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# Improving Patient Safety With Hand Hygiene Compliance Monitoring

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Hand hygiene is important for patient safety; increasing hand hygiene compliance may reduce the frequency of healthcare-associated infections. This paper describes a distributed system that uses instrumented product dispensers and doorway monitors to systematically measure hand hygiene compliance as an alternative to compliance measurements by human observers, which is the current standard. The paper describes two experiments. The first experiment monitored 4,266 doorway crossings and 858 hand hygiene dispenser events for 4 patient rooms over 80 consecutive hours. The second experiment was part of a larger effort that included a direct comparison of a human observer with the automatically recorded observations. The results of the two experiments suggest that large quantities of data could be readily acquired, but the data was sensitive to several limitations not suffered by human observers including: distinguishing between single versus closely spaced multiple threshold crossings and distinguishing staff from patients and visitors. However, a direct comparison of human versus machine readings suggested that the system might overcome observational challenges faced by the human observers, providing more consistent and reliable measurements.

## INTRODUCTION

Healthcare-associated infections affect about 2 million patients in US hospitals each year, resulting in thousands of deaths (Jarvis, 1996; Klevens, Edwards, et al. 2007). Failure of healthcare workers to perform appropriate hand hygiene is one of the leading preventable causes of these infections (Boyce & Pittet, 2002). Nosocomial pathogens also survive in the environment and can spread to patients via healthcare workers' hands (Devine, Cooke & Wright 2001; Rutala, Katz, et al. 1983). Several studies have demonstrated that improving hand hygiene can decrease healthcare-associated infections (Aiello & Larson, 2002; Kampf, Loffler & Gastmeier, 2009; Pittet, Allegranzi et al., 2006).

### Hand-Hygiene Compliance

Monitoring hand hygiene compliance and providing performance feedback to health care workers is recommended by the World Health Organization, and the Joint Commissionon Accreditation of Healthcare Organizations (Boyce & Pittet, 2002; Pittet, Allegranzi & Boyce, 2009; Joint Commission on Accreditation of Healthcare Organizations). Furthermore, many local (Allegranzi, Sax, et al., 2010), national (The Research Committee of the Society of Healthcare Epidemiology of America, 2010; Boyce & Pittet, 2002), and international hand-hygiene campaigns have been launched (Boyce & Pittet, 2002). Notwithstanding, these efforts, good hand-hygiene practice remains an elusive goal (Maskerine and Loeb 2006): rates among healthcare workers remain low, averaging less than 50% (Boyce and Pittet, 2002; Haas & Larson, 2007; Kampf, Loffler & Gastmeier, 2009; Pittet, Allegranzi & Boyce, 2009).

### Barriers to Practicing Effective Hand Hygiene

The literature identifies many hand-hygiene barriers: lack of facilities (*e.g.*, sinks, supplies) (Boyce & Pittet, 2002), undesirable side effects (*e.g.*, dry skin) (Boyce & Pittet, 2002; Jang, Wu, et al. 2010; Larson, 1999; Larson & Killien, 1982; Zimakoff, Kjelsberg, et al., 1992), lack of knowledge about its importance (Boyce & Pittet, 2002), and busy schedules (Boyce & Pittet, 2002; Larson, 1999; Zimakoff, Kjelsberg, et al. 1992).

### Measuring Compliance with Human Observers

Measurement of hand-hygiene compliance is a component of all infection-control programs. *Currently, hand-hygiene compliance is measured almost exclusively via direct observation of healthcare workers by human observers. This is considered the ''gold standard''* (Haas & Larson, 2007; Raju & Kobler, 1991). However, direct observation is labor-intensive (Boyce, Havill, et al., 2004; Aiello & Larson, 2002; Rotter, 1997), and susceptible to observer effects (Adair, 1984; Eckmanns, Bessert, et al. 2006; Eckmanns, Schwab, et al. 2006). Furthermore, the reliability of the readings can be adversely affected by sporadic or inconsistent sampling (Rotter, 1997).

### Measuring Compliance without Human Observers

One alternative to direct human observation is measuring product usage (*i.e.*, alcohol-based gel). Other approaches involve the use electronic monitoring systems. Some such systems count the use of a particular product dispenser (e.g., Boyce, Cooper & Dolan, 2009). Other alternatives use a badge to be worn by a healthcare worker to determine who is using a particular product before or after entering a patient room. Most of these systems rely on radio-frequency identification (RFID) technology and they can be expensive, requiring installation of antennas and wiring in all study areas. Although some systems are already commercially available, there are few extensive reports in the peer-reviewed literature describing these systems. Besides requiring relatively expensive and fixed infrastructure, such systems require healthcare workers to remember to wear the badges without removing them. In addition, the use of badges assigned to individual healthcare workers raises some privacy concerns among those individuals (Ellingson, Polgreen, & Schneider, 2011).

The purpose of this study was to develop an alternative method for measuring hand hygiene compliance that does not rely on substantial infrastructure modifications or long periods of direct human observation. Additionally, the system was designed to be quickly and unobtrusively deployed, for use in short-term compliance monitoring, perhaps as part of a disease outbreak investigation at a working hospital, for example. Instead of focusing on hand hygiene compliance at the level of the healthcare worker, this approach focuses on the compliance for a particular patient room. The principle questions addressed by the study were whether the system was practical and feasible in a clinical setting. The study also sought to identify differences between measurements made by the system and measurements made by human observers, so that this might be studied in greater detail in future experiments.

## METHODS

The system consisted of three battery-powered devices that were designed specifically for this application (Figure 1). The first is a hand sanitizer dispenser modified to generate a radio transmission whenever alcohol gel is dispensed. The other two are an infrared transmitter and an infrared receiver pair that detect and record doorway threshold crossing events and records broadcasts from nearby dispensers. We refer to the transmitter and receiver pair as a door minder. The system electronics were designed around an electronic device called a mote.

### The Mote

The TelosB mote at the core of the electronics is a small, low power, electronic sensor. The TelosB is an open source platform published by UC Berkeley. It contains a MSP430 microcontroller, 1 megabyte of flash memory, a ZigBee-compliant radio and an antenna, all on a single circuit board measuring 65x31mm. The mote is programmed through a USB interface to a computer with a TinyOS operating system. Some of the motes used in this experiment were purchased and some were assembled by the authors. Motes are shown in Figures 2 and 3.

### The Dispenser Trigger

The dispenser is a conventional alcohol foam gel dispenser (Avant brand) retrofitted with a small mechanical switch in its cap (Figure 2). This switch was wired to an electronic instrument attached to the bottle with a plastic ring that hung about the bottle's neck below the cap.

The circuit board provided external access to the USB connector, a power switch, a button to simulate a trigger event, a 3.3V coin cell battery, and an external connection to the cap. Because the device requires almost no power except during trigger events, we estimate that the battery can last a month in normal operation.

The dispenser generated three radio packets in rapid succession for each dispensing event and then disabled further events for 5 seconds. The inactive period was designed to reduce the number of double trigger events for a single user.

### The Door Minder

The door minder receiver also consists of a TelosB mote, 2 AA batteries, and a purpose-built circuit board (Figure 3). The transmitter was similar, but did not include a mote. The infrared LED in the transmitter requires a substantial amount of sustained power, so three AA batteries were used; which allowed the device to operate for about 4 days.

Since the door minders served as the primary data collection devices, it is important to note that they record events relative to the time the device was turned on, rather than absolute time. We have also observed that the speed of the different clocks varied from mote to mote by as much as 1%. One of the authors has developed an algorithm to

Figure 1: From left to right, the dispenser, receiver and transmitter.

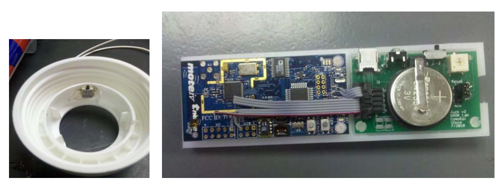

Figure 2: The microswitch mounted inside the cap (left). The electronics including the TelosB mote and custom board with button cell battery at right.

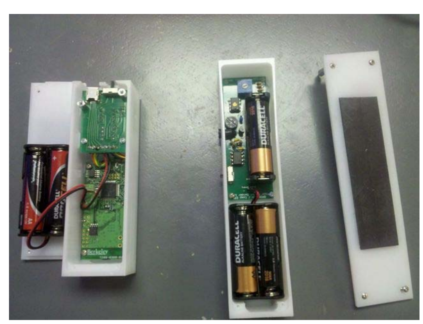

Figure 3: The door minder. The receiver is on the left with the mote (bottom), circuit board (top) and two batteries mounted on the case lid. The transmitter is on the right, with 3 AA batteries and a strip of adhesive magnetic tape on its lid.

synchronize the clocks, but this algorithm was not implemented for this study.

**The Software**

Several software programs were developed to operate the system, in addition to the programs running on the receiver and the dispenser trigger. Two other utility programs are required to download and to clear information from each mote's flash memory. The download utility interacts with a program running on a Linux PC to transfer the flash data over the USB connection. A variety of python scripts were developed to load and call these programs so that the data was properly and consistently stored and decoded.

A variety of scripts were also developed to transform and visualize the data.

**Initial Experimental Setup**

The first experiment was conducted during 4 successive days in a cluster of rooms in an active patient care unit at a large hospital in late November 2010. On Monday morning, a door minder was placed on the doorframe of each of the four patient rooms in the cluster and the four hand sanitizing gel dispensers located in hangers outside each room were replaced with our instrumented triggers. The style and brand of the dispensed gel matched what was being replaced. One of the authors visited the installation each morning and evening to ensure that the equipment was operating as expected. During these visits, a special trigger was activated to produce a notable event in each receiver's log. The equipment worked as expected throughout the experiment, except that on the first evening, the position of one door minder needed to be adjusted and on the third and last day, one of the triggers was no longer indicating its activity by flashing an LED when it was dispensing product. The equipment was collected Thursday evening.

The signals emitted by the dispensers were typically received and recorded by all four door minders, although the time of each event was recorded relative to the door minder's own clock. Consequently, the experiment yielded four data files, each consisting of the events recorded from an individual door minder. Each file contained unique times at which the infrared beam was interrupted for that door minder, as well as the times and unique ID of all the dispenser events received by the door minder.

**The Second Experimental Setup**

In mid-December, the team returned to the same unit and instrumented three clusters of 4 rooms each on a Wednesday morning and retrieved the devices the following Tuesday morning. Members of the team inspected the devices twice each day.

Only the data from one of these clusters will be considered here. In this cluster, the team replaced the soap bottles both inside and outside each of the four rooms with the dispenser triggers (the brand of soap and type of bottle was consistent). In addition, an observer recorded the time at which a person crossed any of the instrumented thresholds, as well as whether or not they washed their hands before or after leaving the room during a 45-minute calibration period.

The four data files from this second experiment were similar in structure to the data files in the first experiment, except that they recorded the transmissions from eight dispenser triggers in the vicinity and that the transmissions from the dispensers *in* the room were generally heard by fewer receivers than the transmissions from dispensers mounted on the wall *outside* each room.

## RESULTS

**Initial Experiment**

After removing redundant trigger event records, we tallied the number of transmissions from each trigger recorded by each door minder. These tallies were generally within 1 unit of each other and Table 1 lists the largest tally for each trigger. Over the 80-hour experiment, the busiest room averaged 20 threshold crossings per hour. The cluster of rooms averaged nearly 1 threshold crossing each 1.1 minutes and one dispenser event every 5.6 minutes.

The table also lists the number of threshold crossings if a five-second period of inactivity was enforced in a manner similar to that used by the dispenser triggers. Filtering in this manner reduces the average threshold-crossing event to once every 1.5 minutes.

In addition to these tallies, a histogram was constructed to count the number of trigger events that occurred during each one-second period from 15 seconds before a threshold crossing to 15 seconds after the threshold crossing. Figure 4 presents a sample of these histograms on the next page.

**The Second Experiment**

The analysis of the second experiment emphasized the construction of a single file representing the synchronized version of all the events that occurred during the experiment. To that end, an optimization problem was devised to solve the time offsets and time scaling problem by rewarding solutions in which many events in the four logs corresponded in time and applying a penalty for events that did not correspond in time. This was solved using a simulated annealing algorithm. The result compared well with a manual solution.

Of particular interest was the comparison between the events in the unified file and the direct observations. An interactive visualization was constructed showing icons for the events recorded by the human observer on the top and the

**Table 1: Event Tallies from First Experiment**

| Door minder | # Threshold Crossings | # Thresh. Crossings 5-sec filter | Associated Dispenser | # Dispenser Events | Dispenser/ Threshold | Dispenser/ Filtered Threshold |
|---|---|---|---|---|---|---|
| A | 1297 | 990 | a | 283 | 22% | 29% |
| B | 723 | 525 | b | 182 | 25% | 35% |
| C | 635 | 470 | c | 145 | 23% | 31% |
| D | 1611 | 1243 | d | 248 | 15% | 20% |

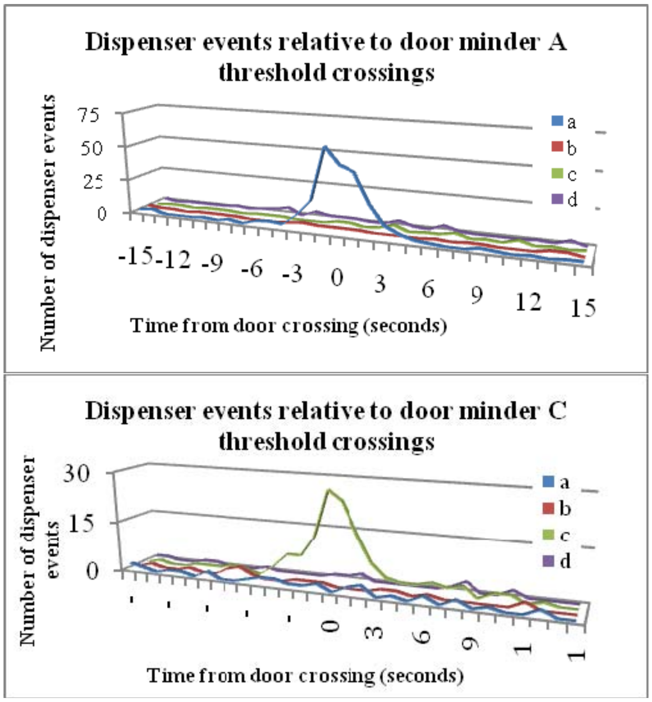


Figure 4: A histogram of trigger events relative to threshold crossings for Experiment 1. The top image shows the four triggers relative to threshold-crossing events for door minder A. Eighty-two percent of all its associated dispenser events occur within 5 seconds of a threshold crossing. The bottom image shows the trigger events relative to threshold-crossing events for door minder C. Ninety-three percent of all its associated dispenser activity occurs within 5 seconds of a threshold crossing.

automatically recorded events on the bottom. A sample of this timeline is provided in Figure 5.

## DISCUSSION

The first experiment assessed whether the dispenser events can be tied to the directly adjacent door. As Table 1 indicates, the inferred hand hygiene compliance rates are substantially lower than the 50% compliance rate that is often reported. The data are also relatively sensitive to threshold-crossing events that occur close together, which can be observed in the difference between the raw and the filtered data rates for the threshold crossing.

Clearly the number of samples that can be collected in this manner are impressive and relatively easy and unobtrusive to acquire. However, the door minder makes no distinction between a nurse preparing a procedure and a visitor, so the compliance rating collected in this manner may not be an accurate reflection of the diligence of the staff, which is a practical concern for hosptial administrators. Microbs, however, are not so discerning; measuring hand hygiene compliance relative to threshold-crossings may be appropriate from the perspective of the disease vector. One could argue that all vistors should be practicing hand hygiene when entering or leaving a hospital room.

The histogram presented in Figure 4 indicates that for one door minder, the near-by dispenser was used nearly exclusively (90%) in proximity to a threshold event, i.e., almost the only time it was used was when someone was either immediately about to enter the room or had just left. The other dispenser, which was close to a major access point into this cluster of rooms, had much less of a exclusive-use property. Still, even in this worst case, 45% percent of its uses closely correlated in time with a crossing of the associated threshold. Anecdotal evidence suggests that the placement of the soap on the wall (left or right of the door), the handedness of the users, and their habits, can influence the association of a trigger event with a particular doorway. Consequently, the system may be less effective if communication among multiple triggers and doors is not considered.

Although the system described here has significant limitations, the second experiment hints at some of the limitations of the human observer. In the short comparison we acquired in this experiment, several discrepancies are notable. At time 7:33 in Figure 5, the human observer notes a room entrance without a hand hygiene event, but dispenser 127, which is associated with that threshold reported an event. Perhaps the observer missed the event or misrecorded it. At 7:55, the observer noted a single hand hygiene event, but the system noted two. One of these occurred inside the room, hidden from the observer's view. At 7:58 the system detected

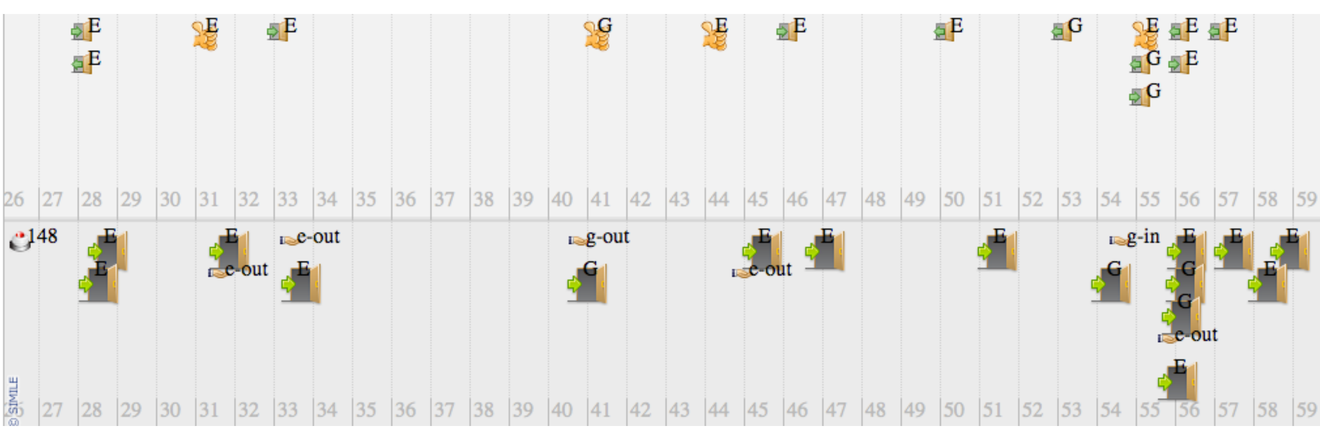


Figure 5: A timeline ranging from 7:26 - 7:59 am showing the events recorded by the human observer above and the events recorded by the system below. In the top section, the door icon indicates a room entrance or exit without a hand sanitizing activity. The thumbs-up icon represents a threshold crossing with a hand hygiene activity. In the lower section, a door icon represents a threshold crossing and an open palm represents a dispenser event.

two threshold crossings not detected by the human observer. This may have been caused by someone lingering in a doorway, or a lapse of attention. Teasing out such differences must be left to future experiments.

These preliminary experiences suggested that the system may habitually report compliance values lower than those to which administrators and staff are accustomed, which may pose an important barrier to introduction. Ultimately, however, the system provides an opportunity to unobtrusively and consistently observe hand hygiene behavior in a clinical setting that can, at the least, supplement current practice. This approach, by focusing on complaince at the room level, avoids focusing blame at the indivdual heatlhcare worker and may provide a more constructive alternative to providing feedback.

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