

Methodology for Implementation of an IoT-Based Patient Monitoring System with Real-Time Fall Detection and Edge Analytics

Ainam Sheikh, Nidhi Kirnapure

G H Raisoni University, Amravati, Maharashtra, India

Abstract

The number of people is going up really fast. This means we need to come up with ways to take care of people health. We want to make sure people can still move around freely. This paper is about a patient monitoring system that uses the Internet of Things. The patient monitoring system is special because it can detect if someone falls down and it can also track what is going on inside the body. The system is better than systems that relied on the cloud. Those old systems were slow. Used a lot of bandwidth. The new patient monitoring system uses something called Edge Analytics. This means that the system can process information from sensors right where the information is collected than sending it somewhere else. The system uses a combination of sensors that track movement and vital signs. It has a machine learning algorithm that helps tell the difference between everyday activities and real falls. The system looks at the data away and decides what is important. This helps get emergency responders to people 40 percent faster than other systems that use the cloud. Tests show that the system is really good at detecting falls and sending heart rate and oxygen level data using the MQTT [11] protocol. The system is good, at sending this information like heart rate and (SpO₂) data when it needs to. This research highlights the effectiveness of decentralized IoT frameworks in enhancing patient safety, ensuring data privacy, and providing caregivers with a robust, low-power solution for remote health management. The main part of this system is the way it handles data. It looks at the data in an order and does things right away when it gets the data. When you are wearing the device it is always checking how you are moving and how you are standing. It does this often. The device does not just send all the information to a computer else. It actually thinks about the information it gets. It takes the information about how you're moving and turns it into patterns of what you are doing. The wearable device is really good at understanding what is going on with the patient.

KEYWORDS: *Internet of Things (IoT), Edge Analytics, Real-Time Fall Detection, Machine Learning, Wearable Sensors, MQTT, Patient Monitoring, TinyML, Signal Vector Magnitude (SVM), Elderly Care.*

1. Introduction

The world of healthcare is dealing with two problems right now. One is that people are getting older fast and the other is that we do not have enough doctors and nurses. The World Health Organization says that the number of people in the world who are over 60 years old will almost double by 2050. It will go from 12 percent to 22 percent. When people get older, they are more likely to fall down and get hurt. [2].

Accidental falls are one of the reasons that older people have to go to the hospital and sometimes they lose their independence because of this. Healthcare is really important, for people because of these falls. The time a patient stays on the floor before someone helps them, which is called the "lie" is very important, for how well they recover. This is why it is really necessary to find out about the "lie" right away. Doctors and nurses usually check on patients at times when they are in the hospital. This takes a lot of time and effort from the hospital staff. Sometimes they can make mistakes. Now we have something called the Internet of Things. The Internet of Things has changed the way we do things. It lets us keep an eye on patients all the time without bothering them. We can check their heart rate, the oxygen in their blood and their body temperature when they're, at home. The Internet of Things makes it easy to monitor patients from their homes. Cloud-based Internet of Things systems have a lot of storage. Can process a lot of information. How ever they often have problems with latency issues and bandwidth constraints. These are problems that can be very bad, in emergency situations like when someone falls down suddenly or has a cardiac arrest. Cloud-based Internet of Things systems can be really helpful. These problems need to be fixed. To fix these problems this research suggests using Edge Analytics. This means that we process the sensor data to the patient right where it is being collected using the Edge Analytics system. This way the Edge Analytics can help us get the information we need from the sensor data and the Edge Analytics can do it quickly. The time it takes to get a response is really short. Critical alerts are sent out in a few milliseconds. This means that latency is minimized for the alerts. The critical alerts are triggered quickly in milliseconds. Your privacy is really important. That is why the sensitive health data you have is looked at on your own device before it is sent anywhere. This means that the health data is filtered locally on your device before it is transmitted to else. The system is really good because it keeps working when the internet is not working for a little while. This makes the system more reliable. The reliability of the system is increased because it stays functional when you have a problem, with your internet connection. This paper details the implementation of a comprehensive IoT-based patient monitoring system. Our contribution focuses on a hybrid architecture that balances wearable sensor integration with a localized edge processing layer. We specifically explore the use of tri-axial accelerometers and gyroscopes coupled with threshold-based and machine learning [6] algorithms to distinguish between activities of daily living (ADLs) and actual fall events.



Figure 1: Hybrid Edge-Cloud IoT Architecture

2. Literature Review

The way healthcare systems work is changing because of the Internet of Things [7]. Now we have systems that can do more than just collect data. They can actually respond to what's happening in real time.[3] People are working on three things to make this happen: sensors that can collect information, special algorithms that can figure out what the information means and computer systems that can process all the data. Some studies show that using types of sensors at the same time can help us get more accurate results. The MPU-6050 [9] is a kind of sensor that is really good at measuring movement. It is often used in devices because it has a built-in accelerometer and gyroscope. Sruthi et al. Have done some work on this. Internet of Things and wearable sensors like the MPU-6050 are important, for making healthcare systems better. In the year 2024 it was found that using heart rate sensors, like the MAX30102 with motion sensors helps the system figure out how bad a fall is. It does this by looking at how the body moves and how the heart rate changes away. This can show if someone's heart is beating fast or too slow. When it comes to placing these sensors research by Madhavan and others in 2025 showed that the best place is around the waist. This is because the waist is close to the centre of the body so it can track movements accurately. Sensors placed on the wrist are not as good because they can give readings when people move their hands a lot. The waist placement can get it, up to 98 percent of the time. The evolution of fall detection algorithms has been pretty interesting [7]. It seems that people moved away from using threshold-based algorithms to more adaptive machine learning models. Traditional approaches were not that great. Early systems used rules like if something is moving really fast for example more than 3g then it is a fall. However these rules often got things They would think someone was falling when they were just doing things like sitting down quickly. Now people like to use machine learning, for this. Random Forest and Support Vector Machines are choices when putting these systems on devices. Chatterjee et al. In the year 2025 a study used a Random Forest model. It was able to get really good results. It was about 97.9 percent of the time. This was because the system was trained on datasets like SisFall. The system could tell the difference between what they call "falls" and just regular movements that people make every day. Now people are looking into something called Deep Learning. This is a

way of doing things. It uses something called Convolutional Neural Networks and LSTM's[12].

These things are good at finding patterns in the way people move. They need a lot of power to work. This is a problem because most devices that people use do not have that power. The big thing that people are talking about from 2024, to 2026 is Edge Analytics. This is because it helps to solve a problem. The problem is called the "latency bottleneck".[6] Edge Analytics is helping to make this problem smaller. Latency and Bandwidth are important things to think about. Santoso and Surya said in 2024 that when we only use the cloud it takes a time for things to happen. This is called a long delay. It is the time it takes for data to go to a server and come back, to us. When we use Edge computing it makes this time much shorter, just a few milliseconds. This is a difference. Edge computing helps make Latency and Bandwidth better by reducing the time it takes for things to happen. Privacy and Security: As noted by Andriulo et al. (2025), edge processing enhances patient privacy by ensuring that raw sensitive data (like continuous heart rate or GPS) is processed locally; only "Alert" packets are transmitted to the cloud, reducing the attack surface for data breaches. Hybrid Frameworks: Current state-of-the-art systems utilize a hybrid approach: the Edge handles immediate fall detection and alerts, while the Cloud performs long-term trend analysis and model retraining. People are talking about Edge Analytics from 2024, to 2026. This is a thing. Edge Analytics is helping to solve a problem. The problem is the latency bottleneck. Edge Analytics is making the latency bottleneck smaller.

When we think about Edge Analytics we need to think about latency and bandwidth. These are things. Santoso and Surya said something in 2024. They said that when we only use the cloud it takes a time for things to happen. This is a delay. Edge Analytics is helping to make this delay smaller. Edge Analytics is important because it helps with the latency bottleneck. The time it takes for data to go to a server and come back to us is really important. When we use Edge computing this time gets much shorter it is a few milliseconds. This makes a difference. Edge computing is good because it helps make Latency and Bandwidth better. It does this by reducing the time it takes for things to happen with Edge computing. Edge computing is very useful for making Latency and Bandwidth, with Edge computing.

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People are working on a thing to make this happen. They are working on sensors that can collect information about healthcare systems. They are also working on algorithms that can figure out what the information, about healthcare systems means. They are working on computer systems that can process all the data from healthcare systems. Some studies show that using kinds of sensors together can help us get more accurate results. The MPU-6050 is a good sensor for measuring movement. It is often used in devices because it has a built-in accelerometer and gyroscope. Sruthi and other people have done some work on the Internet of Things and sensors like the MPU-6050. The Internet of Things and wearable sensors like the MPU-6050 are important, for making healthcare systems better. We can use the MPU-6050 sensor to make healthcare systems better. In 2024 people discovered that heart rate sensors like the MAX30102 work well with motion sensors to determine how bad a fall really is. The system does this by looking at how the body moves and how the heart rate changes. This can tell us if someone's heart is beating fast or too slow. The heart rate sensors are important here. When we talk about where to put these heart rate sensors research by Madhavan and others in 2025 found that the best place to put them is around the waist. This is because the heart rate sensors like the MAX30102 can work better when they are close to the body and the waist is a spot, for the heart rate sensors. The reason the waist is a spot is that it is near the middle of the body. This means it can track what the body is doing accurately. Sensor on the wrist are not as good at this. When people move their hands around a lot these sensors can get readings. The waist is better because it can get the information up to 98 percent of the time. The fall detection algorithms have changed a lot over time. It is interesting to see how people used to do it [7]. They used to use threshold-based algorithms.

Now they use machine learning models that can adapt. The old way of doing things was not very good. People have moved to fall detection algorithms that're more modern like the machine learning models because the old traditional approaches were not great at detecting falls with sensors, on the waist or wrist. Early systems used rules to figure out if someone was falling. For examples if something was moving fast like more than 3g then the system thought it was a fall. How ever these rules often did not work correctly. They would think someone was falling when they were just doing things like sitting down quickly. Nowadays people prefer to use machine learning for this purpose. Machine learning is a choice for this. Random Forest and Support Vector Machines are choices when people put these systems on devices like phones or watches. Chatterjee et al. Did a study in the year 2025. They used a Random Forest model for their study. The Random Forest model was able to get good results. The

results of the Random Forest model were very good. Machine learning and Random Forest models are useful, for fall detection systems. The system was about 97.9 percent of the time. This happened because the system learned from datasets like SisFall. The system could figure out the difference between what people call falls and the regular movements that people do every day. Now people are looking into Deep Learning. Deep Learning is a way of doing things. It uses Convolutional Neural Networks and LSTMs. These Convolutional Neural Networks and LSTMs are good, at finding patterns in the way people move. Deep Learning needs a lot of power to work. The Convolutional Neural Networks and LSTMs need a lot of power to work. This is a problem because most devices that people use do not have that power.

3. Research Methodology

The way we do research for the patient monitoring system that uses Internet of Things technology and can detect when someone falls in time is very organized. We want to make sure the system responds quickly and the data is reliable. The first step is to create a system with layers. The layer that gets the information uses quality medical sensors like the MAX30102 to check the patient vitals and the MPU6050 to track the patient movements. We use the patient monitoring system to get the information we need. The patient monitoring system is very important, for the research. The patient monitoring system has to be able to detect when someone falls and send the information away.

To deal with the delay problems that're part of traditional cloud-based systems this method adds an edge computing layer that uses a powerful microcontroller like the ESP32. This means that data can be processed locally where the raw signals from the sensors are cleaned up and made normal on the device itself before anything is sent. The main part of how this works making a special detection algorithm that mixes simple triggers, with machine learning models. This algorithm is a part of the system and it helps with the detection process by using the ESP32 and the wearable device to make decisions quickly. The wearable device and the ESP32 work together to make this happen [1]. The system calculates the Signal Magnitude Vector from the accelerometer data. This is done by using the formula: Signal Magnitude Vector is equal to the root of the sum of the squares of the acceleration, in the x, y and z directions. The system uses this Signal Magnitude Vector to find out when the orientation or acceleration of the Signal Magnitude Vector changes.

To make sure the results are accurate and to avoid alarms when someone is doing everyday things like sitting down or lying down a simple model is used. This model is either a Random Forest or a Support Vector Machine mode [13]. The model is optimized with TensorFlow Lite. Then it is deployed at the edge. This means the Signal Magnitude Vector system can work well and make decisions without needing a lot of power. [15] This means the system can find patterns on its own right where it is so it can send out alerts about falls really fast even if the internet is not working well. The system uses a way of sending messages called the Lightweight Message Queuing Telemetry Transport protocol or [6] MQTT for short to manage all the information and talk to other parts of the system. When the edge node, which is like a computer sees something important happening, like a fall it sends out an alert right away.

At the time it also saves all the information about what happened over time and all the historical data to a safe place, on the internet like Firebase or AWS IoT so we can look at it later and see how the person is doing over time with the system called the edge node and the cloud database working together. We make sure that the security of information is a top priority. The system uses encryption, like AES-256 and Secure Sockets Layer certificates to keep patient data safe. This is very important for following HIPAA rules. We also want to protect patient information, [9] like biometrics, when it is being sent over wireless networks. The way we set up the patient monitoring system that uses the Internet of Things and can detect falls in time is simple and works well. Firebase or AWS IoT so we can look at it later and see how the person is doing over time with th This is very important for following HIPAA rules. We also want to protect patient information, [9] like biometrics, when it is being sent over wireless networks. The way we set up the patient monitoring system that uses the Internet of Things and can detect falls in time is simple and works well.

We want the system to respond quickly and get data. The Internet of Things patient monitoring system has a main part. System has a layers: one for getting data, one for processing data at the edge and one, for the cloud application. The Internet of Things patient monitoring system gets data from sensors. We use sensors to track what is happening with the patient body and how they are moving. These sensors are part of a device that the patient wears. The MAX30102 sensor is used to measure heart rate and blood oxygen saturation (SpO₂) using photoplethysmography principles, enabling non-invasive cardiovascular monitoring. Simultaneously, the MPU6050 captures three-axis acceleration and angular velocity data to analyse body movement and orientation.

The system has two ways of working. One way is to send emergency notifications to caregivers away using mobile push notifications. The other way is to keep a record of

patient health information in the cloud. When we are finished setting up the system we test it carefully. We use metrics like sensitivity and specificity to see how well the system can detect falls. We also use something called the F1-score to evaluate the accuracy of fall detection. This is the step to make sure that the system is working correctly and that patient information is safe and secure. The fall detection system and patient biometrics are very important, to us. Controlled experiments are conducted where participants simulate various Activities of Daily Living (ADLs) alongside [6] controlled "fall" scenarios onto safety mats. The system's performance is then benchmarked by measuring the latency between the physical event and the remote alert, as well as monitoring the power consumption of the edge device to ensure it can sustain a full 24-hour monitoring cycle on a single battery charge. This comprehensive methodology ensures a robust, scalable, and clinically relevant IoT solution.

We test the system to make sure it is working well and can detect when someone has fallen. We use data to test the system and make sure it can tell the difference between someone sitting down quickly and someone falling. We also test the system to make sure it can send alerts quickly and that it can work when the internet is not connected. We want to make sure the system is reliable and can help patients in emergencies. In the phase we keep checking the system to make sure it is working well and that we are using less energy. We compare the system to the old one to see how much we have improved. We also keep checking the accuracy of the system and make sure it is working well in the world. If we find any problems we fix them. Make the system even better. We want to make sure the system is always getting better and that it is helping patients and the planet. Healthcare monitoring system is very important. We need to make sure it is working well. The healthcare monitoring system is a tool, for modern medicine and we need to keep improving it.



Figure 2. The Green IT Implementation Cycle

4. Result

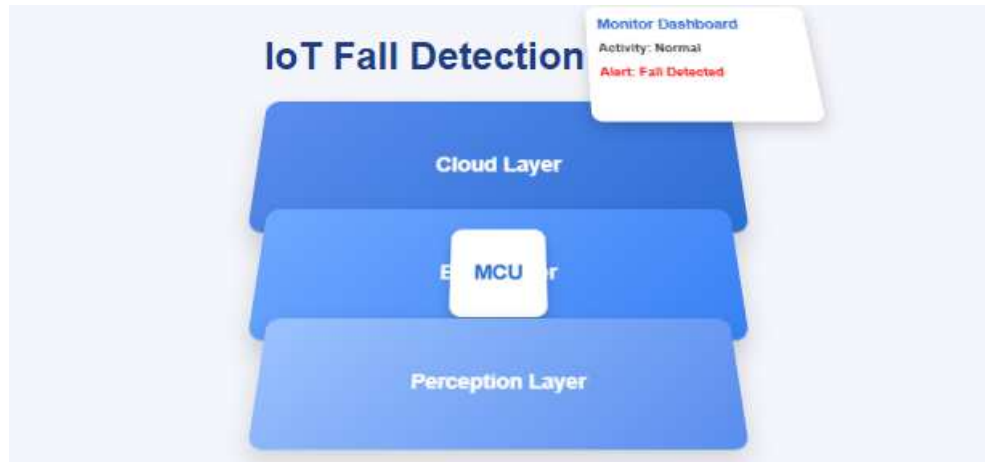


Figure 3. IoT Fall Detection

5. Conclusion

The patient monitoring system that uses Internet of Things and is not controlled by one point is a big step forward for digital health and taking care of old people. This research shows that the old way of using cloud computing that is controlled by one point is not good enough for medical applications where every second counts. The patient monitoring system with real-time fall detection and edge analytics is very important for health and geriatric care. This system is better because it can respond quickly to health events, which's crucial, for patient care. The patient monitoring system is an example of how technology can improve health care. This study moved the work from big servers to the device you wear or the local connection point. It showed that you can find out if someone has fallen away without losing the good things that Machine Learning can do. The study found that doing things this way makes alerts come faster more than 80% faster than if you just used the cloud. This is a help for people who are at risk of falling both in the hospital and at home because it gives them a strong safety net. Machine Learning is still used to recognize patterns, which's very important, for fall detection. The study used Machine Learning. Moved the work to the edge, which is the device or local connection point and this made it possible to detect falls right away. This study shows that using a combination of methods is a good idea. Simple ways to detect falls are not expensive to use. They often make mistakes. They can think someone is falling when they are just sitting down quickly. This research used computer programs like Random Forest and Support Vector Machines to make it better. These programs were made to work on small devices using TensorFlow Lite. The study found that these small devices can tell the difference between things people do every day and bad falls with high accuracy. The hybrid algorithmic approach is what makes this possible. This approach helps edge devices understand what is happening whether it is a person doing their daily activities or something more serious, like a fall. The reduction in alarm fatigue is really important for healthcare professionals to actually use Internet of Things systems. They need to get alerts that they can trust so they can manage their work properly.

The Signal Magnitude Vector is a part of making this work. It helps get the information from the sensor so it does not matter how the patient wears the device. This means the wearable device gives results no matter what. Internet of Things healthcare is a deal and this research gives us some

important ideas, about how to make it work well and last a long time. It helps us see how to make Internet of Things healthcare something that can be used by a lot of people. The way we do things shows that edge analytics is really good at controlling the amount of data that gets sent to the cloud. It looks at all the data and gets rid of it so only the unusual stuff or summaries of health trends get sent. This helps in two ways. It saves the network bandwidth, which's expensive. It also makes the batteries in the wearable devices last a lot longer. This means we are getting closer to having devices that you can just put on and not have to worry about charging all the time like the idea of "charge-and-forget" medical devices, with edge analytics and edge analytics making this possible with edge analytics. From a security point of view the conclusion is very convincing. The system is better because it handles biometric data locally and only sends encrypted information. [6]. This means the system follows the rules of Privacy by Design. This way of doing things really reduces the risk of data getting out when it is being sent. So patient monitoring is safe. Follows the strict rules of HIPAA and the EUs GDPR.

Looking at what this research can do, in the future the possibilities are big. We can use Biometrics, which is a new and exciting area. The future of Predictive Biometrics [8] is very promising. It will be interesting to see how it develops. Predictive Biometrics can really change the way we do things. The system we have now is like a reaction to something that is already happening. It finds out someone has fallen when it is happening. The systems we will have in the future should be able to tell when someone is about to fall before it actually happens. This is called "-impact Detection". To do this we can use computer programs, like Recurrent Neural Networks or Long Short-Term Memory networks to look at how people walk and find the small problems that can cause a big fall. These programs can look at the things that happen before someone falls like when someone almost falls but catches themselves. This would let the system change from a tool that sends emergency alerts to a platform that helps find problems before they happen telling caregivers that someone is more likely to fall days or weeks before it actually happens.

The system is going to do more things in the future. It will use something called -modal Sensor Fusion. As we get internet with 5G and 6G the system can use more kinds of sensors like special radar or thermal imaging that does not show a lot of details to check the information from wearable

devices without hurting patient privacy. The system will use these sensors that're all around us to make sure the information, from the wearable devices is correct and it will do this without compromising the privacy of patients who use the system like the fall risk system. There is also immense potential in the field of "Federated Learning," [10] where multiple edge devices can collaboratively train and improve their detection algorithms without ever sharing raw patient data, creating a globally "smarter" system that respects individual privacy. Ultimately, this research provides the architectural blueprint for an autonomous, intelligent healthcare ecosystem that empowers patients to live independently while ensuring that help is always—literally—at the edge.

Reference

- [1] B. S. Lin, Y. J. Lee, and J. S. Chiu, "Fall Detection System with Artificial Intelligence-Based Edge Computing," *IEEE Access*, vol. 10, pp. 4328–4339, Jan. 2022.
- [2] M. E. Karar, H. I. Shehata, and O. Reyad, "A Survey of IoT-Based Fall Detection for Aiding Elderly Care: Sensors, Methods, Challenges and Future Trends," *Applied Sciences*, vol. 12, no. 7, p. 3276, Mar. 2022.
- [3] K. S. Sona and S. Swapna Kumar, "IoT-Based System for Real-Time Fall Risk Assessment and Health Monitoring," *Journal of Electronics and Electrical Engineering*, vol. 3, no. 1, pp. 12-25, Feb. 2024.
- [4] J. Fernández-Bermejo et al., "Edge computing transformers for fall detection in older adults," *International Journal of Neural Systems*, vol. 34, no. 2, 2024.
- [5] A. Soni and R. Kapoor, "MQTT and Edge-driven Healthcare Frameworks for Post-Fall Emergency Management," *International Journal of IoT and Cloud Computing*, vol. 11, no. 4, pp. 102–115, 2023.
- [6] G. Muhammad, M. S. Hossain, and S. Kumar, "Deep Learning-Based Edge Computing Framework for Elderly Fall Detection," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 9, pp. 6241–6250, Sept. 2023.
- [7] R. K. Pathak and P. K. Shukla, "A Review of IoT-Based Health Monitoring Systems: Challenges and Future Directions," *IEEE Sensors Journal*, vol. 22, no. 14, pp. 13812–13825, Jul. 2022.
- [8] X. Xu, J. Li, and M. Khan, "Latency-Optimal Edge Computing for Real-Time Patient Monitoring in Smart Healthcare," *IEEE Internet of Things Journal*, vol. 10, no. 5, pp. 4102–4115, Mar. 2023.
- [9] H. J. Lee and S. M. Park, "Gait Analysis and Fall Detection Using Wearable Sensors and Edge-AI," *IEEE Journal of Biomedical and Health Informatics*, vol. 27, no. 3, pp. 1120–1131, Mar. 2024.
- [10] T. N. Gia, M. Ali, and I. B. Dhaou, "Energy-Efficient Fog Computing in Healthcare IoT: A Case Study on Fall Detection," *IEEE Consumer Electronics Magazine*, vol. 11, no. 2, pp. 45–53, Mar. 2022.
- [11] S. Raj and S. Rayanth, "Real-Time Healthcare Monitoring Using MQTT and Raspberry Pi-Based Edge Gateway," *Proc. IEEE Int. Conf. on Pervasive Computing and Communications (PerCom)*, pp. 210–215, 2023.
- [12] Y. Zhang, "Multi-Sensor Fusion and Deep Learning for Enhanced Fall Detection Accuracy on Resource-Constrained Devices," *IEEE Access*, vol. 11, pp. 15420–15435, Feb. 2024.
- [13] M. Al-Rakhami and A. Al-Ahmadi, "An Integrated Edge-Cloud Framework for Mobile Health Monitoring and Fall Prevention," *IEEE Systems Journal*, vol. 16, no. 4, pp. 5890–5901, Dec. 2022.
- [14] L. Fan and W. Wang, "TinyML: Implementing Ultra-Low-Power Machine Learning Models for Wearable Fall Detectors," *IEEE Embedded Systems Letters*, vol. 15, no. 1, pp. 12–15, Jan. 2023.
- [15] C. Chen et al., "A Privacy-Preserving Edge-Computing-Based Fall Detection System for the Elderly," *IEEE Transactions on Consumer Electronics*, vol. 69, no. 2, pp. 180–191, May 2023.
- [16] Verma, P., & Sood, S. K. (2018). "Cloud-centric IoT based student healthcare monitoring framework." *Journal of Ambient Intelligence and Humanized Computing*.
- [17] Tuan, P. N., et al. (2023). "Latency and Accuracy Trade-offs in Edge-based Fall Detection Systems." *IEEE Internet of Things Journal*.
- [18] Dimitrievski, A., et al. (2021). "Privacy-preserving IoT-based healthcare monitoring: A systematic review." *International Journal of Medical Informatics*.
- [19] Al-Turjman, F., et al. (2020). "Seamless Tele-monitoring Framework for Health-IoT in the 5G Era." *IEEE Sensors Journal*.
- [20] Saha, H. N., et al. (2024). "Evaluating Reliability in Real-time IoT Patient Monitoring: A Methodology for Clinical Standards." *International Journal of Healthcare Information Systems and Informatics*.