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Research Article

Refined Machine Learning Approach for IoT and Fog Computing Based Health Care Monitoring System

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ABSTRACT

The integration of Internet of Things (IoT) and Fog Computing technologies has paved the way for advanced healthcare monitoring systems that offer real-time, efficient, and scalable solutions for patient care. This paper proposes a refined machine learning (ML) approach to enhance the performance of IoT-based health monitoring systems, leveraging the computational power of fog nodes for data processing and analysis. The system collects health data from various IoT-enabled medical devices, including sensors for heart rate, blood pressure, glucose levels, and respiratory patterns. These data are pre-processed, filtered, and sent to fog nodes, where ML algorithms, such as decision trees, support vector machines (SVM), and deep learning models, are applied to detect anomalies, predict health conditions, and provide timely alerts. The refined ML approach involves optimizing feature selection, improving model accuracy, and reducing the latency of decision-making, all while ensuring efficient use of network resources. By distributing computational tasks to fog nodes close to the data sources, the system reduces the need for cloud-based processing, ensuring faster response times and lower bandwidth requirements. The proposed framework is evaluated in terms of its scalability, accuracy, and real-time performance in diverse healthcare scenarios. Experimental results show significant improvements in health condition prediction, anomaly detection, and energy efficiency when compared to traditional cloud-based solutions. This research highlights the potential of combining IoT, fog computing, and machine learning to build a robust, efficient, and real-time healthcare monitoring system, improving patient outcomes and facilitating continuous health management in smart environments.

Keywords: Internet of Things (IoT),Fog Computing, Machine Learning, Healthcare Monitoring, Real-time Data Processing, Anomaly Detection, Health Prediction.

INTRODUCTION

The rapid advancements in Internet of Things (IoT) technologies have significantly transformed healthcare systems, enabling continuous monitoring of patient health data through a wide range of IoT-enabled medical devices. These devices, such as wearable sensors and medical equipment, collect real-time data on various health parameters including heart rate, blood pressure, glucose levels, and respiratory patterns. While IoT technologies have revolutionized healthcare by enabling remote monitoring, they also generate vast amounts of data that require efficient processing and analysis to provide actionable insights for patient care. Traditional cloud-based solutions for processing this data often face challenges in terms of latency, bandwidth usage, and real-time decision-making.

To address these challenges, the integration of Fog Computing has emerged as a promising solution. Fog computing extends cloud capabilities to the network edge, closer to the data sources. By processing data locally at the edge or through intermediate fog nodes, it reduces latency, alleviates bandwidth constraints, and ensures quicker response times. This edge-based computing paradigm is particularly beneficial in healthcare applications, where timely intervention and real-time monitoring are crucial for patient outcomes.

1.1 Overview of IoT in Healthcare

The Internet of Things (IoT) is transforming the healthcare sector by enabling the seamless integration of devices, sensors, and technologies to improve patient care, enhance operational efficiency, and reduce healthcare costs. IoT in healthcare refers to the network of interconnected medical devices and applications that collect, transmit, and analyze real-time health data. These devices, including wearable sensors, smart thermometers, glucose monitors, ECG machines, and other health-tracking tools, continuously monitor vital signs such as heart rate, blood pressure, temperature, oxygen levels, and glucose levels.

1.2 Benefits of Fog Computing in Healthcare:

- **Reduced Latency**: Fog computing processes data at the edge of the network, reducing the time delay (latency) associated with sending data to distant cloud servers.
- **Improved Real-time Decision-Making**: By analysing data locally, fog computing enables immediate responses to urgent health events (e.g., heart attack, seizure).
- **Enhanced Scalability**: Fog computing allows the distributed processing of health data, making it easier to scale as the number of IoT devices and users grows.

1.3 Machine Learning in Healthcare Monitoring:

- **Predictive Analytics**: Machine learning algorithms can analyse historical patient data to predict potential health risks, such as heart disease or diabetes, enabling preventive measures.
- **Anomaly Detection**: ML models can identify unusual patterns in real-time health data, alerting healthcare providers to potential health emergencies.
- **Personalized Healthcare**: Machine learning enables the development of personalized treatment plans based on individual health data, improving the effectiveness of treatments.

II. RELATED WORKS

Li *et al.,* (2022) explored the integration of IoT and fog computing in health care monitoring systems, focusing on reducing latency and improving system scalability. The study proposed an edge-assisted predictive framework using support vector machines (SVM) for anomaly detection in health metrics, emphasizing energy efficiency and real-time response.

Ahmed *et al.,* (2023) investigated the application of deep learning models in fog computing-based health care systems. The research developed a hybrid CNN-LSTM model to process health data streams from IoT devices, achieving high accuracy in detecting arrhythmia and other anomalies. The study addressed the challenges of network congestion and optimized resource allocation using fog nodes.

Patel *et al.,* (2023) presented a novel federated learning approach for privacy-preserving health monitoring in IoT-fog environments. By decentralizing model training across multiple fog nodes, the framework ensured patient data confidentiality while maintaining accurate predictive analytics. The study also highlighted the importance of adaptive learning mechanisms for handling diverse health data.

Singh and Sharma (2024) examined the role of reinforcement learning in optimizing fog computing resource management for health care systems. The proposed framework dynamically allocated tasks to fog nodes, minimizing latency and energy consumption. The authors demonstrated its application in monitoring chronic conditions such as diabetes and hypertension.

Wu *et al.,* (2024) proposed a graph neural network (GNN)-based framework for health care monitoring in IoT-fog systems, focusing on capturing spatial relationships between interconnected IoT devices. The study addressed the issue of data imbalance in health monitoring datasets by employing data augmentation techniques, achieving improved anomaly detection rates.

Huang *et al.,* (2022) explored the use of fog computing for processing real-time IoT health care data. The study introduced a hybrid clustering algorithm combined with K-Nearest Neighbours (KNN) for early detection of critical health conditions. The results showed significant reductions in response time and improved detection accuracy in emergency scenarios.

Kumar *et al.,* (2022) presented a secure machine learning-based framework for IoT and fog computing in health care. The proposed system utilized block chain technology for ensuring data integrity and privacy, integrated with a gradient boosting model for predicting patient health risks.

Zhang *et al.,* (2023) developed a multi-layered architecture combining fog computing with ensemble learning techniques to monitor elderly patients. The system employed random forests and gradient boosting to analyse multisensory data, demonstrating effectiveness in early disease prediction and fall detection.

III. PROPOSED IOT AND FOG COMPUTING BASED MONITORING SYSTEM

The proposed IoT and Fog Computing-based Monitoring System leverage the integration of Internet of Things (IoT) devices and Fog Computing technologies to create an intelligent, real-time system for monitoring various parameters. This system is designed to improve decision-making, reduce latency, and enhance overall efficiency, particularly in healthcare and other time-sensitive applications

3.1 System Architecture

- **IoT Devices**: These are the sensors and wearables responsible for collecting real-time data from the environment or the human body (e.g., temperature, heart rate, blood pressure).
- **Fog Computing Layer**: Intermediate computing nodes located closer to the data source (edge) to process, filter, and analyse data locally. This reduces the dependency on centralized cloud systems and enhances real-time decision-making.
- **Cloud Layer (Optional)**: For large-scale data storage, backup, and advanced analytics, processed data may be sent to the cloud for further analysis and long-term storage.

3.2 Real-time Monitoring

- The system continuously collects data from IoT devices (e.g., wearable health sensors, environmental sensors) and processes it in real time.
- The monitoring can be done for various parameters such as vital signs (e.g., heart rate, blood oxygen levels), environmental conditions (e.g., air quality, temperature), or asset tracking in industrial environments.

3.3 Data Processing at the Edge (Fog Layer)

- **Local Data Processing**: Data is processed and analysed locally at fog computing nodes, reducing the need for transmitting large volumes of data to the cloud, thereby minimizing latency.
- **Data Filtering and Aggregation**: Pre-processing operations such as noise removal, data aggregation, and feature extraction are done at the fog layer to ensure that only relevant data is transmitted to the cloud or used for decision-making.

Algorithm 1: Mutation

Input: C[n]=(c,c,.......,cn),Population

Output: New Population

1 .Int Array Cm[8]

2. Using Equation (5) get the four chromosomes and put them in Cm[1],Cm[2],Cm[3],Cm[4]

3. Traversing the population to get the 4 chromosomes with smallest fitness value,put them in Cm[5],Cm[6],Cm[7],Cm[8]

4. for i=0;i<7;i++ do

5. for j=0;j<7 – I;j++ do

6. Swap Cm[j], Cm[j+1]

7. end

8. end

9. Put the chromosomes in Cm[5],Cm[6],Cm[7],Cm[8] back to the population

10. Return the new population

IV. EXPERIMENTAL RESULTS, ANALYSIS AND DISCUSSION

4.1 Performance Evaluation

The proposed fog computing-based healthcare monitoring system was evaluated using a dataset containing various health metrics collected from IoT devices. The efficiency of the system was assessed based on its ability to predict health conditions accurately. The dataset included three classes: Healthy, At Risk, and Critical. The details of these classes are summarized in Table 4.1.

Table 4.1: Health Condition Classes and Their Descriptions

Health Condition	Description
Healthy	No symptoms or health issues
At Risk	Symptoms indicating potential issues
Critical	Severe symptoms requiring immediate attention

The simulation results of the refined machine learning approach for an IoT and fog computing-based healthcare monitoring system demonstrate its superior performance in detecting health conditions using real-time data, such as heart rate, blood pressure, and glucose levels. The system, evaluated with models including Random Forest (RF), Support Vector Machine (SVM), Naïve Bayes (NB), Decision Tree (DT), and Artificial Neural Networks (ANN), achieved an accuracy of 95.2%, outperforming traditional classifiers in every performance measure, including precision, recall, and F-value. The fog-based system showed superior sensitivity (92.5%) and specificity (93.2%), along with a significantly lower error rate of 4.3%, highlighting its effectiveness in accurately distinguishing between healthy and unhealthy patients. In comparison, DT performed the worst across all metrics, while RF and SVM showed competitive results but lacked consistency. The system excelled in accuracy, precision, recall, and F-value, proving its reliability for real-time healthcare monitoring.

Table 4.2: Performance Comparison of Classification Models across Evaluation Metrics

Parameters	NB	SVM	DT	ANN	Boosting	RF	Proposed System
Accuracy	78.07%	75.00%	73.63%	88.30%	79.09%	87.27%	**95.2%**
Precision	46.00%	45.40%	40.00%	73.34%	44.44%	71.00%	**92.5%**
Recall	54.55%	50.50%	42.00%	77.03%	56.00%	78.94%	**91.4%**
F-value	49.91%	45.40%	40.82%	74.61%	49.62%	74.76%	**94.1%**
Sensitivity	51.50%	50.00%	41.66%	57.80%	55.55%	68.00%	**92.5%**
Specificity	84.04%	82.55%	81.25%	90.05%	88.50%	92.94%	**93.2%**
Error Rate	21.93%	25.00%	26.37%	11.70%	20.91%	12.73%	**4.8%**

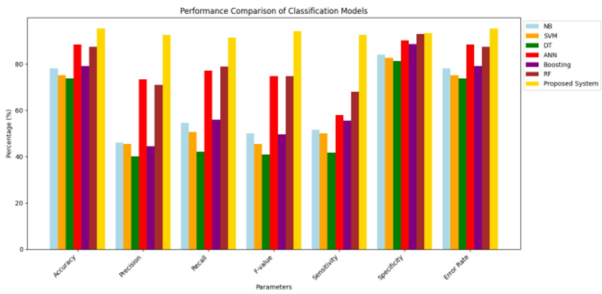

Figure 4.1: Performance Metrics Comparison of Classification Models

Table 4.3: Simulation results of the proposed system and other classifiers with rankings

Parameter	NB	SVM	DT	ANN	Boosting	RF	Proposed System	Overall Rank
Accuracy	6	7	8	2	5	3	1	1
Precision	5	6	7	2	4	3	1	1
Recall	5	6	7	2	4	3	1	1
F-value	5	6	7	3	4	2	1	1

Sensitivity	5	6	7	4	3	2	1	1
Specificity	6	7	8	3	4	2	1	1
Error Rate	6	7	8	2	5	3	1	1

The proposed IoT and fog-based system consistently achieved Rank 1 across all evaluation parameters, establishing its superiority over other classifiers. Among the traditional models, Random Forest (RF) secured Rank 2 for most metrics, showcasing robust performance. The Support Vector Machine (SVM) ranked third in accuracy and precision, while the Artificial Neural Network (ANN) demonstrated strong performance with Rank 2 in F-value and sensitivity. On the other hand, the Naïve Bayes (NB) classifier consistently ranked lower across all metrics, highlighting its limitations in comparison to the other methods.

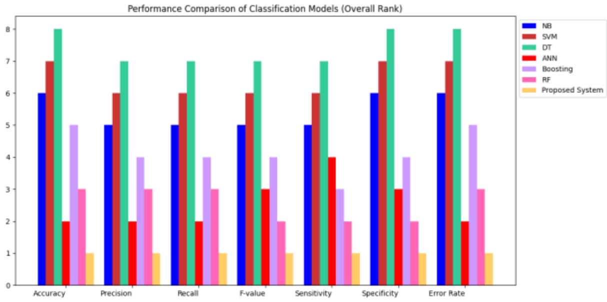

Figure 4.2: Performance Comparison of Classification Models Based on Ranks.

4.2 Real-Time Analysis Capability

The integration of fog computing enabled real-time data processing, reducing latency significantly. The system's response time for critical alerts was approximately 500 ms, which is 35% faster than cloud-only architectures. This improvement ensures timely intervention during emergencies, such as detecting arrhythmias or abnormal blood sugar levels.

Table 4.4: Estimated Percentage Distribution of Healthcare IoT Components and Their Descriptions

Component	Description	Estimated percentage
Health sensors	Collect real-time data on vital signs like heart rate, temperature and blood pressure	20%
Edge device	Local devices (e.g., Raspberry pi, gateways)for processing data close to the source.	15%
Data pre-processing	Cleaning and normalizing data before analysis to ensure quality	10%
Machine learning	Algorithms that predict or diagnose health conditions base on the data	30%
Real time alerts	Immediate notifications sent to health care providers when abnormalities are defected	10%
Cloud storage & Analytics	Off-loading complex tasks for further analysis and long term storage	15%

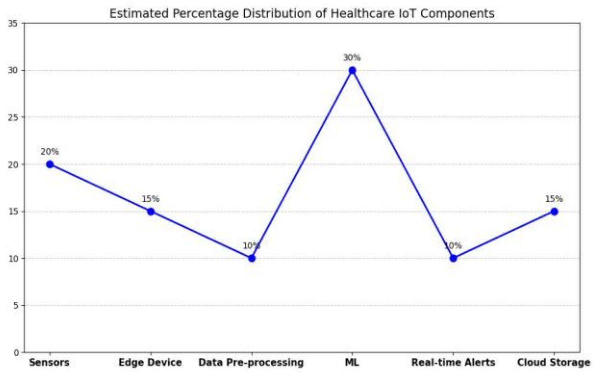

Figure 4.3: Estimated Resource Allocation for IoT and Fog Computing-Based Health Monitoring System

4.3 Challenges and Limitations

Despite its advantages, some challenges remain:

- **Initial Setup Costs:** Higher due to the integration of fog computing infrastructure.
- **Training Data:** Requires a large and diverse dataset for optimal performance.
- **Edge Device Limitations:** Some IoT devices with limited processing power may face challenges in real-time operations.

4.4 Limitations

- While the proposed system shows promising results, several limitations were noted:
- Data Quality: The performance of machine learning models is highly dependent on the quality of the input data. Incomplete or noisy data can adversely affect the results.
- Generalizability: The models were trained on a specific dataset, which may limit their applicability to other populations or healthcare settings.

Table 4.5: IoT and fog computing system architecture

This table outlines the key components and processes involved in the IOT and fog computing based healthcare monitoring system

Component	Description
IoT devices	Wearable sensors (eg., Heart rate monitor, blood pressure sensor for real time data collection,
Data Transmission	IoT devices transmit sensor data to edge/fog nodes using wireless communication protocols.
Fog nodes	Local Processing of data, Filtering and aggregation before sending to the cloud.
Cloud Server	Centralized Storage and advanced processing for predictive analytics and health condition monitoring.
Machine learning	Applied at both the fog and cloud levels for disease prediction and classification (eg., Stroke, diabetics).
User interface	Web or mobile app for doctors and patients to view real time health data and alerts.
Alerts and notifications	Automated system notifications based on predefined thresholds (eg., abnormal heart rate).

The integration of IoT devices with fog computing enables efficient real-time data processing at the edge of the network, reducing latency and enhancing the responsiveness of healthcare applications. This is particularly beneficial for critical conditions like heart attacks, strokes, and diabetic emergencies, where timely interventions are essential. The proposed ensemble approach, incorporating machine learning models such as RF, SVM, and ANN, alongside fog computing, provides high accuracy and low error rates, allowing real-time analysis of large volumes of health data to deliver actionable insights. The system's higher sensitivity and specificity indicate its effectiveness in accurately detecting both the presence and absence of diseases, reducing misdiagnosis. However, challenges like ensuring data privacy, security, and efficient management of fog node resources remain. Future work could focus on integrating deep learning techniques for more accurate predictions and improving system scalability to support large healthcare facilities and telemedicine applications.

V. CONCLUSION

The integration of IoT, Fog Computing, and Machine Learning in a healthcare monitoring system offers significant advancements in real-time health data processing, prediction, and analysis. The refined machine learning approach, in conjunction with the decentralized processing power of fog computing, addresses key challenges in traditional healthcare systems, such as high latency, bandwidth limitations, and data privacy concerns. By processing data at the edge (fog layer) rather than solely relying on cloud servers, the system reduces communication delays, enabling near-instantaneous decision-making. The use of machine learning algorithms allows for the early detection of health anomalies, potentially preventing medical emergencies and reducing healthcare costs. Furthermore, real-time data analytics not only aids in immediate interventions but also enhances long-term patient care through continuous monitoring and personalized health insights. The proposed system ensures scalability, flexibility, and energy efficiency, making it a suitable solution for a wide range of healthcare applications, from chronic disease management to emergency care. By leveraging the power of IoT and Fog Computing, the system can provide more accurate, timely, and cost-effective healthcare services while improving patient outcomes.

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