Towards an RTLS-based Hand Hygiene Notification System

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Abstract

Rising infection rates in healthcare is a global issue that causes complications for the patient, extended hospital stay, financial difficulties, and even death. One of the crucial factors that reduce those infections is better hand hygiene. Due to the lack of automated systems that could help monitoring hand hygiene compliance and reporting on collected data, some hospitals use direct observations, surveys, dispensers usage measurements and other such methods to monitor the compliance of care providers. This paper proposes an alternative system that takes advantage of emerging off-the-shelf infrastructures in hospitals, and in particular of Real-Time Location Systems (RTLS) and intelligent hand sanitizer dispensers. Our RTLS-based approach improves upon the current methods by enabling interactions with care providers through notifications when they do not execute expected hand hygiene actions during care processes, even for fine-grained location situations.

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1. Introduction

A healthcare associated infection (HAI) is “an infection that a patient contracts (or acquires) in a setting where healthcare is delivered (e.g., a hospital) or in an institution (e.g., a long-term care facility) or in a home care arrangement. The infection was neither present nor developing at the time the individual was admitted” [12]. Raising...
HAI rates represent a severe issue. Every year in Canada, HAI affect more than 200,000 patients, with more than 8,000 dying as a result [12]. Deaths caused by *C. difficile* infections have tripled since 1997, while the infection rate associated with methicillin-resistant *Staphylococcus aureus* has increased by more than 1,000% between 1995 and 2009. Such trends are observed worldwide by the World Health Organization. In addition, such infections are very costly. For example, the overall annual direct medical costs of HAI to U.S. hospitals were estimated to be between $35 billion and $45 billion in 2007 [13].

Hence, HAI represent a major threat to the sustainability of our healthcare system, from safety and financial perspectives. In order to address this threat, this paper contributes a new prototype system that takes advantage of a commercial Real-Time Location System (RTLS) to monitor healthcare personnel during their activities. The prototype builds upon the commercial system to incorporate real-time notifications when there is lack of compliance with *hand hygiene* (HH) requirements, even in complex scenarios involving rooms with multiple patient beds.

2. Related Work

Although HH regulations exist (in Ontario, healthcare personnel must wash their hands upon entering/leaving rooms, and between patients), many hospitals only audit their staff for compliance [8]. Manual auditing is however susceptible to the “Hawthorne effect”, whereby the subjects improve their behavior when they know they are being observed by an auditor, sometimes with a 300% difference [2]. As manual auditing through direct observation is not reliable, many approaches attempted to improve the compliance of performing HH in healthcare by developing automated monitoring systems. These systems vary in terms of the complexity of their technology and algorithms.

At the Toronto Rehabilitation Institute, Levchenko *et al.* [11] designed personal wearable electronic monitors that can identify HH opportunities and record actions taken by healthcare providers (HCPs). These devices receive signals from dispensers when they are activated. Based on the collected data and its HH algorithm, the system reminds healthcare providers of missed HH opportunities and records their responses to the alerts. The findings showed that HH activity rates have increased by more than 1.5 times compared to the baseline observational study.

Fisher *et al.* [10] developed automated measures of HH compliance among healthcare workers using ultrasound technology. Their system is also monitoring HH actions and notifying healthcare providers of missed HH opportunities. Transmitters are embedded into dispensers to send signals when they are used. These transmitters are used to monitor certain zones, and wireless tags are carried by healthcare providers to receive signals from the transmitters. This system underestimated HH opportunities/compliance by 5.2% in comparison to manual audits.

While most systems are designed to monitor HH compliance, Boudjema *et al.* [5] developed a system that exploits Radio Frequency Identification (RFID) technology to analyze non-compliance behavior that could occur because of bad positioning of dispensers, the inconvenient structure of rooms, or similar causes. This system records movements and paths taken by health providers to reach patients. Each room is instrumented with four floor-level antennas (in a room entrance, below two dispensers, and in a patient’s area) in order to read tags embedded in shoes of health providers. The decision to perform HH actions is taken based on steps that health providers take to reach patients and the level of hydro-alcoholic liquid in dispensers.

An interesting observation about the above systems is that their developers all had to create new hardware solutions. Yet, commercial off-the-shelf systems offer many opportunities for improving HH compliance. Many such systems are RTLS-based [7]. For example, Aeroscout integrated a sensor into automated infrared (IR) sanitizer dispensers and used it side-by-side with its own RTLS technology [1]. The result is a system that can track health providers through beacons and badges (meant to track location in general, e.g., for care flow management [6], and not just for HH compliance), and receive IR activation signals from smart dispensers once they have been activated.

On the other hand, there are systems quite different in terms of structure and features. For example, the BioVigil system provides small sensors meant to be located above the door of a patient’s room [3]. Those sensors send hand-washing reminders (red/yellow light with an audible alert) to health providers wearing portable BioVigil tags when they get closer to the rooms. The tags use chemical sensing technology to decide whether providers respond to the reminders by washing their hands or not [4].

The system we are developing is also tracking healthcare providers and reminding them of washing their hands where required. However, its uniqueness lays in the identification of fine-grained HH opportunities, including moving from a patient to another in the same room. In addition, almost all systems rely on infrared signals sent from
the activated hand sanitizer dispensers. In our system, we propose a novel approach to receive activation messages from dispensers wirelessly to increase the precision of the identification. Our system also handles the case in which more than one healthcare provider are in the same dispenser zone at the same time.

3. RTLS-based Hand Hygiene Monitoring and Notification System (RHMNS) Architecture

Our system is composed of four major subsystems (Fig. 1(a)): a Real-Time Locating System (RTLS), a home-made application server for information correlation, a database management system (MySQL), and a reporting information system (IBM Cognos BI). For the first component, we use the Ekahau RTLS\(^9\) to track healthcare providers and to monitor zones. Each patient’s bed and hand sanitizing area (where a dispenser is located) is monitored by IR beacons. Each HCP is carrying a badge that can read IR signals transmitted by beacons and report on the received data wirelessly to the Ekahau server. The location of HCPs outside beacon areas is monitored via the hospital Wi-Fi network (using triangulation). The application server works mainly as an information correlation engine. It receives events from the RTLS server and sends/retrieves data in real time to/from a database, whose events are stored in tables according to the simplified schemas illustrated in Fig. 1(b), where ZoneName is the last zone visited. Moreover, the application server sends actions back to the RTLS server based on our HH opportunity detection algorithm (which encodes provincial compliance rules). For instance, if a HCP enters or leaves a patient room of a beacon area, an event will be generated by the Ekahau server and will be sent to the application server, which listens to streaming events. Based on a sequence of such events, the application server will decide if the HCP needs to wash or has washed her/his hand. If a HH opportunity was missed, the application server sends an action back to the RTLS server in order to send an audible alert, in real time, to the HCP’s badge in order to remind the nurse or doctor about washing their hands. The application server is written in Java and exploits Ekahau’s Standard Development Kit (SDK). IBM Cognos is connected to the database to generate and visualize compliance reports.

4. Implementation of Two Approaches

The system components discussed in the previous section compose the infrastructure of two different HH management approaches we are investigating. The approaches differ in terms of the factors used to make decisions on HH compliance. However, they share similar features: track, record, remind and report. For both approaches, we place an IR beacon above each bed in a patient room, and also above each alcohol-based hand sanitizer dispenser.

**Time-based approach**: The system tracks HCPs at regular time intervals (every few seconds). It determines that a HCP did not wash his/her hands if an appropriate enter hand sanitizer zone event was not received: i) within 30 seconds of receiving an enter patient room event, ii) before receiving an enter bed zone event, iii) before receiving an exit room event, or iv) if the time spent in the hand sanitizer zone was less than 15 seconds (minimum time for performing HH action using alcohol-based hand rub). In such cases, the system sends a buzzer and audible alert to the HCP badge, as a reminder.

**Activation-based approach**: This approach is logically similar to the time-based approach, but with a significant addition. The core idea is to make dispensers send events wirelessly when they are being activated (instead of waiting, as HCPs seldom stay near a dispenser while washing their hands). An RTLS tag is located in each dispenser zone that sends an event to the application server when activated. The system detects the activation event and performs the same decision process as the time-based approach. If a HH opportunity was missed, the application server sends an action back to the RTLS server in order to send an audible alert, in real time, to the HCP’s badge in order to remind the nurse or doctor about washing their hands.
such that it is pressed once an HCP uses the dispenser, resulting in an activation message being sent to the Ekahau server, and then to the application server. The decision regarding hand washing is hence based on concrete evidence (sanitizer being dispensed) rather than inferred based on a duration (without evidence that sanitizer was dispensed).

There are two different categories of situations covered by this system: the One-HCP case, where there is only one HCP in the hand sanitizer zone, and the Multi-HCP case, where there are many HCPs in the zone. In the One-HCP case, the system recognizes precisely who performed the hand hygiene action. In the Multi-HCP case however, it becomes challenging for the system to determine who used the dispenser and who did not, and to what badge(s) notifications should be sent. In this latter case, the system counts the number of HCPs that are in the hand sanitizer zone at once and the number of times that the dispenser has been activated. If the number of times the dispenser was used is less than the number of HCPs, the system takes a conservative approach and sends notifications to all HCP badges involved. Otherwise, the system assumes that all HCPs performed proper hand hygiene actions.

5. Testing and Validation

We used one patient room at The Ottawa Hospital (TOH) and its corridor to do testing and to demonstrate the system to TOH personnel. There were two beds in the room and one hand sanitizing (HS) area, as shown in Fig. 2. Infrared beacons were located above the two beds and the dispenser in the hand sanitizing area in order to precisely monitor the three zones all the time. Access points we located in different levels and positions, so as to receive data sent from badges wirelessly (the hospital Wi-Fi network could have been used, but we did not want to interfere with their operations). The team members were wearing the badges and performing these hand-washing scenarios:

1- **Worst-case scenario**: the HCP enters the room and stays there for over 30 seconds without going to the hand sanitizing zone, visits the patient in bed 1 and then the patient in bed 2, and exits the room. For each of these four missed HH opportunities, a reminder is sent to the HCP’s badge.

2- **Best-case scenario**: the HCP performs HH actions once he/she enters the room, before moving from one patient to the other, and before leaving the room. In these cases, no reminder is sent to the HCP’s badge.

This first RHMNS prototype was able to track the movements of the participants all around the room and make correct decisions on the collected data in almost all test instances. It is capable of recording missed HH opportunities, taken HH actions, and the response to the reminders for each HCP individually. As anticipated, the activation-based approach proved to be more accurate than the time-based approach. However, the performance of the system was fluctuating sometimes due to noticeable issues:

1- The delay in receiving the current location of badges leads to delays in notifying HCPs of missed hand hygiene opportunities (the latter delay was about 5 to 15 seconds).

2- The beacons were covering areas larger than expected (advertised 3’x3’ area), likely because of reflection in the IR signals. As a result, some zones were overlapping, resulting in a number of and false positives/negatives.
Overall, this prototype shows that the RHMNS ideas work provided that close attention is paid to the beacons’ location and to the performance of the underlying RTLS system. Note that our equipment was two years old during this validation phase, and that a newer generation of Ekahau tags and servers has appeared since then [9].

6. Conclusion and Future Work

Our prototype RHMNS is a system that exploits an off-the-shelf RTLS to automate the process of monitoring the compliance of HCPs in term of performing hand hygiene. It is designed in a way that also supports real-time interactions with HCPs by notifying them of missed hand hygiene opportunities. RHMNS has much in common with existing systems [1,10,31], but it can also handle Multi-HCP situations and fine-grained location scenarios when HCPs move from a patient to another in the same hospital room. Another interesting feature is the sending of wireless activation messages by dispensers. This feature prevents the need for dispensers to communicate with HCP badges using infrared (as in other solutions), hence avoiding issues with the positioning of dispensers in hospital (at the appropriate height) and badges that are flipped on the side where they cannot receive any signal.

In terms of future work, we are planning to expand the monitoring process to cover sink zones and hand sanitizer zones located in corridors. We plan to improve the accuracy and speed up the response time of the RTLS component. We are also working on a third approach that will accommodate a new generation of touch-free dispensers where infrared detection is used to dispense hand sanitizer instead of a button (in order to minimize contamination), which will require the dispenser to send wireless signals without the use of an RTLS tag. In addition, we need to understand whether there are situations where other duties may preempt the need for hand hygiene when entering a room. As for privacy, user tolerance to tracking will need to be studied in pilot studies.

We acknowledge the many limitations of our validation so far. Our future plan is to avoid biases by having even more detailed scenarios (with a good coverage of approaches, number of HCP, paths to be taken, and delay parameters) and repeat them to get statistical significance in precision and recall results. We also want to measure the reliability of the platform under different conditions at The Ottawa Hospital and in our university lab.

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