up at the entrance door of a two bed Hospital room.

Detection statistics referring to 50 tries for each scenario are summarized in Table 2.

If a person is in the room and he stands more than 1 m from the door, the corridor sensor never detects him, and the room detector always does (scenarios 1, 2, 7 and 8). Closer than 1 m from the door, there is a 10% false negative by the corridor sensor (scenarios 3 and 4) and a 30% false positive by the corridor sensor. In other words the CS puts people in the corridor when they are in the room (30%) and does not see a person in the corridor when he actually is there (10%).

Table 2 CAMACUA Room RFID Tag Detection Error Rate

Scenario	Should detect tag?		Error rate (%)	
	CS	RS	CS	RS
1. corridor >1 m door. CD	Yes	No	0	0
2. corridor >1 m door. OD	Yes	No	0	0
3. corridor < 1 m door. CD	Yes	No	10	0
4. corridor < 1 m door. OD	Yes	No	10	0
5. room > 1 m door. CD	No	Yes	0	0
6. room > 1 m door. OD	No	Yes	0	0
7. room < 1 m door. CD	No	Yes	30	0
8. room < 1 m door. OD	No	Yes	30	0

CS corridor sensor; RS room sensor; CD closed door; OD open door.

On the other hand, regarding medication error mitigation functionality, not enough data were collected to give a quantitative evaluation on system performance yet, although - in testing scenarios - CAMACUA always prevented the user from administering a unit-dose to a wrong patient.

An approximated budget of USD 1500 was enough to buy the necessary equipment to build CAMACUA.

VI. CONCLUSIONS

A system with enough flexibility to define risk situations was built. RFID technology proved to suit the requirements successfully. Barcode as a complementary technology was a good choice, for the system to be built with a reduced budget. Future work includes refinement in the system user interface and evaluation of further field metrics on safety and error reduction impact. Nurses reacted positively to the use of CAMACUA as help to strengthen patient safety by way of assisting in medication administration.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Author: Franco Simini
Institute: Núcleo de Ingeniería Biomédica
Street: Hospital de Clínicas, Av. Italia S/N, 11600
City: Montevideo
Country: URUGUAY
Email: simini@fing.edu.uy