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Concise Communication

Leveraging Bluetooth low-energy technology to improve contact tracing among healthcare personnel in hospital setting during the coronavirus disease 2019 (COVID-19) pandemic

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Abstract

To improve contact tracing for healthcare workers, we built and configured a Bluetooth low-energy system. We predicted close contacts with great accuracy and provided an additional contact yield of 14.8%. This system would decrease the effective reproduction number by 56% and would unnecessarily quarantine 0.74% of employees weekly.

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Contact tracing with quarantine and isolation is an essential tool for epidemic control when asymptomatic and presymptomatic transmission occurs.[1] Many countries have endorsed digital contact tracing software applications (apps), but adoption rates and results have remained low.[2]

Healthcare personnel (HCP) are at significant risk for contracting and spreading severe acute respiratory coronavirus virus 2 (SARS-CoV-2) .[3] Several methods relying on Bluetooth low-energy (BLE) have been explored in clinical applications focusing on single individuals.[4] The results of a pilot study indicated that BLE wearable tags may be a tool for detecting contacts in hospital settings.[5]

Given the need for reliable and rapid contact tracing, we developed and tested an automated BLE-based contact-tracing system designed for healthcare settings, focusing on contacts among HCP in the hospital environment.

Methods

The study was conducted at Washington University School of Medicine, Washington University McKelvey School of Engineering and Barnes Jewish Hospital (BJH) in St. Louis, Missouri. The study included 2 COVID-19 hospital units: 1 medical ward and 1 intensive care unit (ICU). All HCP including clinicians, environmental staff, and clerical staff working on the study units received 3 emails about the study with a link to informed consent. We focused on clinicians assigned to the study units and less so on consultants. The medical ward was staffed by hospitalists and advanced practice providers, and the ICU clinicians included trainees. At the time of the study, SARS-CoV-2 vaccination was mandatory at BJH. HCP wore surgical masks while on duty and N-95 masks, eye protection, and disposable gowns when caring for COVID-19 patients. Because the study units were COVID-19 units, we only focused on HCP-to-HCP transmission, and we monitored all spaces (eg, break rooms, conference rooms, nurses' station, and hallways), but we excluded patient rooms. Close contact was defined as having 15 minutes of cumulative exposure within distance of 2 m (6 ft) over a 24-hour period.

System infrastructure, operation, and maintenance

The system comprised wearable BLE devices (beacons) worn by HCP, small-embedded computers (anchors) and an edge server. The beacons are small coin-sized, battery-operated devices with a unique identifier that attach to badges. They transmit short-range radio signals captured by anchors plugged into the hospital's outlets and computers. These signals are time stamped and uploaded via the hospital's secure wireless network to the edge server, where contact-tracing algorithms can be applied to the data.

The system's functionality was initially tested in the computer science laboratory to determine the device configuration. The system was then deployed on the 2 clinical units for 6 months between May 2021 and November 2021. The system was continuously monitored, and batteries and anchors were replaced as needed.

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Experiments

We conducted and observed experiments in locations where HCP would congregate during working hours with 2 or 3 beacon users at known distances and periods. We also recorded rounds in the ICU, during which multiple team members participated. Rounds usually involved a core group (attending physicians and trainees) and additional members who may temporarily join rounds, such as bedside nurses. These data defined the baseline against which we calculated the system's sensitivity and specificity.

Analyses

For indoor geolocation, we calculated the proximity between users. These data were extracted in 2 steps: (1) room-level location and (2) proximity location by predicting the user's location based on beacon signal intensity and calculating the distance between them. To determine close contacts during patient rounds, we developed a clustering algorithm.[6] The algorithm computes the similarity score between each pair of users and the density within the group of HCP participating in patient rounds is higher than outside this group.

When an individual tests positive for SARS-CoV-2, the generated output lists all potential contacts, location, date, and cumulative contact time. We report the sensitivity, specificity, accuracy, and F1 scores in all clinical scenarios. Because no HCP cases occurred on the 2 units during the study period according to Occupational Health Services, we simulated a positive case by having a participant intensivist try to remember all potential close contacts for the preceding 7 days and to evaluate the validity of the contact list generated by the system.

The impact of BLE contact tracing was estimated using a modified susceptible, exposed, infected, and recovered compartmental model (SEIR).[7] The benefit of contact tracing comes from quarantining asymptomatic and presymptomatic individuals. The cost may be quantified by the number of quarantine events in individuals who will not develop the disease. The assumptions and equations used are available in the Supplementary Material (online).

Results

In total, 186 HCP participated in our study, for a participation rate of 44.6%, which varied across occupations (Table 1). The total observed experiment time was 43 hours, and the system recorded data for 6 months.

The accuracy for room-level location (ie, break rooms, nurses' stations, conference rooms, and hallways) ranged between 0.96 and 1.0. The location accuracy improved as the number of anchors increased. We were able to predict close contacts in all study areas with an accuracy between 0.88 and 1.0 and an F1 score of 0.91–1.0 (Table 2).

During patient rounds, the core group comprised 7 members on average. The total observed time was 36.8 hours during different days and at different locations. Our clustering method accurately identified the personnel present during rounds and the time spent in contact with the group with accuracy and F1 score above 0.9 (Table 2).

When adjusting sensitivity to 0.95, the system's specificity decreased to 0.57–0.69, accuracy decreased to 0.82–0.87, and the F1 score decreased to 0.88–0.93. Generating a list with potential close contacts for 7 days required 18–43 minutes.

The simulated positive study participant recalled 27 contacts, and 31 contacts were generated by the automated system. The additional 4 contacts were reviewed as correct by the simulated index case, for an additional contact yield of 14.8%.

For 10,000 employees at BJH, with 4 positive cases introduced from the community daily and an average of 19 contacts per week, the number of false-positive potential contacts would be 37 per week. The effective reproduction number would decrease by 56% from a baseline of 2.5 if BLE-based contact tracing were used.

Table 1. Healthcare Personnel Participation Rates by Occupation and Study Unit[a]

	Intensive Care Unit		Medical Unit	
Occupation	No.	%	No.	%
Respiratory therapist	15/34	44.1		
Pharmacist	5/5	100		
Secretary	3/5	60	2/3	66.7
Environmental services	2/3	66.7		
Social worker	2/4	50	2/5	40
Fellow	6/21	28.6		
Dietician	1/1	100		
Intensivist	18/25	72		
Hospitalist			9/45	20
Advance practice providers	10/13	76.9	0/6	0
Technician	3/3	100	3/3	100
Resident physician	28/61	45.9		
Nurse	58/139	41.7	19/36	52.8

[a]All healthcare personnel including clinicians, environmental and clerical staff working on the study units were approached via email. The medical ward was staffed by hospitalists and advanced practice providers, and the intensive care unit was staffed by intensivists, fellows, residents, and advanced practice providers.

Table 2. Location and Contact Tracing in Different Locations on the Study Wards Using the Fingerprinting and Clustering Methods[a]

	Contact Tracing Performance			
Location	Sensitivity	Specificity	Accuracy	F1 Score
Nurses' stations (9 anchors)	1	0.87	0.92	0.91
Nurses' stations (17 anchors)	1	1	1	1
Break rooms	0.90	0.85	0.88	0.91
South hallway including patient rounds	0.93	0.79	0.90	0.93
North hallway including patient rounds	0.94	0.72	0.90	0.94

[a]For indoor geolocation, we calculated the proximity between users in 2 steps: (1) room-level location and (2) proximity location by predicting users' location and calculating the distance between them. Close contact was defined as <2 m (6 ft) for at least 15 minutes cumulative time over 24 hours. To capture participants in patients rounds, we added clustering methods identifying the group of people rounding together.

Discussion

BLE-based contact tracing demonstrated excellent performance characteristics in locating HCP at the room level and identifying close contacts as defined by the CDC criteria.

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In a pilot study in New Zealand, Bluetooth-enabled cards detected more contacts than reported by the staff, and all surveyed participants were willing to use a similar card again.[8] In Singapore, in-hospital, tag-based, real-time location had a sensitivity of 95.3% for detecting potential contacts, compared to 6.5% for manual tracing.[5] "Hybrid" models integrated contact tracing data with genomic analyses to inform directionality of transmission.[9] The role of digital contact tracing was tested in other hospital-acquired infections.[10]

This study had several limitations. We were unable to analyze the impact on transmission events and with different group participation; thus, our results may not be generalizable to other populations or settings. In our study, intensivists were significantly more likely to participate. The enrollment rate required for epidemic control in healthcare settings is unclear. Digital technologies do not account for mitigation strategies, and it is unclear how much additional work our system would add to infection preventionists in the clinical setting. During the study period, the system was maintained by a research coordinator and doctoral student with input from a physician and computer science engineer.

BLE-based contact tracing presents an affordable and scalable system that may function as a screening tool to complement traditional contact-tracing methods.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2023.227

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Competing interests. All authors report no conflicts of interest relevant to this article.

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