Envisioning the Future of Health Informatics and Digital Health
J. Mantas et al. (Eds.)

doi:10.3233/SHTI250102

Sensor-Based Monitoring of Hand Hygiene in Hospitals: Strengths and Weaknesses of an IoT-Based System

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Abstract. Hand hygiene is a critical aspect of patient safety in hospitals. To assess adherence to hand hygiene protocols, a sensor-based system has been developed that monitors the movements of healthcare professionals using Bluetooth technology. This system comprises a Data Collection Node (DCN) and several Bluetooth beacons strategically installed within the monitored department. Results from a study conducted at the Eastern Switzerland Children's Hospital indicate that while the system is capable of generating movement profiles, it fails to provide reliable adherence profiles for hand hygiene. It is essential to develop more precise technologies, which may be more costly than the Bluetooth beacon technology currently employed. Nevertheless, this project highlights potential avenues for enhancing hospital hygiene practices through digital monitoring and support.

Keywords. IoT, Hand Hygiene Monitoring, Healthcare Compliance Tracking, Bluetooth Beacons, Hygiene Adherence

1. Introduction

Nosocomial infections pose a serious and persistent challenge to healthcare systems. In Switzerland alone, approximately 70,000 patients are identified annually with a nosocomial infection [1]. The most effective measure against the spread of these pathogens is rigorous hand hygiene [2]; however, adherence to hand hygiene protocols is difficult to quantify [3]. Direct observation, currently the gold standard for measuring hand hygiene adherence, is labor-intensive and time-consuming, and may lack reliability due to the Hawthorne effect [4]. When hand hygiene adherence can be effectively monitored, it enables the provision of feedback and facilitates targeted interventions aimed at increasing awareness and supporting process improvements [5].

To address these challenges, this study examines the following 3 research questions: (i) Can the current gold standard of continuous physical monitoring throughout an entire day be effectively replaced by an automated surveillance system utilizing Internet of Things (IoT) technology without compromising information quality? (ii) How can the commonly used hygiene bottles among healthcare professionals be integrated into such

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a solution? (iii) What technical feedback options for hand hygiene and individual staff members are feasible and acceptable to the stakeholders involved?

In the following section, we will first present our use case, after which we will describe the concept of sensor-based tracking for hand hygiene events. The objective is to measure the indicators according to the WHO's "My 5 Moments" for hand hygiene. Subsequently, we will outline the key components of our solution and present the results of the compliance evaluation. Finally, we will critically assess our solution and provide recommendations for potential future research directions.

2. Methods

Our use case involves a Swiss acute care hospital aiming to enhance hand hygiene monitoring to more effectively prevent infections. The current implementation of the "CleanHands" module for monitoring hand hygiene adherence relies on manual observations conducted by trained hospital hygiene staff, which are recorded using mobile devices and stored in a centralized database [6]. While this method is well-established and valuable, its associated costs limit its application to only a few days each year. Therefore, the objective is to integrate IoT-based sensors into the existing "CleanHands" infrastructure to enable continuous monitoring while maintaining or even improving efficiency, accuracy, and real-time capabilities. The proposed solution will autonomously collect and analyze data, providing immediate feedback to nursing staff. This approach aims to facilitate more frequent monitoring without additional personnel, thereby reducing the burden on hospital staff and enhancing overall hygiene quality.

Our solution aims to implement the WHO concept of "My 5 Moments for Hand Hygiene", which defines five critical phases during which healthcare personnel should perform hand disinfection to prevent the spread of infections [7]:

1. Before Patient Contact: Perform hand disinfection prior to any initial physical contact with the patient to protect them from external pathogens.
2. Prior to Aseptic Procedures: Conduct disinfection before undertaking invasive or sterile procedures (e.g., catheter insertion) to safeguard the patient from microorganisms present on the healthcare personnel's skin.
3. After Contact with Body Fluids: Execute hand disinfection immediately following exposure to blood or other body fluids, regardless of whether gloves were worn, to mitigate the risk of pathogen transmission.
4. After Patient Contact: Implement hand disinfection after leaving the immediate vicinity of the patient to prevent the spread of contamination.
5. After Contact with the Patient's Environment: Carry out hand disinfection after touching surfaces or objects within the patient's environment, even in the absence of direct patient contact, to reduce the risk of cross-contamination.

This concept is internationally recognized and serves to standardize and enhance hand hygiene practices in healthcare facilities.

The final IoT-based hand hygiene tracking system employs a combination of stationary and mobile Bluetooth beacons to monitor and enhance compliance with hygiene protocols [8]. Stationary beacons positioned in patient areas and at hand sanitizer dispensers emit signals to detect the proximity of healthcare personnel, triggering events upon their approach or departure. Handwashing compliance is approximated by requiring personnel to stand at the dispenser for at least 5 seconds, although 100% certainty of handwashing cannot be guaranteed. Dispensers are placed sufficiently away from common agitation zones, reducing the risk of false readings. Mobile beacons attached to hand sanitizer bottles and semi-stationary dispensers recognize movement to determine sanitizer usage. The two beacon models utilized from kontakt.io are the Smart Beacon SB18-3 for stationary applications and the asset tag S18-3 for mobile applications. Specifically, the system incorporates 10 beacons for patient beds and the patient area, 4 beacons for automatic stationary dispensers, 6 beacons for manual stationary dispensers, 2 beacons for hand sanitizer bottles, and 10 beacons for semi-stationary dispensers. It is important to note that radiation levels from devices like Smart Beacons are relatively low compared to more powerful sources like mobile phones.

A mobile device, designated as the Data Collection Node (DCN), is responsible for capturing signals from beacons and transmitting the data to a backend system for analysis. This functionality enables the tracking of specific hygiene-related events and provides real-time feedback on compliance with hygiene standards. To optimize for availability and user familiarity, an Android device has been selected as the DCN. While the communication with the beacons utilizes the Bluetooth stack, the Android implementation of the Bluetooth interface is not employed directly. Instead, the SDK from the beacon manufacturer kontakt.io, version 3.3.2, is utilized. This SDK simplifies and enhances various aspects of Bluetooth communication, addressing several challenges associated with this technology.

Over a span of four consecutive days in the hospital's intensive care unit, two experimental series were conducted to evaluate the IoT system. On the first day, all beds and dispensers were equipped with Bluetooth beacons, and their connectivity was tested. The first experimental series took place on the second day, during which four staff members were equipped with a DCN, and their events were recorded throughout their shifts. However, due to technical issues, fewer data points were collected than initially planned. The third day was dedicated to resolving these issues by switching connectivity to 4G and migrating the backend to an Amazon web services cloud. On the fourth day, data collection resumed as scheduled. Two staff members were tracked sequentially using the DCN while being simultaneously observed by an infection control specialist to compare sensor data with reference data.

3. Results

Since the central results were generated on the final day, we will focus our discussion on these findings. On this day, two test executions were conducted sequentially, allowing for a direct comparison between the sensor-based system and the existing solution, known as “direct observation”. At approximately 9 AM, a healthcare professional was equipped with a DCN and was simultaneously subjected to a direct observation assessment by a specialist from the hospital hygiene department. Figure 1 illustrates the reporting data generated by the sensor-based system, while Figure 2 presents the evaluation of the data obtained through the direct observation method using CleanHands. Received Signal Strength Indication (RSSI) refers to the signal strength of the beacon as perceived by a receiving device (e.g., a smartphone).

The results indicate that the IoT system provides a detailed movement profile that is too complex and inaccurate for the classification of hand hygiene events when compared to manual tracing, which serves as the gold standard. Several factors contribute to these inadequate results. First, the complex and spatially constrained environment of a pediatric intensive care unit, where the study was conducted, presents significant challenges. Second, measurement errors could not be filtered as anticipated. The generated event data prove to be surprisingly complex to interpret. On one hand, there is a spatial dependency among the individual events; for instance, Event 1 from Beacon A is related to Event 4 if the latter originates from the adjacent Beacon B. Additionally, events from the same beacons are interdependent, as a new event is generated every second. Furthermore, significant measurement errors exist, making diagnostics challenging. It remains unclear whether a person has genuinely moved away from Beacon A or if the signal from Beacon A is simply no longer being received. Additionally, errors may arise from transmission issues, particularly when the signal from the beacon is received on the DCN but is not correctly relayed to the backend system.

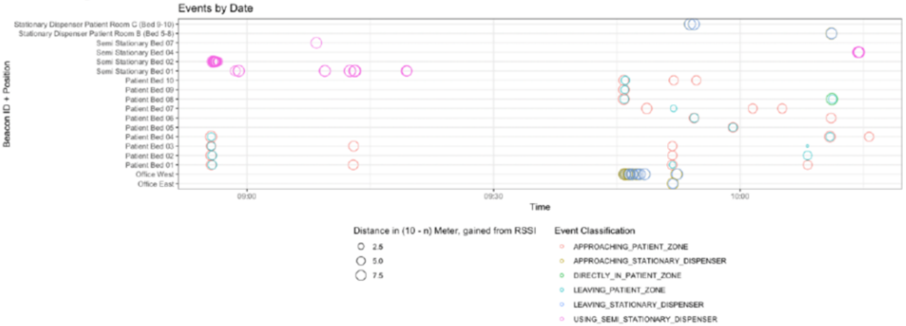

Figure 1. Events according to the sensor-based system.

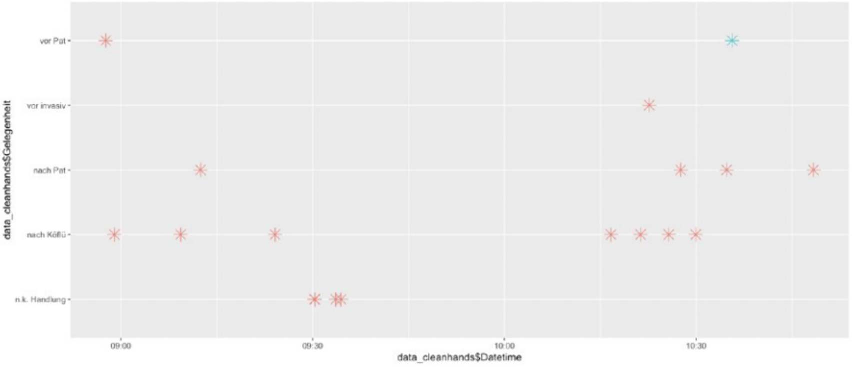

Figure 2. Hand hygiene events according to direct observations.

4. Discussion

The implementation of the IoT-based system in a fast-paced and spatially constrained environment presents more challenges than initially anticipated, especially when operating within a limited budget. It would be beneficial to test this concept in different settings, such as nursing homes, where there is generally more spaciousness and clearer separations between patients, potentially increasing the likelihood of success. During the data collection phase of our use case, it quickly became evident that sensor-based monitoring does not achieve the accuracy of direct observation, which is considered the gold standard. Nevertheless, we were able to derive insights from the collected data regarding the movement patterns of the observed individuals. Movement profiles in the healthcare sector are particularly intriguing, as staff members typically cover an average distance of over five kilometers during an 8.5-hour shift.

Smartwatches are a promising alternative for detecting handwashing by leveraging built-in sensors such as accelerometers, gyroscopes, and motion sensors to track characteristic hand movements, including rubbing, rotating, and the duration and frequency of these actions. For instance, wrist rotations or repeated hand motions under water could indicate handwashing. However, challenges remain in distinguishing handwashing from other activities with similar movements, and detection accuracy depends on the smartwatch's ability to accurately recognize and analyze these patterns.

We still see significant potential in IoT solutions for monitoring processes in healthcare settings, despite the limitations stemming from our restricted budget. However, it is important to note that successful implementation requires a thorough understanding of the specific challenges and needs of the environment. For example, we had to immediately discard an initial idea for video monitoring of hand hygiene events due to concerns about data privacy, as well as a general discomfort associated with the perception of constant surveillance which was seen as a significant deterrent (see also [9]). With video, the person themselves is often the focus, which may lead to feelings of being watched or spied on. In contrast, sensors can be designed to monitor only specific actions. Finally, even though our primary research questions yielded negative results, the other two research questions were answered positively, and the insights we have gained are instrumental in guiding our next steps.

References

[1] Gasser M, Cassini A, Lo Fo Wong D, Gelormini M, Nahrgang SA, Zingg W, Kronenberg AO. Associated deaths and disability-adjusted life-years caused by infections with antibiotic-resistant bacteria in Switzerland, 2010 to 2019. Euro Surveill. 2023 May;28(20):2200532. doi: 10.2807/1560-7917.ES.2023.28.20.2200532.

[2] Issa M, Dunne SS, Dunne CP. Hand hygiene practices for prevention of health care-associated infections associated with admitted infectious patients in the emergency department: a systematic review. Ir J Med Sci. 2023 Apr;192(2):871-899. doi: 10.1007/s11845-022-03004-y.

[3] K, Chipungu J, Dreibelbis R, Ejemot-Nwadiaro R, Gordon B, Esteves Mills J, Cumming O. Recommendations for hand hygiene in community settings: a scoping review of current international guidelines. BMJ Open. 2023 Jun 21;13(6):e068887. doi: 10.1136/bmjopen-2022-068887.

[4] Armstrong-Novak J, Juan HY, Cooper K, Bailey P. Healthcare Personnel Hand Hygiene Compliance: Are We There Yet? Curr Infect Dis Rep. 2023 May 26:1-7. doi: 10.1007/s11908-023-00806-8.

[5] Boyce JM. Current issues in hand hygiene. Am J Infect Control. 2023 Nov;51(11S):A35-A43. doi: 10.1016/j.ajic.2023.02.003.

[6] Schmutz JB, Grande B, Sax H. WHO 'My five moments for hand hygiene' in anaesthesia induction: a video-based analysis reveals novel system challenges and design opportunities. J Hosp Infect. 2023 May;135:163-170. doi: 10.1016/j.jhin.2023.03.002.

[7] Svenšek A, Muršec D, Fijačko N. Assessing the incorporation of the 'Five Moments for Hand Hygiene' into nursing procedure textbooks. Nurse Educ Pract. 2024 Aug;79:104044. doi: 10.1016/j.nepr.2024.104044.

[8] Wei S, Wright-Freeman K, McConnell ES, et al. Feasibility and Utility of Wearable Bluetooth and RFID Sensors to Measure Care Interactions. Work Aging Retire 2024;10(1): 46–50.

[9] McKay KJ, Li C, Sotomayor-Castillo C, Ferguson PE, Wyer M, Shaban RZ. Health care workers' experiences of video-based monitoring of hand hygiene behaviors: a qualitative study. Am J Infect Control. 2023 Jan;51(1):83-88. doi: 10.1016/j.ajic.2022.03.010.