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concise communication

Method for Automated Monitoring of Hand Hygiene Adherence without Radio-Frequency Identification

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Many efforts to automatically measure hand hygiene activity depend on radio-frequency identification equipment or similar technology that can be expensive to install. We have developed a method for automatically tracking the use of hand hygiene dispensers before healthcare workers enter (or after they exit) patient rooms that is easily and quickly deployed without permanent hardware.

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Monitoring the hand hygiene adherence of healthcare workers (HCWs) and providing performance feedback to HCWs is recommended by the Centers for Disease Control and Prevention,[1] the World Health Organization,[2] and the Joint Commission.[3] Currently, adherence is commonly measured by direct observation; this approach is considered the gold standard for determining adherence.[2,4] However, observational surveys are labor-intensive and expensive.[4-6] Also, results are susceptible to observer effects,[7] and their reliability can be affected by sporadic sampling.[8]

A number of electronic monitoring systems for hand hygiene have been reported,[4] with more under development. Many efforts to directly measure adherence (ie, as opposed to measuring product usage) depend on radio-frequency identification (RFID) infrastructure or similar technology. Unfortunately, these approaches can be prohibitively expensive, because they require the installation of radio antennas or some other equipment (eg, motion sensors) in areas under study. We have developed a relatively low-cost method for automatically tracking the use of hand hygiene dispensers before HCWs enter (or after they exit) patient rooms that is easily deployed without installation of any permanent hardware or wiring.

methods

Our system consists entirely of small credit-card-sized devices called motes. Motes are active, battery-powered, programmable devices consisting of a small processor, flash memory, and an Institute of Electrical and Electronics Engineers (IEEE) 802.15.4–compliant wireless radio. Each mote is programmed to broadcast a message (ie, a time-stamped identity packet) to other motes. Each message can be received by other motes; from a message one can derive the following information: (1) the identifier of the mote that sent the message, (2) the received signal strength, and (3) the time the message was received. These data are recorded on the receiving mote. The motes communicate over unused space in the WiFi spectrum and do not interfere with medical devices.

We program our motes to perform 1 of 3 different roles, which we call badges, beacons, and triggers (Figure 1). Badges are worn by HCWs and are contained in recycled pager cases. Beacons are placed in patient rooms, and triggers are attached to off-the-shelf hand hygiene dispensers. Each of the 3 components is capable of sending wireless messages to the other components and receiving wireless messages from the other components, and each can be programmed to process and record messages from other components. The badges record signals from both the beacons in patient rooms and the triggers on hand hygiene dispensers, whereas hand hygiene dispensers are programmed to broadcast messages only when the dispenser is activated. All messages are time stamped and stored on the receiving mote. By merging the contact logs of individual motes, we can generate an explicit contact tracing, and by analyzing the received signal strength and the event time stamps, we can infer whether an HCW wearing a badge has entered and/or exited a patient room without using a hand hygiene dispenser equipped with a trigger.

The exercise outlined below demonstrates how our system works. During this exercise, the badge wearer walked in and out of a patient room 45 times (see travel path in Figure 2). Before entering, she used the hand hygiene dispenser located outside the room. For each transit, she spent approximately 30 seconds both inside and outside the room.

results

The dark color located above the line in the lower graph of Figure 2 shows the signal strength detected by the beacon located inside the patient room. The light color in the lower graph shows the signal strength detected by the beacon outside the patient room. The vertical lines in the same graph indicate the activation of the trigger on the hand hygiene dispenser outside the room, as recorded by the experimenter's badge.

In this exercise (1 beacon inside of the room and badged individuals staying within the room for only 30 seconds) we achieved a sensitivity of 91.1% and a specificity of 100%, with a positive predictive value of 100% and a negative predictive value of 95.7%. With theadditional beacon added outside of the patient room (the configuration shown in the upper half of Figure 2) and with time within room set at 30 seconds, we achieved a sensitivity of 97% and a specificity of 100%, with a positive predictive value of 100% and a negative predictive value of 97%. These results were generated by comparing the mote data with ground truth recorded by an observer for the exercise outlined above. Note that more so-

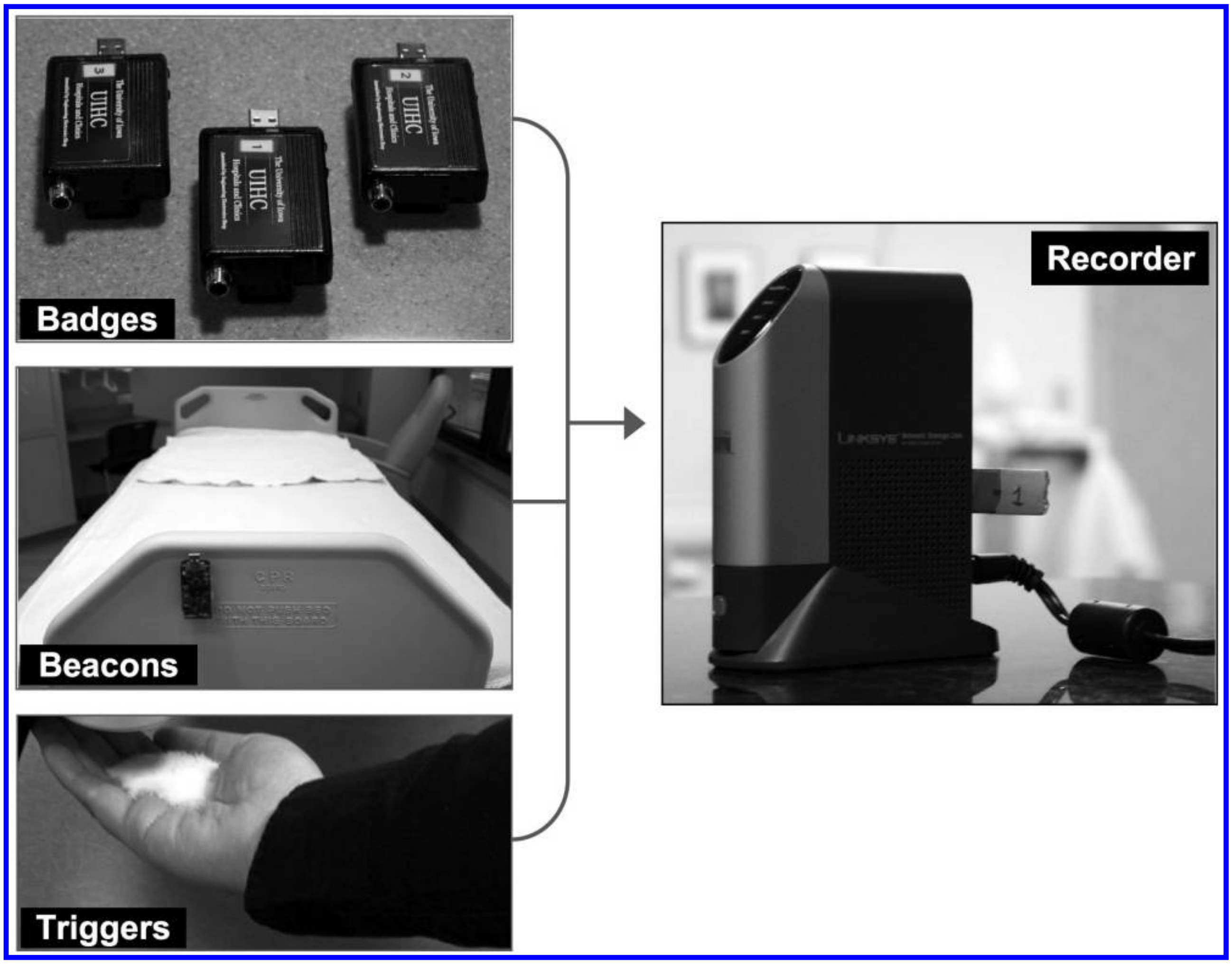

FIGURE 1. Hand hygiene monitoring components. Badges, beacons, and triggers each contain an active, battery-powered, programmable device called a mote.

phisticated definitions of "in" or "out" of a patient's room (ie, defined in terms of patterns of mote messages exchanged over time as opposed to a single message received or missed) can be used to yield higher sensitivity and specificity.

DISCUSSION

We have described a novel method to measure hand hygiene adherence in healthcare settings. Our method collects data that can be used to directly and quickly generate electronic reports at either the unit or the individual level.

Our mote-based approach holds a number of advantages over other electronic monitoring systems. First, we measure both hand hygiene events and opportunities. Some other approaches measure only events.[9,10] Second, although certain other approaches detect opportunities (eg, entering a room) in addition to events (eg, detecting dispenser use with an alcohol sensor[11]), this typically requires the installation of radio antennas or motion sensors that require extensive and permanent wiring. Motes, however, do not require this expensive infrastructure; they work in a distributed fashion and they do not require any centralized database. Because our system consists of only motes, it is portable and easily reconfigured. Thus, a single kit could be reused to audit several areas. Furthermore, we have integrated (ie, incorporated) motes in multiple different commercial touchless dispensers and in traditional pump-based dispensers. Third, with proper placement of mote beacons, sensor motes promise much higher location resolution than that offered by RFID systems. Because RFID badges are passive (ie, unpowered), they must infer colocation of multiple badges from their interactions with a fixed detector. For this reason, RFID systems cannot generally produce resolution better than room level. Finally, because motes are active, they can be modified to incorporate enunciators (ie, audible signals or vibrating devices) to remind or to prompt HCWs about hand hygiene opportunities as they occur.

The use of motes, like any new technology, introduces a

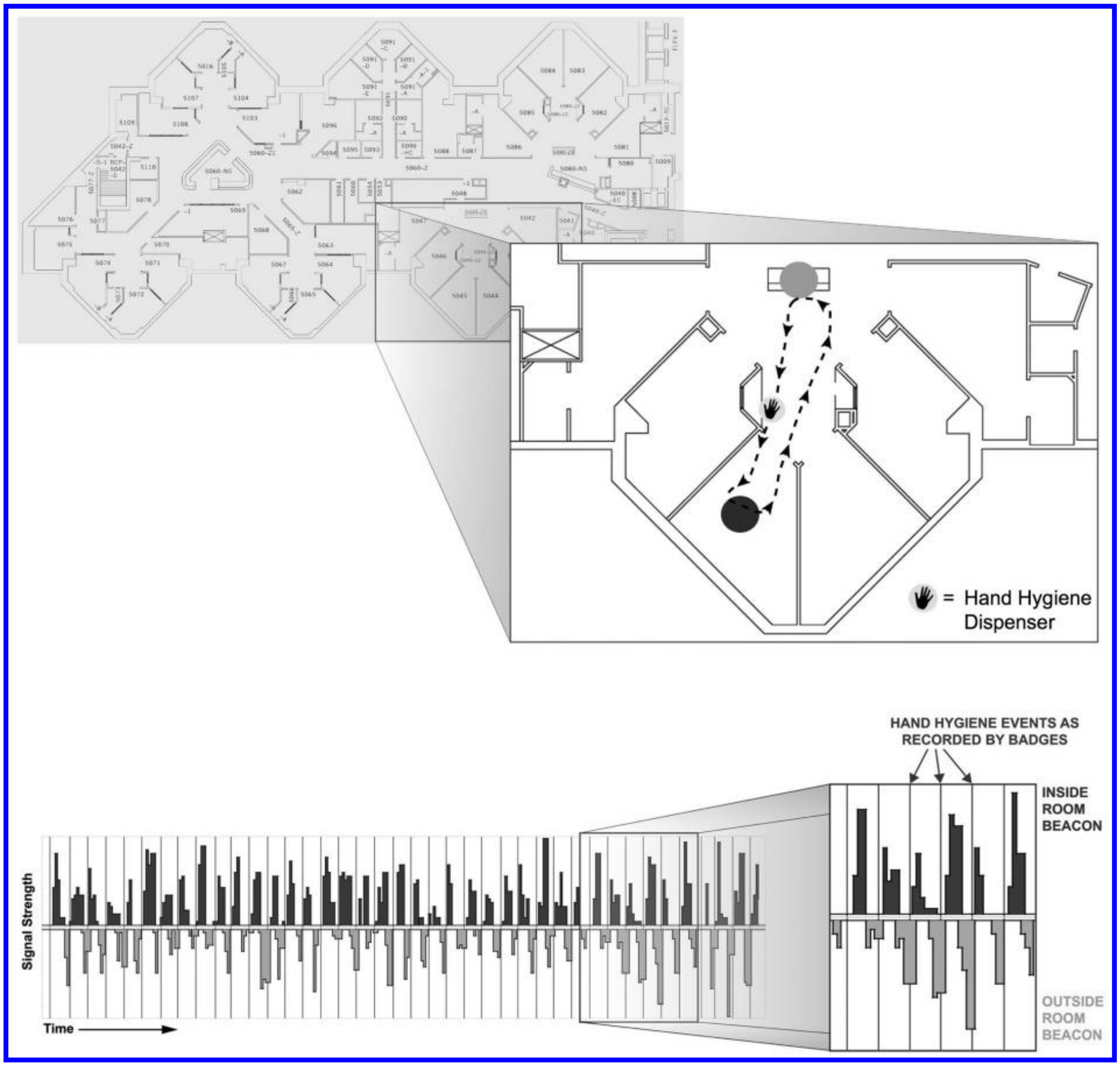

figure 2. Sample experiment. During this exercise, the badge wearer walked in and out of a patient room 45 times. Before entering, she used the hand hygiene dispenser located outside the room.

number of technical challenges. Motes require battery power for radio transmission, computation, and on-board storage. One technique for extending battery life, thereby reducing weight and size requirements, is to duty cycle the mote so that it wakes up for only a few milliseconds approximately every 5–10 seconds.[12] This technique requires that all deployed motes operate in synchrony, so that they all wake up at the same time, or at least have overlapping cycles of operation. Duty cycling also presents special problems for the triggers, because they must signal a detected hand hygiene event only when the badges and beacons are known to be listening. Distributed clock synchronization represents a difficult technical problem that must be solved in a fashion appropriate to the deployment parameters.[9] Because the signal strength from the trigger-mote–based messages decays with distance, it is possible to discriminate between people who are using a dispenser and those who are just standing nearby. However, when people stand unnaturally close to each other, it is possible for both to be credited for practicing hand hygiene. Another limitation is that we would like to detect other opportunities for hand hygiene.[2] For example, it is possible for the motes to recognize proximity to one another, there is currently no way for our motes to detect if an HCW actually touched a patient. Therefore, recognition of some of the World Health Organization–recommended "5 moments of hand hygiene"[2] presents additional technical challenges. In addition, a number of administrative challenges exist. Deployment and system diagnostic procedures must be developed so that motes can be used by nontechnical personnel. Also, recharging and device checkout procedures must be developed and field tested before widespread deployment. Finally, a number of ethical and privacy issues remain (eg, how to balance HCW privacy with patient safety needs). HCWs may be receptive to wearing monitoring devices, but privacy concerns exist.[10,13]

Notwithstanding these challenges, our system promises to provide accurate measurements of hand hygiene adherence at relatively low cost. Future work will explore deployments in clinical areas and ways to feed back mote-generated data to HCWs. Finally, the colocation of multiple badges within the same room does not adversely affect our system. In fact, we can use badge-to-badge messaging to generate contact networks to study the spread of infection and to measure exposure risks.

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