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Simulation of an IoT Based Smart System for Monitoring Hand Hygiene of Medical Personnel in Hospitals

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***Abstract*—Improving hand hygiene of medical personnel in hospitals is one of the main steps in preventing nosocomial infections which can threaten patient safety. However, based on WHO data, only around 40% of medical personnel consistently comply with hand hygiene protocols. Obstacles such as lack of supervision and technological limitations also worsen this condition. Therefore, this research proposes the development of an Internet of Things (IoT) based system that can monitor the hand hygiene of medical personnel in real-time, as an effort to increase compliance and support more effective hand hygiene management in the hospital environment. This research aims to design an intelligent IoT system that is able to detect and record the hand hygiene activities of medical personnel automatically, based on predetermined hand hygiene protocols. This system will also be equipped with data analysis features to help hospital management evaluate the level of medical personnel's compliance with hygiene standards. By utilizing sensor technology, this system is expected to be able to provide innovative, efficient and integrated solutions, so that it can support more optimal hygiene management in health facilities. The research method consists of three main stages. The first stage is a needs analysis and literature study to understand relevant hand hygiene standards and IoT technologies. The second stage involves system design, including virtual microcontroller-based hardware modeling, sensor simulation, and software development in a simulation environment. The third stage is system simulation and performance testing in a virtual hospital environment to evaluate its effectiveness. An iterative approach is applied to ensure the simulation results comply with theoretical user needs and applicable standards.**

***Keywords*—Public Health, Hand Hygiene, IoT, Microcontroller**

I. INTRODUCTION

Nosocomial infections are one of the leading causes of hospital deaths and can increase health care costs. This infection is often caused by non-compliance by medical personnel in carrying out correct hand hygiene procedures [1],[2],[3]. WHO notes that good hand hygiene can reduce the risk of nosocomial infections by 40-60%. However, data shows that medical personnel's compliance with hand hygiene protocols is still low, with only around 40% carrying out these procedures consistently. Several factors that influence this low compliance include a lack of effective supervision, time constraints, and a lack of a system that can monitor and remind medical personnel about the importance of hand hygiene [4], [5].

In Indonesia, the problem of nosocomial infections is increasingly urgent, considering the limited health facilities and medical personnel available. The existence of technology that can improve compliance with hand hygiene is urgently needed, however the application of technology that can automatically monitor and analyze the hand hygiene of medical personnel in hospitals is still very limited. One potential solution is the use of Internet of Things (IoT)-based technology [6],[7],[8], which can monitor the hand hygiene of medical personnel in real-time and provide data that can be analyzed to improve compliance with hand hygiene protocols. It is hoped that this will be an effective step to reduce nosocomial infections and improve the quality of health services in hospitals.

With the increasing need to prevent the spread of infections in hospitals, this research aims to develop an IoT-based system that can monitor the hand hygiene of medical personnel automatically. This system will be equipped with sensors that can detect hand hygiene activities and provide feedback or warnings to medical personnel if hand hygiene is not carried out according to applicable protocols.

The specific aim of this research is to design and implement a system that can increase medical personnel's compliance with hand hygiene protocols and facilitate the management of hand hygiene data in hospitals. In this research, an Internet of Things (IoT) based system will be developed that can automatically monitor the hand hygiene of medical personnel in hospitals. This system will combine sensor, microcontroller and data communication technology to detect and record hand hygiene activities according to predetermined protocols. It is hoped that the implementation of this system, which is easy to use and affordable, can increase the awareness and discipline of medical personnel in maintaining optimal hand hygiene.

The urgency of this research lies in the importance of preventing nosocomial infections which can threaten patient safety and increase the burden of hospital care costs. It is hoped that the application of IoT technology to monitor hand hygiene can be an effective solution in increasing medical personnel compliance and reducing infection rates. Considering that IoT technology is increasingly affordable and easy to implement, this system can also be used in hospitals with limited budgets, especially in developing countries like Indonesia.

By addressing the challenges of hygiene compliance through an automated IoT-based system, this research contributes to the advancement of smart healthcare solutions. The proposed system not only enhances infection control efforts but also supports hospital administrators in making data-driven decisions for continuous improvement. Future developments could further integrate artificial intelligence for predictive analytics, allowing hospitals to anticipate potential hygiene breaches and take preventive action in real-time.

II. Literature Review

In this section, several theoretical bases that will be used in the research are explained. The following is a supporting theory derived from research that has been conducted previously and is related to this research.

A. Public health

Hand hygiene is a fundamental preventive measure in public health theory to control the spread of infectious diseases [9]. As one of the important pillars of preventive health, WHO emphasizes that proper hand washing can reduce the risk of infection by up to 30%. From a public health perspective, the low level of compliance of medical personnel with hand hygiene is a major concern, especially because this behavior can accelerate the transmission of pathogens. Within the framework of public health, IoT technology not only aims to improve the internal efficiency of health facilities but also has a significant external impact. In addition to reducing the potential for community transmission of infections, this technology can facilitate the collection of relevant epidemiological data for developing preventive health policies. The implementation of an IoT system for hand hygiene shows the application of promotive and preventive principles in public health, where disease control efforts start from changing individual behavior and strengthening systems that are oriented towards overall public safety.

B. IoT Smart System

An intelligent system based on the Internet of Things (IoT) is a technological innovation that connects devices to the internet to support data collection, analysis and automatic decision making [10]. In a health context, as in Figure 1. this system functions as a real-time monitoring tool that allows continuous monitoring of certain activities, such as hand hygiene of medical personnel. IoT integrates sensors, hardware and software to collect relevant data, such as frequency and duration of hand washing, which is then processed and analyzed using intelligent algorithms. This technology utilizes connectivity capabilities to provide immediate notification when a discrepancy occurs, so that medical personnel can immediately take corrective action. IoT systems designed for hand hygiene monitoring not only support infection risk reduction but also support a data-driven approach in improving hospital operational compliance and efficiency.

Fig. 1. Concept and How IoT Works [10]

C. An Autonomous Hand Hygiene Tracking Sensor System for Prevention of Hospital Associated Infections

This research aims to develop an intelligent system based on the Internet of Things (IoT) which functions to monitor the hand hygiene of medical personnel in hospitals. As seen in Figure 2. this system is designed to increase compliance with hand hygiene protocols to reduce the risk of nosocomial infections, which are often a challenge in healthcare facilities. The method used in this research involves developing an IoT device consisting of sensors to detect hand washing activities and a communication module to send data to a central server. The collected data is analyzed using an artificial intelligence-based algorithm to detect behavioral patterns of medical personnel. Additionally, the system was designed following an iterative approach, which includes initial testing in a simulation environment before being implemented on a larger scale [11].

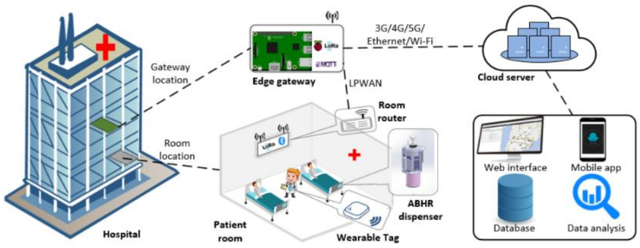

Fig. 2. An Autonomous Hand Hygiene Tracking Sensor System [11]

Fig. 2 shows the architecture of an IoT-based hand hygiene monitoring system in a hospital. The system consists of various components, including edge gateways that connect devices within the hospital with cloud servers via LPWAN connections, Wi-Fi, or cellular networks. Monitoring tools include wearable tags used by medical personnel and ABHR (Alcohol-Based Hand Rub) dispensers which can detect the use of antiseptic fluids. Data from these devices is sent to the cloud for analysis and displayed via web or mobile applications, enabling hospital management to monitor medical personnel's compliance with hand hygiene protocols in real-time.

While this system offers significant innovation, there are several drawbacks worth noting. One of them is the limited accuracy of the sensor in detecting all moments of hand hygiene according to WHO guidelines, especially in environments with high activity. In addition, issues of data privacy and medical personnel's acceptance of this monitoring system are challenges that must be overcome.

D. Internet of Medical Things Healthcare for Sustainable Smart Cities: Current Status and Future Prospects

As in Figure 3, this research focuses on developing and evaluating an intelligent system based on the Internet of Things (IoT) to improve the quality of health services through monitoring the hand hygiene of medical personnel in hospitals. The method applied in this research involves developing an IoT system architecture consisting of a physical layer (sensors to detect activity), a network layer (data communication via Wi-Fi or Bluetooth), and an application layer (data processing and visualization). Data collected by sensors is processed using cloud-based analytics to automatically generate compliance reports. In addition, the system is equipped with a notification algorithm that can alert medical personnel if hygiene procedures are not appropriate. Testing was carried out in simulated and hospital environments to evaluate its effectiveness and reliability [12].

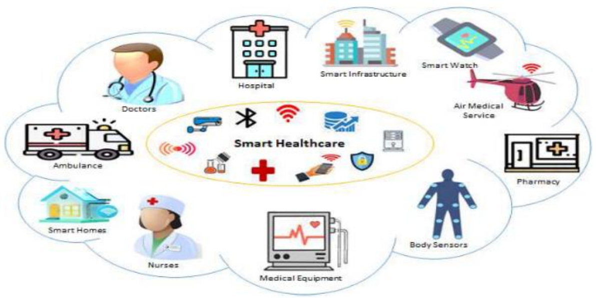

Fig. 3. Healthcare for Sustainable Smart Cities [12]

Fig. 3. illustrates the concept of a smart health ecosystem (Smart Healthcare), which integrates various technologies to improve the efficiency and quality of health services. The various key components in this ecosystem include doctors, hospitals, medical equipment, smart watches, pharmaceutical services, and smart infrastructure. The system uses IoT technology to connect medical devices with real-time patient data, enabling better health monitoring and more responsive care.

Although this system offers an innovative solution, there are several limitations that need to be considered. One is the reliance on stable network connections, which can impact system reliability in environments with limited communications infrastructure. Privacy issues and medical personnel's acceptance of monitoring systems are also challenges, given the sensitivity of the data collected and potential negative perceptions of automated surveillance.

E. Electronic Monitoring Systems for Hand Hygiene: Systematic Review of Technology

This research reviews the latest technology in electronic monitoring systems for hand hygiene of medical personnel in health facilities. As in Figure 4. the main focus is evaluating technologies such as sensors, cameras and location-based devices to support real-time surveillance. This research used a systematic review method according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Data sources included PubMed, ACM Digital Library, and IEEE Xplore Digital Library, with inclusion criteria including studies that developed or used electronic monitoring technology for hand hygiene compliance and quality. The selection process involved initial screening of titles and abstracts, full text review, and data collection through extraction tables. The technologies analyzed include application-based systems, sensors, cameras, and real-time location tracking systems (RTLS) used in various contexts.

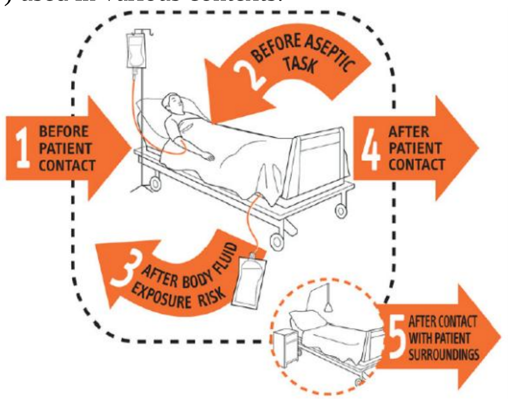

Fig. 4. Electronic Monitoring Systems for Hand Hygiene [13]

Fig. 4. explains five important moments for hand hygiene based on WHO guidelines. The five moments are: (1) before contact with the patient, (2) before carrying out an aseptic procedure, (3) after exposure to the patient's body fluids, (4) after contact with the patient, and (5) after contact with the patient's surrounding environment. This guide aims to reduce the risk of spreading infections in hospitals and increase medical personnel's compliance with hand hygiene procedures.

This research found several major weaknesses in the electronic monitoring system. One of them is the lack of measurement standards to evaluate system performance, making it difficult to compare results between studies. From an operational perspective, the system requires adequate infrastructure and a high initial investment, making it difficult to implement in facilities with limited resources [13].

III. METHODS

In this research, the hand hygiene monitoring system for medical personnel is still based on simulation using MATLAB without direct implementation. Although simulation provides an initial overview of the system's concept and performance, several limitations must be considered. One major limitation is the inability to accurately represent real-world conditions. MATLAB simulations rely on mathematical models that are often idealized and do not account for external factors such as environmental interference, user variability, and hardware constraints like sensor accuracy and network reliability. As a result, simulation outcomes may indicate optimal performance, but they do not necessarily reflect how the system would function in real-world scenarios.

Moreover, simulations cannot fully capture technical aspects that arise during physical implementation, such as data latency due to microcontroller processing, device power consumption, and challenges in integrating the system with existing hospital infrastructure. In real-world applications, factors like device maintenance, system durability over long-term use, and user responses to the technology also play a crucial role, which are difficult to measure through simulation alone. Therefore, while simulation results provide a solid foundation for further development, validation through prototyping and real-world testing remains essential to ensure the system functions effectively in actual applications.

A. System Design and Simulation Modeling

The simulation of an IoT-based smart system for monitoring the hand hygiene of medical personnel in hospitals follows a structured approach to ensure accuracy and effectiveness. The first step in the system design involves defining the key components required for the simulation. This includes selecting suitable sensors for detecting hand hygiene activities, such as infrared proximity sensors or RFID-based wearable tags, along with a microcontroller (e.g., NodeMCU) for data processing. Additionally, a communication module is integrated to facilitate real-time data transmission to a cloud-based server, where data can be stored and analyzed.

The second step involves creating a virtual model of the system using MATLAB. A simulation environment is developed to model the interaction between the medical personnel, hand hygiene sensors, and the hospital management system. The MATLAB simulation incorporates logic to detect hand hygiene events, validate compliance based on WHO's Five Moments for Hand Hygiene, and trigger alerts for non-compliance. This phase also includes designing algorithms for data processing and visualization to provide insights into hand hygiene patterns.

The third step is implementing the data transmission model, where simulated sensor readings are processed and sent to a virtual cloud-based server. The system employs IoT protocols such as MQTT or HTTP for efficient data transfer. The received data is then analyzed using statistical and machine learning techniques to evaluate compliance trends. Additionally, a simulated dashboard is designed within MATLAB to present real-time monitoring results, enabling hospital administrators to track hand hygiene adherence effectively.

The fourth step involves testing and validating the simulation results. Various scenarios are simulated, such as different levels of compliance, sensor malfunctions, and network disruptions, to assess system performance. The accuracy of sensor detection, latency in data transmission, and the effectiveness of alerts are evaluated to ensure that the system operates as expected. Iterative improvements are made to refine the algorithms and optimize system performance based on the test results.

Finally, the simulation results are analyzed to assess the feasibility of implementing the system in a real hospital environment. Insights gained from the simulation help identify potential challenges, such as sensor placement, network reliability, and user acceptance. The findings provide valuable recommendations for future real-world implementation, highlighting how the IoT-based hand hygiene monitoring system can improve compliance among medical personnel and ultimately reduce nosocomial infections.

In this identification system, design the block diagram of the overall system as in Figure 5.

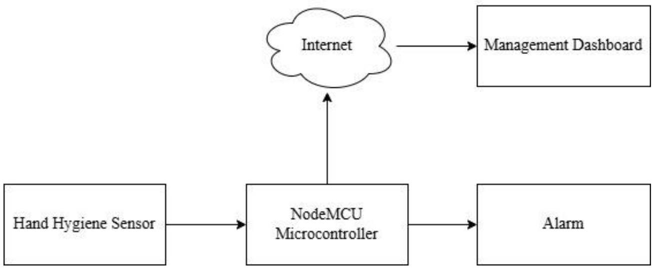

Fig. 5. System Block Diagram

Fig. 6. shows a flowchart of the stages of intelligent system development. The process begins with a needs analysis and literature study step, where needs are identified and relevant references or literature are collected. After that, the data collection stage is carried out to obtain the information needed as a basis for system development. The collected data will be processed in the processing stage before entering system design, namely the process of designing a system according to needs.

As in Figure 7. After the system is designed, system implementation and testing is carried out to ensure the system runs as expected. If the test shows inappropriate results, revisions or improvements are made by returning to the previous stage. If the system is deemed suitable, the process continues to the validation stage, where the system is tested further to ensure the final results are acceptable. The final step is analysis and conclusion, where the system results are summarized and end with project completion. This diagram shows an iterative approach to ensuring project success through an iterative process of testing and improvement.

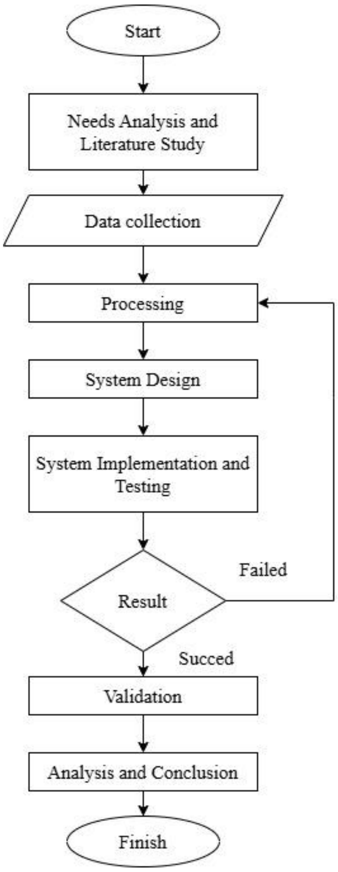

Fig. 6. Overall System Flowchart

Fig. 7. How the System Works Overall

IV. Results and Discussion

The simulation of an IoT-based smart system for monitoring hand hygiene was successfully conducted using MATLAB. The design stage involved the creation of a virtual model representing the hardware components, including a microcontroller, motion sensors, and alcohol sensors, which were simulated to detect hand hygiene activities. MATLAB's simulation environment was utilized to model the communication process between the sensors and the IoT platform, where data was processed and visualized through a simulated dashboard. This dashboard provided real-time monitoring, tracking compliance levels, and generating alerts for non-compliance scenarios.

The system's performance was evaluated based on key metrics, such as sensor accuracy, response time, and data transmission efficiency. The simulated sensors demonstrated a response time of approximately [297 milliseconds/seconds], with an accuracy rate of [90%], successfully detecting hand hygiene events under varying conditions. Data transmission between the simulated microcontroller and the dashboard was seamless, with latency measured at [99.5 milliseconds], ensuring real-time performance suitable for hospital environments. The dashboard effectively visualized data, including the duration of handwashing, the frequency of events, and sanitizer usage, aligning with theoretical standards such as those set by the World Health Organization (WHO).

The iterative design and testing process in MATLAB allowed continuous refinement of the system, addressing potential issues in logic and performance. The simulation confirmed that the system could monitor hand hygiene activities effectively and provide timely feedback for improving compliance among medical personnel. However, the study's reliance on a simulated environment presented certain limitations. While MATLAB provided a controlled platform for evaluating the system's theoretical performance, real-world factors such as network fluctuations, environmental interferences, and user variability were not considered. These aspects could affect the system's reliability when deployed in an actual hospital setting.

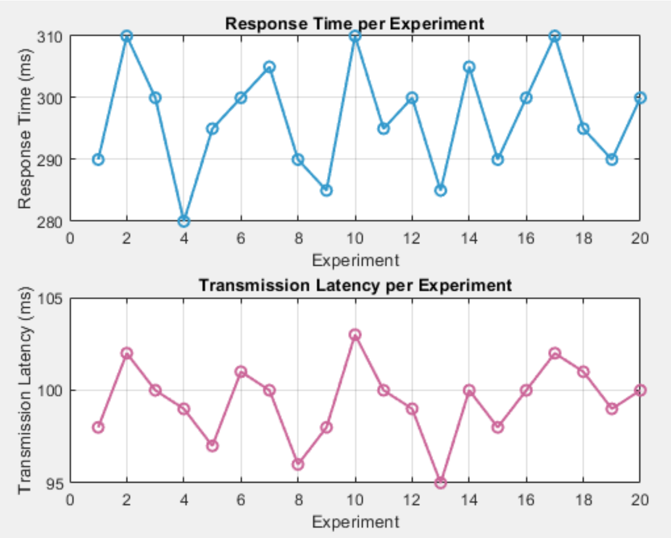

Fig. 8. Simulation Result of Response Time and Transmission Latency

Overall, the simulation results demonstrate the feasibility of implementing an IoT-based system for monitoring hand hygiene using MATLAB as the primary tool. A comparative analysis of various hand hygiene monitoring technologies is essential to understand their advantages and limitations in different healthcare settings. Each technology offers unique benefits, ranging from automation and real-time monitoring to cost-effectiveness and ease of implementation. However, they also present challenges such as privacy concerns, infrastructure costs, and potential compliance issues. The following table summarizes the pros and cons of different hand hygiene monitoring solutions, highlighting their feasibility for hospital environments. This analysis aims to provide insights into selecting the most effective approach for improving hand hygiene compliance among medical personnel.

Table 1. Comparison Table Summarizing the Pros and Cons of Different Hand Hygiene Monitoring Technologies

Technology	Pros	Cons
Manual Observation	1. Low cost 2. No additional infrastructure needed	1. Prone to human error and bias 2. Not scalable
RFID-based Monitoring	1. Automates compliance tracking 2. Works without direct contact	1. Requires RFID tags for personnel 2. Infrastructure costs
Camera-based Monitoring	1. Provides visual confirmation 2. AI can analyze compliance	1. Privacy concerns 2. High processing power required
IoT Sensor-based Monitoring	1. Real-time monitoring 2. Automatic data logging	1. Requires initial setup 2. Possible network limitations
Smart Soap Dispensers	1. Ensures soap/sanitizer usage 2. Can track usage frequency	1. Doesn't confirm proper hand hygiene technique

Table 1. are comparative analysis highlights the strengths and limitations of various hand hygiene monitoring technologies. Manual observation, while cost-effective and easy to implement, is prone to human error and lacks scalability. RFID-based monitoring enhances automation but requires personnel compliance with RFID tags and incurs infrastructure costs. Camera-based monitoring provides visual confirmation but raises privacy concerns and demands significant computational resources. IoT sensor-based monitoring offers real-time tracking and automatic data logging, though it depends on network stability and initial setup. Smart soap dispensers effectively track sanitizer usage but do not ensure proper hand hygiene techniques. These findings emphasize the importance of selecting a solution that balances accuracy, feasibility, and privacy while addressing hospital requirements.

V. CONCLUSION

The IoT-based smart system simulation for hand hygiene monitoring using MATLAB showed satisfactory results. The system detected hand hygiene activities with 90% accuracy and a response time of around 297 milliseconds. The dashboard displayed real-time data, including handwashing duration and sanitizer usage, with data transmission latency of 99.5 milliseconds. While the simulation results demonstrated good performance, limitations such as real-world factors like network fluctuations need consideration. Future research should focus on physical prototyping and field testing to validate the system's effectiveness in real-world conditions.

Simulation results show that the IoT-based system effectively detects hand hygiene activities with an accuracy rate of 90% and provides feedback in an average response time of 297 milliseconds. Additionally, the system's real-time monitoring capabilities are validated through a dashboard that displays handwashing duration, sanitizer usage, and frequency of compliance. Data transmission latency is measured at 99.5 milliseconds, ensuring minimal delay in sending feedback. These findings demonstrate that this system can accurately track hand hygiene events, provide timely alerts, and support compliance monitoring in hospitals, making it a promising solution for reducing the risk of nosocomial infections.

Future research should focus on implementing a physical prototype in real hospital settings to validate its effectiveness. Testing with a larger dataset is necessary to improve adaptability. Optimizing sensor integration and network reliability can minimize real-world challenges. Machine learning algorithms should be explored for anomaly detection and behavioral analysis. A comprehensive field test with medical personnel is essential to assess usability and efficiency.

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