Poster Abstract: CleanHands: An Integrated Monitoring System for Control of Hospital Acquired Infections

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ABSTRACT

A leading cause of mortality of hospitalized patients are hospital acquired infections (HAI). Unclean hands of healthcare personnel (HCP) are the most common factor contributing to HAI, but their strict compliance to hand hygiene protocols is difficult to supervise. In this work, we propose *CleanHands*: a simple, low-cost and scalable monitoring and alerting system to ensure adequate thoroughness of disinfection. *CleanHands* uses a combination of low-cost Bluetooth low energy (BLE) beacon tags and mobile phones for HCP tracking. It integrates infection control models and state-following algorithms for alarming in the event of noncompliance to hand hygiene. Our preliminary experiments in a mockup, small scale intensive care unit (ICU) facility shows promising results with less than 5% false positives.

Categories and Subject Descriptors

C.2.4 [**Distributed Systems**]: Distributed applications

General Terms

Design, Algorithms, Experimentation, Measurement

Keywords

Localization, Tracking, Bluetooth Low Energy, Android

1. INTRODUCTION

Infections acquired from a hospital environment, as a result of admission and treatment, are a leading cause of death of hospitalized patients. Commonly referred to as hospital acquired infections (HAI), they pose a genuine health hazard not only to patients but also to the healthcare personnel (HCP) and community at-large. The average infection rate is 3% world-wide; but, it is significantly higher in developing countries such as India. The prevention and control of HAI is, therefore, of *great* importance for enhancing the quality of care and well-being in hospital environments.

Infection control measures, through sanitation protocols, are a way to limit the spread of infectious diseases. While HCP in medical facilities, such as the intensive care units (ICU), are expected to follow hygiene protocols to prevent the spread of infections, their strict compliance to these measures cannot be supervised. Simple measures, such as good hand hygiene, are greatly effective in controlling the spread of HAI, but are often ignored. Statistics suggest that low compliance to hand hygiene accounts for 40% of cases reported in HAI.

Several approaches have been developed over the years to improve compliance with hand sanitation protocols. They include formal training and audits, the use of technological assistance such as instruction charts, hand wash timers and controls, and monitoring systems. Many sophisticated monitoring systems are commercially available; for example, radio-frequency identification (RFID) wristbands and active tags combined with location monitoring and tracking support. While monitoring solutions have the largest potential for providing a comprehensive infection monitoring capability, they typically require large investments in infrastructure, training, and usually involve the addition of sensors or tags that are very often seen as intrusive or disruptive to the doctors' normal processes. For example, the Aeroscout system requires active tags to be worn by personnel and specially modified Wi-Fi access points to track the location transmissions from the tags. For these kinds of solutions to reach price and performance points where they can be used in hospitals in developing countries, or in smaller clinics and medical facilities in developed nations requires a rethinking of the architecture of such solutions.

In this work, we propose *CleanHands*: a combination of 'inverting the monitoring architecture' (by using extremely low cost tags placed in association with key entities such as room entrances and exits, critical equipment, patient beds and other facilities); with custom software installed on cellphones (already ubiquitously used by hospital staff). This replaces the physical infrastructure of current solutions with *crowd sourced* infrastructure from the hospital staff themselves to potentially dramatically lower the cost and simplicity of deployment of a monitoring solution, and drive behavioral changes. In the next two section, we elaborate on its system design for an ICU environment (a critical medical facility in an hospital) and presents preliminary results.

2. SYSTEM DESIGN

System architecture. The system is composed of three units. The *sensing unit* consists of two classes of sensors: multi-range proximity beacon tag and handpump sensor. Multi-range proximity tags provide different proximity lev-

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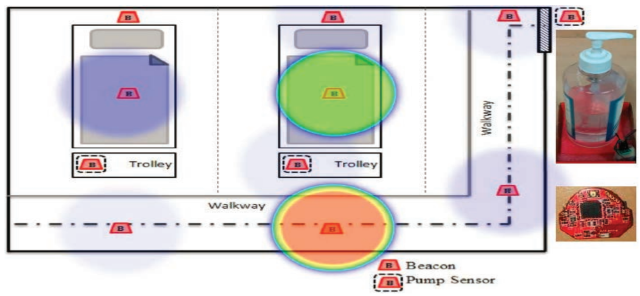

Figure 1: **Tracking and monitoring infrastructure of the *CleanHands* system.** *Heat map of the movement of people in the mockup ICU.*

els (such as far and immediate) to provide a range of granularities required for both coarse and fine-grained location capability. They are responsible for covering the physical space-of-interest with a reference grid for localization using undirected Bluetooth Low Energy (BLE) broadcasts [?] along with simple measurement information. The hand-pump sensor is interfaced with the handwash unit to record a handpress event. The *control unit* consists of a resourceful device that is capable of listening and receiving broadcast data contained in BLE advertisements, perform local computations and feed in (limited) information to the higher levels. The *coordinator unit* is a private Cloud service, running the hospital information system (HIS), that aggregates high-level location details and coordinates state tracking in the ICU. In our case, the beacon tag is a custom designed CC2540*Cheep* BLE platform, the control unit is an Android v4.4.4 smartphone that uses Bluedroid, and the coordinator unit is a Amazon cloud computing service.

Platform details. The custom designed beacon platform, CC2540*Cheep* of dimensions [28×25×8] mm, consists of a TI CC2540 [?] system-on-chip (SoC), a RF balun filter, a chip antenna, and a CR2032 battery holder. The SoC comprises of an: 8051 microcontroller core, a Bluetooth v4.0 compliant 2.4 GHz RF transceiver, 8 kB RAM, 256 kB programmable flash, and a 12 bit ADC. The handpump sensing unit consists of a: CC2540*Cheep* beacon tag, SEN-09376 force sensitive resistor (FSR) and SI1300BDL-T1-E3 MOSFET switch.

Tracking and handwash detection. The *CleanHands* system performs context-based tracking and monitoring of every HCP in the ICU. Infection control models are integrated into the system to alarm if hand hygiene is not practiced. The basic *ranging* mechanism uses the broadcaster mode of BLE to transmit unsolicited advertisement packets from the beacon units. Passively listening (mobile) control units are able to receive such broadcasts when they are in the proximity range of the beacons. As the beacons are placed at regions-of-interest (for contextual tagging), the proxemic cue helps to correlate the presence of mobile units to the contextual vicinity (e.g., if an HCP is in the walkway or patient zone of the ICU). The infection control protocol requires every HCP to handwash upon entering and existing patient zones. This activity is monitored by sensing the handwash event, wherein the pressure exerted on the handwash liquid dispensing unit is recorded by the FSR and is subsequently communicated using the beacon tag. In case of handwash violations, an alarm is sounded on the (mobile) control unit of the defaulting HCP and the same is also logged in the HIS.

Table 1: Phone orientation vs. False Negatives

Phone orientation	False -ve (%) <3 s	>3 s
Screen facing away + Radio upwards	0	0
Screen facing away + Radio downwards	15	0
Screen facing towards + Radio upwards	2.5	0
Screen facing towards + Radio downwards	0	0

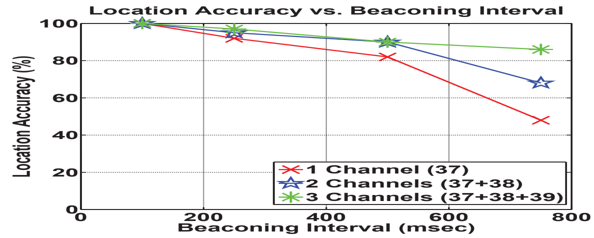

Figure 2: **CleanHands: Tracking performance.**

3. PRELIMINARY RESULTS

We performed preliminary experiments in a mockup ICU (Fig. **??**) with 2 patient, where the walkway/bed dimensions and bed spacing were kept consistent with the ICU of the hospital were we will be deploying this system. It was instrumented with a set of 9 beacons and 3 handpump sensor units. The beacons were configured to broadcast advertisement packets at an interval of 250 ms and at their lowest transmit power of -23 dB. For our evaluation, for about an hour, 5 people carried Android smartphone running the *CleanHands* service. Proximity events were also streamed to the HIS, which aggregated the data from all 5 mobile units and generated a real-time location heat map of the movement of people in the ICU space. Fig. **??** shows the raw heat map, and represents the density of user presence at each location over the entire duration, with the color going from light blue (low density) to deep red (high density).

For recording the reliability of the system, we performed experiments with different orientation of the phone in the users' pocket and the time spend (t) by the user at the patient zone. For $t < 3$ s, we observed that the rate of false negatives are less than 2.5% for all orientations (Table **??**), except when the phone is placed with its screen facing away from the user and the radio is pointing downwards; while the same is close to null for $t > 3$ s. Next, we analyzed the accuracy of (context-based) tracking with respect to the beaconing interval of the beacon units (Fig. **??**). We observed that shorter beaconing intervals (100 ms) resulted in cent percent location accuracy; but, at the cost of higher energy usage with a limited short battery life of 7 days. On the otherhand, longer beaconing intervals (500-750 ms) significantly improved the operational duration of the beacons, but with reduced location accuracy levels (<85%). Therefore, for deriving the best tradeoff between location accuracy and energy consumption, we used 250 ms as the optimal beaconing rate.

Future work. The *CleanHands* system is getting deployed in one of the hospital ICUs of our medical partner, a 30 bed facility that will be instrumented with 120 beacons. We are also developing robust algorithms to improve the reliability of the system in high multipath environments.

4. REFERENCES

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[2] CC2540. http://www.ti.com/product/cc2540l.