Proactive monitoring and predictive alerts for COVID-19 patient management using internet of things, artificial intelligence, and cloud

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ABSTRACT

The coronavirus disease 2019 (COVID-19) pandemic has sparked changes across various domains, encompassing health, commerce, education, and the economy. Given the widespread impact of COVID-19 across numerous nations, it has strained hospital resources, oxygen reserves, and healthcare personnel. Consequently, there exists an urgent necessity to exploit sophisticated technologies such as artificial intelligence and the internet of things (IoT) to monitor patients effectively. This scholarly article proposes a prototype that integrates IoT and artificial intelligence (IA) for the surveillance of COVID-19 patients within healthcare facilities. Wearable IoT devices, equipped with embedded sensors, autonomously collect vital information like oxygen levels and body temperature. Notably, oxygen saturation and heart rate serve as significant markers in COVID-19 cases. These metrics are discerned through the deep learning capabilities of the TensorFlow library. The prototype aims to augment the intelligence of IoT sensors to identify these crucial signs through a trained model. A meticulously labeled dataset comprising oxygen saturation and heart rate data is amassed. Deep neural networks are deployed to prognosticate the disease's progression. The utilization of these technologies harbors the potential for rapid advancements in healthcare, thereby mitigating risks to human life and fostering more proactive responses to health crises.

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1. INTRODUCTION

Global healthcare systems have been severely impacted by the coronavirus disease 2019 (COVID-19) pandemic, which has also put a great deal of strain on hospital resources, such as medical personnel and oxygen supplies. Efficient patient care is essential for bettering clinical results and lowering death rates, particularly in urgent situations. This article explains how to use cutting-edge technologies like cloud computing, artificial intelligence (AI), and the internet of things (IoT) to proactively monitor and manage COVID-19 patients.

The IoT has emerged as a crucial tool in health monitoring, enabling remote control and monitoring of physical devices via the internet [1], [2]. The development of smart wearable monitoring devices has revolutionized approaches to managing the pandemic. After contact tracing and testing, monitoring of patients with mild symptoms who are quarantined at home due to health resource constraints is a major concern. IoT offers a promising solution by enabling the creation of a monitoring system capable of measuring physiological parameters such as oxygen levels, cough detection and heart rate without human intervention [3]. This implementation can ease the burden on healthcare workers by improving efficiency, especially when oxygen saturation and heart rate are common indicators of COVID-19 infection [4].

Despite significant advances, several issues remain unresolved, including optimizing prediction accuracy and improving systems integration for rapid and effective response to changes in patient conditions. Deep neural networks, inspired by the human brain and possessing similar learning capabilities, have enabled the processing of critical indicators of COVID-19 infection [5], [6]. Due to the scarcity of healthcare professionals, an effective health surveillance system could reduce physical contact, hospitalizations and associated costs for patients, while easing the burden on healthcare workers.

This study proposes an integrated framework using IoT, AI, and cloud for proactive monitoring and predictive alerts in the management of COVID-19 patients. Contributions include the development of improved AI algorithms for accurate predictions and the integration of these systems for continuous monitoring and rapid management. The proposed system involves the deployment of specialized sensors responsible for monitoring patients' vital parameters as directed by attending physicians. The collected data is then transmitted to medical staff for further evaluation and appropriate actions.

The COVID-19 pandemic led to the development of various technological innovations and applications aimed at monitoring patients and reducing the burden on healthcare systems [7]. In this regard, several studies explored the potential of IoT-based health monitoring systems, pulse oximetry devices, and machine learning algorithms for the early detection and preliminary diagnosis of COVID-19. In a study conducted by Mashrur *et al.* [8] a proposed monitoring system for COVID-19 patients in self-isolation focused on supervising physiological parameters like heart rate and location. The authors presented an IoT-based health monitoring system that measures body temperature, pulse rate, and oxygen saturation of COVID-19 patients using an Arduino Uno-based system, which could be synchronized with a mobile application for real-time access. The results obtained from the system were found to be accurate and quick, making it a potentially valuable tool during the COVID-19 pandemic.

A tracking system that identified impacted individuals more precisely was presented in a different study by Benreguia *et al.* [9]. Using a 2.4 GHz proprietary protocol, the system tracked anonymous risky contacts in places where people are highly concentrated, like schools, hospitals, big social gatherings, and businesses. It also allowed individual devices to communicate with each other. The device was a bracelet that captured signals from other devices to determine the proximity and duration of contact between individuals, aiding in controlling the spread of the virus. Qomariyah *et al.* [10] presented an IoT-based system for monitoring the vital signs of COVID-19 patients. The system employed sensors to measure temperature, pulse rate, and oxygen saturation, which were critical indicators of the health status of COVID-19 patients. The data collected by the system was transmitted to a cloud server, where it was analyzed and used to generate alerts for medical personnel if necessary. This approach helped prevent the spread of the virus and ensured that patients received timely medical attention.

A study assessing the use of a pulse oximeter-a device that measures blood oxygen and pulse rate-for the purpose of identifying COVID-19 was proposed by Ahmed *et al.* [11]. Patients who had been evaluated for symptoms consistent with COVID-19 and released from urgent care or the emergency department were included in the study. The patients were given a portable pulse oximeter and told to take readings twice a day for 14 days, both at rest and during physical activity. The study used a dataset of 200 audio recordings of coughs from patients with confirmed COVID-19 and 200 recordings from patients with other respiratory conditions. The researchers trained machine learning algorithms to distinguish between cough sounds from COVID-19 patients and those from patients with other respiratory conditions. The study found that the machine learning algorithms achieved an accuracy of up to 92.8% in distinguishing between coughs from COVID-19 patients and those with other respiratory conditions. Overall, these studies highlighted the potential of using technology to monitor COVID-19 patients and detect the virus in its early stages. IoT-based health monitoring systems, pulse oximetry devices, and machine learning algorithms helped healthcare providers reduce the burden on healthcare systems and provide timely medical attention to patients.

New technologies that could aid in early virus detection, diagnosis, and monitoring are critically needed, as the COVID-19 pandemic has highlighted. Healthcare system challenges, such as the COVID-19 pandemic, have been addressed by artificial intelligence (AI) and machine learning (ML), which have demonstrated considerable promise. A unified framework for trustworthy COVID-19 increase COVID-19 detection accuracy and reliability, the framework employed deep ensemble learning, cost-sensitive loss, uncertainty estimation, data augmentation, and an ImageNet-pretrained ResNet-50 model. With an area under the curve-receiver operating characteristic (AUC-ROC) of 85.43%, the suggested approach is deemed promising for the detection of COVID-19.

To The COVID-19 pandemic highlighted the need for cutting-edge technologies that could support early virus detection, diagnosis, and surveillance. ML and AI have demonstrated great promise in tackling a number of issues facing healthcare systems, such as the COVID-19 pandemic. In a study, Chang *et al.* [12] used crowdsourced cough audio to propose a unified framework for trustworthy COVID-19 detection. To increase the precision and dependability of COVID-19 detection, the framework made use of data augmentation, an ImageNet-pretrained ResNet-50 model, cost-sensitive loss, deep ensemble learning, and uncertainty estimation. The suggested approach demonstrated promise in COVID-19 detection with an AUC-ROC of 85.43%. Other studies also emphasized the potential of AI and ML in addressing the challenges posed by the COVID-19 pandemic.

Ghimir *et al.* [13] highlighted the significant success of AI and ML in addressing numerous challenges within healthcare systems, including diagnostic tools, prediction of mortality rates, advancements in vaccine and drug development, sentiment analysis of COVID-19 related comments, and identification of misinformation. Similarly, Taiwo *et al.* [14] emphasized the potential of technology in reducing the workload of doctors and medical personnel during a pandemic. The development of an IoT application for smart home automation allowed real-time health updates from patients to be communicated to healthcare professionals and doctors, facilitating prompt guidance. Yu *et al.* [15] discussed the role of the IoT technology in the development of smart hospitals. The study identified the technical infrastructure required for the establishment of smart hospitals, including five layers: perception layer, transport layer, processing layer, application layer, and business layer. The smart hospital concept involved the use of IoT, data analytics, personalized services, and AI to optimize healthcare management systems.

This article presented a sophisticated system designed to monitor patients suffering from COVID-19. The primary goal of this system was to facilitate real-time patient monitoring, enhance the quality of care, and ultimately optimize the effectiveness of healthcare interventions to save lives. The system included a prototype for monitoring patients affected by COVID-19, which periodically evaluated critical parameters such as body temperature, Oxygen saturation (SpO2) level, and heart rate. The article also discussed the design of a dataset for the detection of SpO2 and heart rate, major factors for monitoring the progression of the disease. The performance and reliability analysis of the AI-based model was also presented, evaluating various parameters such as precision, recall, and F1-score. The main contributions of this article include:

- The introduction of a prototype for monitoring patients affected by COVID-19. The device periodically evaluates critical parameters such as body temperature, SpO2 level, and heart rate.
- The design of a dataset for the detection of SpO2 and heart rate, which are major factors for monitoring the progression of the disease.
- The performance and reliability analysis of the AI-based model, evaluating various parameters such as precision, recall, and F1 score.

The structure of this article is as follows: section 2 presents the overall theoretical objectives and describes the chosen prototype in detail. Section 3 presents the proposed methods, including the justifications for the methodological choices in AI. Section 4 describes the results obtained and discusses them by comparing them with previous studies. Finally, section 5 concludes the study by highlighting the importance of our results and proposing directions for future research.

2. THE COMPREHENSIVE THEORETICAL BASIS

In this section, we will present the main design of the prototype, specifically developed to monitor people infected with COVID-19. This prototype is based on connected sensors that collect essential clinical data in real time. This information is then transmitted to a data management system in order to monitor the evolution of the patients' condition and alert healthcare professionals in case of deterioration.

2.1. The proposed architecture

The proposed system involves developing an IoT-based solution to capture various health data related to COVID-19 from infected individuals. It integrates multiple sensors to gather health metrics such as body temperature, SpO2 level, heart rate, and more. The sensor data is transmitted via an IoT gateway to a web-based interface, allowing healthcare professionals to monitor patients remotely. The server application performs analysis and visualization of these health parameters.

Robotics has seen significant growth, creating a parallel universe in various sectors, including manufacturing and healthcare. The application areas of robotics continue to expand, providing rapid and efficient execution with minimal or no risk of exposure [16], [17]. During the current epidemic, robotics has played a crucial role in providing rapid intervention, accurate interpretation of diseases, and ongoing treatment of patients. This paper proposes an intelligent control system for infected individuals admitted to the hospital, which aims to replace medical staff with a robot capable of controlling clinical parameters.

The system collects the values of measurable medical parameters in real-time and transmits them to the cloud for storage and interpretation by a doctor from the hospital health department [18]. The intelligent monitoring system proposed in this paper offers an innovative solution for monitoring and treatment of infected patients, using robotics technology to improve the efficiency and accuracy of healthcare. A deep learning model has been trained to identify critical health parameters such as oxygen saturation levels and heart rate [19]. In case of detecting abnormal oxygen saturation or irregular heartbeat, the relevant data is computed and transmitted via the internet to notify caregivers of any deterioration in the patient's health.

The system can still transmit real-time alerts to caregivers in case of any deterioration in the patient's health, along with the relevant information needed to identify the patient. Traditional methods involve regular monitoring by medical professionals to track the progression of COVID-19 in patients, but this approach poses a high risk for healthcare workers interacting directly with infected patients. To mitigate this risk, the proposed system utilizes robots as intermediaries, thereby reducing direct contact between individuals. The system is built on three primary subsystem platforms.

2.2. Data collection

The incorporation of IoT technology significantly streamlines the process of data collection. Various IoT sensors operate efficiently with minimal power consumption, allowing for continuous data collection and transmission. Monitoring patients' oxygen levels is critical, particularly considering the impact of suboptimal SpO2 levels on COVID-19 cases. Routine SpO2 measurement plays a pivotal role in detecting 'silent hypoxemia' in self-isolating COVID-19 patients [20]. Additionally, heart rate serves as another essential health parameter. To accurately measure both SpO2 and heart rate, we employed the CMS 50DL model pulse oximeter sensor. Furthermore, a dedicated temperature sensor was utilized to assess the patient's body temperature.

These IoT sensors seamlessly collect and transmit data to the IoT gateway, as depicted in the previous Figure 1. The sensor data model serves as input for the Arduino modules, contributing to the ongoing monitoring of the patient's condition. This continuous data transmission ensures real-time updates, allowing for timely interventions by healthcare professionals.

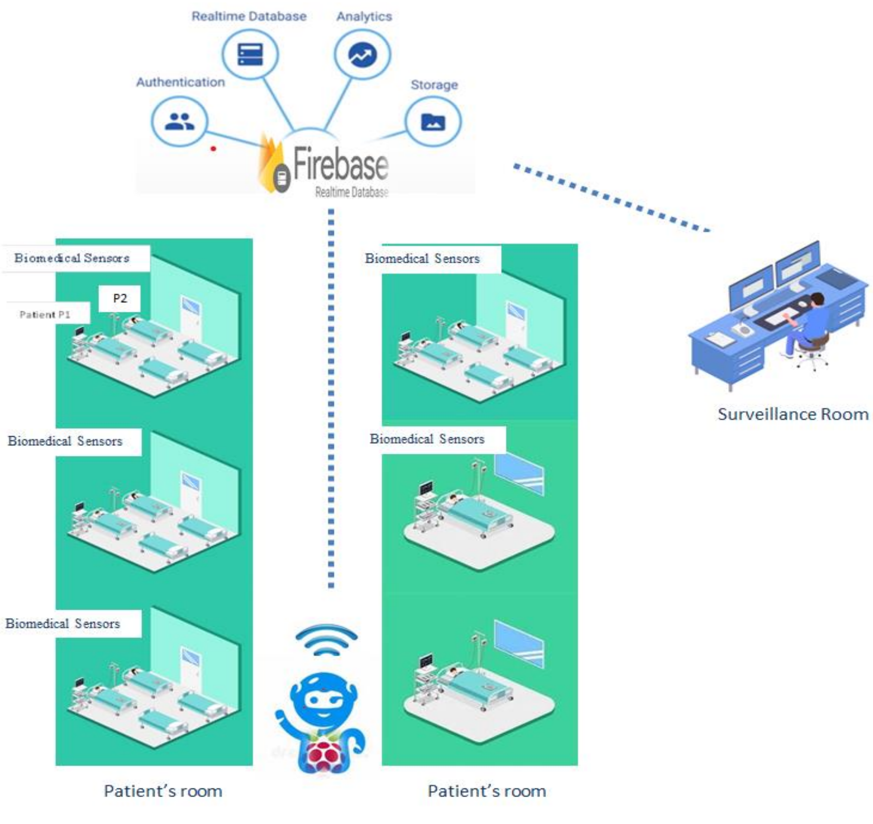

Figure 1. Global system architecture

2.3. Data transmission

The IoT data transmission sensors are essential in relaying patient information to the healthcare facility's data center at the monitoring room level, with IoT facilitating data transfer from nearly any remote location. Upon receiving data from the sensors, it is centralized into a cloud-based database and then displayed visually via a web app. Firebase operates as a managed database, providing exclusive features like user authentication, real-time NoSQL database, remote configuration, hosting capabilities, and integration compatibility with various mobile or web applications [21], [22]. The system uses a web application for monitoring, which will display a dashboard of patients' clinical parameters and send alerts in critical situations. The architecture of this intelligent surveillance system consists of three subsystems, as illustrated in Figure 2. The first subsystem (IoT subsystem) consists of sensors connected to the COVID-19 patient side, measuring clinical parameters and transmitting them instantaneously to the robot. The robot acts as a gateway, sending these values in real-time to a cloud server.

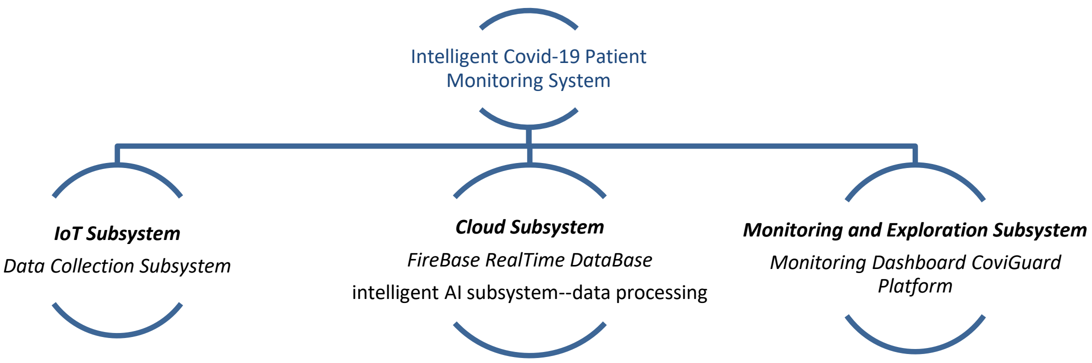

Figure 2. Subsystems

The cloud subsystem contains a database server, firebase real-time database [23], [24]. Here, the robot connects to this database in real-time using appropriate credentials. Sensor data is saved in firebase real-time database as JSON key-value pairs and can be retrieved from other devices and applications using the firebase real-time database API. This API also enables access to firebase services like firebase real-time database, firebase authentication, and firebase cloud messaging from the web page [25]. This facilitated the addition of features such as authentication, data storage, and push notifications to the web application due to cloud messaging (FCM). The last subsystem is represented here by a workstation which accesses the web platform to monitor the evolution of the condition of COVID-19 patients through a dashboard. It receives alerts when the intelligent subsystem predicts that the patient's situation is getting worse.

3. PROPOSED METHOD

In the context of mathematical modeling, we propose that the symbol $'S'$ serves as a representation of our envisioned system, proficient in assimilating diverse inputs designated as $i1$ (temperature), $i2$ (heart rate), and $i3$ (SpO2 level). Within the framework of the set $'F'$, the functionality of our system encompasses crucial tasks, including data collection, transmission, and anomaly detection. The resulting output $'O'$ from the S system amalgamates all gathered data, meticulously presented through a web application. This interface proves invaluable for healthcare professionals, facilitating the monitoring of COVID-19 patients' health status with heightened efficiency. The essence of our proposed system, denoted as $'S'$, is succinctly expressed by the formula $S = \{I, F, O, C\}$. In this formulation, $'S'$ represents our conceptualized system, 'I' specifies the input parameters, 'F' encompasses a suite of executed functions, $'O'$ denotes the system-generated output, and $'C'$ encapsulates inherent constraints of the system, including considerations such as Internet connectivity and sensor status.

The method is based on the use of a multi-layer neural network (MLP) to classify the data, most suitable for the case of a tabular dataset which contains clinical parameters [26]. According to doctors at the covid-19 services, the main parameters that need to be monitored frequently are oxygen saturation, heart rate and temperature. For this purpose, the program is trained with a dataset of 10,000 values corresponding to clinical values measured per hour.

The program is based on three-layer MLP architecture with 64 and 32 hidden units and rectified linear unit (ReLU) activations, as well as sigmoid activation for the last layer. The model is trained using stochastic gradient descent with a binary cost function and balanced class weights to account for the majority class in the data. The data is normalized to and the categorical values in the "Result" column are encoded as numeric values. The data is balanced by resampling the majority class to avoid classification bias. Model performance is evaluated on the training and testing sets by calculating accuracy, precision, recall, and F1-score. Loss values versus epochs are also shown to track model training. The balance between classes is important to avoid over fitting and to obtain good performance on the test set. The model correctly classified 98.67% of the samples in the test set.

4. RESULTS AND DISCUSSION

4.1. Key findings and interpretation

The results obtained from our model indicate that the precision, recall, and F1-score are all equal to 0.98. Accuracy, defined as the ratio between the number of true positives (samples correctly predicted as positive) and the total number of predicted positives, indicates that the model correctly identified most positives. Recall, the ratio of true positives to the total number of actual positives, suggests that the model accurately identified most true positives. The F1-score, the harmonic mean of precision and recall, is particularly useful in scenarios with unbalanced classes. The high values of these metrics demonstrate that the model performs exceptionally well on the test set.

4.2. Detailed analysis

In this study, probability predictions and class predictions were generated for each example in the test set. For instance, a probability prediction of 0.01077571 for the first example indicates a 1.077571% probability that the patient will deteriorate. Class predictions, based on a threshold of 0.5, provide a binary outcome where a value above the threshold predicts deterioration.

To evaluate model performance more comprehensively, we utilized a precision-recall curve. This curve plots precision against recall for different threshold values, offering a visual representation of the model’s performance across various decision thresholds. An average accuracy of 0.9992801963022501 and an average recall of 0.9849699398797596 further validate the model’s high performance.

4.3. Comparative analysis

Having examined the detailed performance metrics of our model, we now compare these findings with previous studies to contextualize our results within the broader field of COVID-19 patient monitoring. Our model’s high precision and recall values underscore its robustness and reliability. While some studies report similar metrics, the consistency of our results across different thresholds highlights the model’s superior capability in handling the specific dataset used for COVID-19 patient monitoring.

4.4. Study’s strengths and limitations

One of the strengths of our study is the use of a three-layer MLP architecture with 64 and 32 hidden units, which has proven effective for the dataset at hand. However, the study also has limitations, including potential biases in the dataset and the need for real-time data processing capabilities. Unexpected results, such as occasional misclassifications, were analyzed by revisiting the model's training process and examining the data for anomalies. This helped identify potential areas for improvement and refine the model's accuracy. These findings suggest that future research should focus on enhancing data preprocessing techniques and exploring alternative algorithms to mitigate misclassifications and improve overall model robustness.

4.5. Implications and future work

This study's findings emphasize the importance of integrating AI with IoT for real-time health monitoring, particularly in the context of COVID-19. The high accuracy and recall of our model suggest that it can significantly aid healthcare professionals in early detection and intervention, potentially saving lives. Future research should focus on enhancing the dataset by including more diverse and comprehensive data points, improving real-time data processing, and exploring the use of other machine learning algorithms to further increase accuracy and reliability. Additionally, implementing the system in a real-world healthcare setting will be crucial to validate its effectiveness and practical applicability.

The precision-recall curve presented in Figure 3 illustrates the good performance of the model, with precision and recall values remaining high across different thresholds. This continued high performance, as further shown in Table 1, indicates significant robustness, which is essential to ensure reliable monitoring of COVID-19 patients. Indeed, this stability allows the model to correctly identify critical cases while limiting false positives, which is crucial in a medical context.

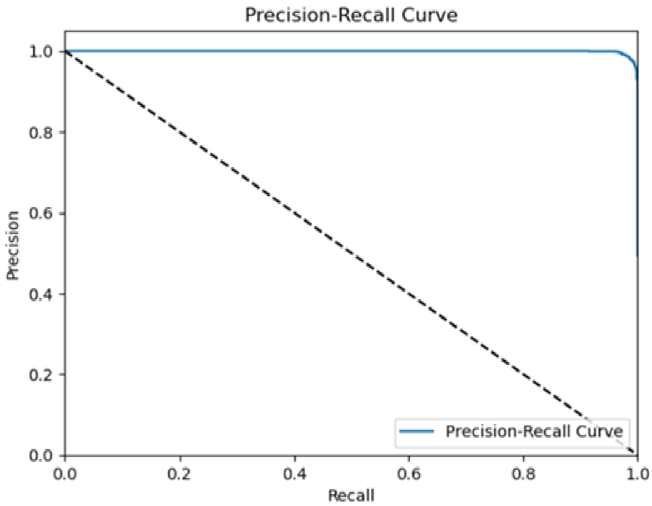

Figure 3. Precision-recall curve

Table 1. Summary table of model performance

Metric	Value
Precision	0.98
Recall	0.98
F1-score	0.98
Average accuracy	0.999
Average recall	0.985

5. CONCLUSION

In this paper, we presented a method for monitoring COVID-19 patients admitted to a hospital using a MLP architecture trained on clinical data collected via an IoT system. The results demonstrated that this method has high performance in predicting whether the patient's condition is worsening, with an average precision value of 0.9992801963022501 and an average recall value of 0.9849699398797596. Utilizing an IoT system to collect clinical data minimizes constant contact with patients, which is crucial to prevent the spread of the virus. Additionally, storing data in the cloud allows it to be recorded and analyzed later, which is beneficial for research and epidemiological surveillance. The local subsystem can communicate in real time with the cloud using a secure Internet connection, allowing clinical data to be transmitted and predictions of patient health status to be received in real time. If a patient's condition deteriorates, the local subsystem can send an alert to the monitoring website hosted on Firebase, enabling caregivers to intervene quickly before the situation becomes critical. Our findings indicate that an IoT and AI-based hospital admission monitoring system for COVID-19 patients can significantly improve patient monitoring, reduce the need for constant physical contact, and enable rapid intervention in the event of a patient's health deterioration. The implications of our research extend beyond COVID-19 patient management, suggesting potential applications in various healthcare settings where real-time monitoring and predictive alerts can enhance patient care. Future research could explore the integration of additional data sources and the application of this method to other diseases to further validate and extend its usefulness in the medical field.

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