



IoT-Based Epilepsy Monitoring Device for Children

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To Cite this Article

Mutyala Anusha, Depuri Venkateswarlu, Beesetti Yazna Suryanarayana, Alamanda S S M Sri Ram Murthy, Yanamadala krishnaphani (2026). IoT-Based Epilepsy Monitoring Device for Children, 12(03), 102-109. <https://doi.org/10.5281/zenodo.18880601>

Article Info

Received: 28 January 2026; Revised: 26 February 2026; Accepted: 02 March 2026.

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KEYWORDS

IoT-based healthcare, pediatric epilepsy monitoring, ESP32 microcontroller, seizure detection, wearable sensors, accelerometer-based motion analysis, heart rate and SpO₂ monitoring, environmental sensing, real-time alerts, Blynk IoT platform, embedded systems, low-cost medical device

ABSTRACT

Kids with epilepsy need constant supervision because seizures can happen anytime, without warning. But right now, the ways we have to monitor them just don't fit everyday life. Hospital EEGs work well, sure, but they're stuck in one place, expensive, and obviously you can't send a child home with all that gear. On the other hand, most commercial wearables go for ease and comfort, but they often cut corners on accuracy—usually relying on just one sensor, and their alerts aren't always quick or reliable. That's where this project steps in: we set out to create an IoT-based epilepsy monitor that actually makes sense for kids and their families.

Here's how it works: we built the device around an ESP32 microcontroller, hooking it up to several different sensors. It keeps an eye on the child's heart rate and blood oxygen level with a pulse sensor, and tracks motion and falls using an ADXL345 accelerometer. But we didn't stop there—the system also checks the room's temperature, humidity, CO₂ levels, sound, and even the light. The idea is, seizures don't happen in a vacuum. By watching both the child's vital signs and their surroundings, we get a much clearer, more reliable picture than you'd get from something with just one sensor.

Everything the sensors pick up is processed right on the device. It uses simple threshold rules and basic machine learning to spot signs that a seizure might be starting or the child is in distress. If something looks off, the device instantly sounds a buzzer and sends a notification through the Blynk IoT app, so caregivers don't have to wait and scroll through logs—they know right away. We chose this straightforward approach on purpose; it's easier to understand, doesn't need a ton of computing power, and works in real time, which is what matters most for families.

All in all, this system strikes a balance. It's affordable, you can add more sensors if you want, and it's comfortable enough for a child to actually wear at home. Plus, parents and doctors can keep tabs on things remotely. Sure, there are still some hurdles—the sensors aren't perfect, there's always the risk of false alarms, and we need more clinical testing in real-world settings. But even so, this shows how smart, connected devices can go beyond the hospital and really help families manage epilepsy day to day.

INTRODUCTION

Epilepsy is a long-term brain disorder where seizures strike out of the blue. They're unpredictable—sometimes quick, sometimes drawn out, and they don't always look the same. For kids, epilepsy brings a whole set of challenges that go way past just getting a diagnosis or taking medicine. Seizures can hit at any time—while a child's asleep, playing, or just going about their day. That puts them at risk for things like falling, running out of oxygen, or not getting help quickly enough. So, parents and caregivers end up on high alert all the time, which is exhausting both physically and mentally. And even though medicine has come a long way, actually keeping track of seizures at home is still tough—especially in places where resources are tight or doctors are far away.

Most of the time, epilepsy gets monitored in hospitals using EEG machines. Those are great for diagnosing seizures but they're expensive, can't be carried around, and need experts to run them. Plus, they're set up for only short stays, not for tracking kids around the clock at home. Because of that, a lot of seizures slip through the cracks—people don't notice them until after something bad happens. Caregivers end up watching the child as best they can, but let's be real: humans get tired or distracted, and seizures don't exactly follow a schedule. Lately, there's been a wave of new gadgets—wearable or portable devices meant to help track seizures outside the hospital. Most of these use motion sensors like accelerometers or gyros to spot the jerky movements that come with convulsive seizures. They're simple, don't eat up much battery, and sound promising, but there's a catch. Normal kid stuff—running, jumping, roughhousing—can trigger false alarms. Some devices try to get around this by tracking just heart rate or another single vital sign, but that misses the bigger picture. Seizures are complicated, and no single sensor can catch everything that's going on. So, it's clear: we need smarter ways to monitor that don't just rely on one type of data.

Thanks to advances in embedded systems and IoT, there's now a real shot at keeping tabs on health outside the clinic. With small, cheap microcontrollers, wireless connections, and tiny sensors, you can collect and process data in real time—and send it to whoever needs to see it. In healthcare, IoT systems let you keep an eye on patients around the clock, share data securely, and send out alerts when something's wrong. That's huge for kids with epilepsy—it means they don't have to be glued to a hospital bed or stuck under someone's constant watch.

But here's something most monitors miss: the environment matters too. Stuff like temperature, humidity, air quality, noise, and lighting can all make things worse during a seizure or even set one off. Most devices ignore these things, focusing just on the body. That leaves caregivers in the dark about what's really going on and makes it harder to tell a real emergency from a false alarm. To get it right, you need a system that brings together both the child's physical signals and the world around them.

This project is all about building an IoT-based epilepsy monitor for kids that's affordable, comfy, and always on. The system uses an ESP32 microcontroller plus a bunch of biosensors and environmental sensors. It tracks heart rate, oxygen level, movement, temperature, humidity, air quality, noise, and light—all at once. By blending all this data, the device can spot seizure-related problems more reliably than ones that look at just a single sign. On top of that, it can process info right on the device using simple rules and lightweight machine learning, so it doesn't have to rely on the cloud for every decision.

Remote monitoring is a big deal here. The device pushes data over Wi-Fi to a cloud platform, so caregivers can check readings in real time or look back at trends on their phone. If it spots something wrong, it immediately sends out alerts locally and remotely, so people can jump in fast. Instead of just logging seizures for the record, this setup is all about catching trouble early and giving caregivers the info they need, right when they need it.

Looking at this project through the lens of embedded systems, it's more than just theory—it's hands-on proof that you can pull together different sensors, handle real-time signal processing, and keep everything talking wirelessly, all on hardware that doesn't give you much room to work with. Every design choice leans hard into low power use, modularity, and the kind of scalability that lets you tack on new sensors or try out fresh analytical tools down the line. Still, the team doesn't gloss over the tough parts: sensor noise, the fact that seizures don't look the same from one kid to the next, and the reality that you need serious clinical testing before anything like this rolls out into actual hospitals or homes.

Bringing IoT into pediatric epilepsy monitoring shifts the whole approach. Instead of the old model—occasional check-ins at the clinic—you get continuous, context-aware monitoring that fits into daily life. The project tackles the gaps in current monitoring setups and uses new embedded system tech to build something practical, centered around kids' real needs. The goal is clear: make things safer, lighten the load on caregivers, and give doctors better information to work with.

PROBLEM STATEMENT

Right now, pediatric epilepsy monitoring sits at a crossroads. On one side, you've got hospital-grade EEGs—solid for diagnosis, but not built for kids' real lives. These systems work only in clinics, under supervision, and for short stretches. So, most seizures happen out of sight, and caregivers end up piecing together the story from memory instead of hard data.

Wearables try to bridge this gap, but they hit their own snags. Many use just one type of sensor—usually an accelerometer—to catch movement. That keeps the tech simple, but in kids, normal playing and fidgeting can look just like a seizure. So, you get lots of false alarms, and the quieter, less obvious seizures slip by unnoticed. Some devices add physiological sensors, like heart rate monitors. But without context, a spike in heart rate doesn't say much. On top of that, many of these products are expensive, uncomfortable for kids, or designed with adults in mind.

There's another blind spot: almost nobody's tracking the environment. Things like temperature, noise, air quality, or lighting can all affect seizure risk and safety,

but most monitors ignore them. Without this context, it's hard to tell a real emergency from a harmless blip. Cloud-connected options exist, but they tend to focus on recording data, not jumping in with real-time help during a seizure. That delay makes them less useful when timing matters most.

If you look at this from an embedded systems angle, stitching together multiple sensor feeds on low-power hardware is tough. Computational limits, noisy data, battery drain, and spotty connectivity all make real-time analysis a challenge. People pitch machine learning as a solution, but not many actually balance the complexity of these models with what's possible on small, resource-limited devices—especially for children.

Put all this together, and the field is missing a system that's continuous, context-aware, affordable, and actually designed for kids. The problem isn't a lack of sensors. It's the absence of a unified, reliable, and practical setup that can spot seizures as they happen, in the real world, without overwhelming families with false alarms. Solving this means rethinking how we combine sensors, process data on the device, and send alerts—all within the tight limits of embedded IoT tech.

LITERATURE REVIEW

Epilepsy monitoring has taken plenty of twists and turns, mostly shaped by the constant balancing act between clinical accuracy, usability, and what's actually practical to deploy. Right now, most research divides into four big camps: clinical-grade neurophysiological monitoring, motion-based wearables, single-parameter physiological monitoring, and multi-sensor IoT frameworks. Each of these handles part of the challenge but still leaves serious gaps.

Clinical neurophysiological monitoring is still the gold standard. These setups use high-resolution neural signals—think EEG, often paired with video—to pin down seizures with impressive precision. Doctors trust these systems because the data is clear and interpretable. But the catch isn't technical—it's structural. You have to be in a hospital, hooked up to specialized gear, and watched by trained staff. Most of the time, that means only short monitoring windows, and everything happens in a controlled setting that doesn't match real life. So even though the diagnostics are strong, the system falls short in everyday scenarios, especially for kids who have seizures when nobody's watching [1].

To get around this, researchers started building motion-centric wearables. These usually pack accelerometers or gyroscopes to catch the strong, rhythmic movements of convulsive seizures. The appeal? They're simple, low-power, and easy to wear. For generalized tonic-clonic seizures, they pick up a fair number of events. But portability comes at a price, especially with children. Kids move around a lot—jumping, falling, playing—which triggers false alarms. And if a seizure doesn't come with big movements, the device misses it. Studies on these wearables paint a mixed picture, but the bottom line is clear: relying on motion alone just isn't enough to capture neurological events accurately [2].

The third approach zooms in on single physiological parameters—heart rate, oxygen saturation, things like that—to catch the body's autonomic responses to seizures. These signals are less noisy than motion sensors when it comes to picking up normal activity, but they bring their own problems. Heart rate and similar metrics jump around for all sorts of reasons: stress, exercise, temperature changes, you name it. Without extra context, changes in a single signal don't say much. Some research finds a link between these physiological changes and seizures, but plenty of studies report overlaps with normal fluctuations. So, tracking just one physiological measure doesn't reliably separate seizures from regular life outside the clinic [3].

Lately, multi-sensor IoT-based monitoring has started to get real traction. These systems combine motion sensors, physiological monitors, sometimes even environmental data, and send everything to the cloud for visualization and alerts. The real strength here is sensor fusion—combining streams cuts down on the noise from any single source. IoT connectivity means caregivers can get real-time alerts from anywhere, plugging a big hole in earlier setups. But more sensors and data mean more complexity. Real-time analysis on tiny, low-power devices is tough—memory, processing, and battery life all become bottlenecks. Many systems still lean on basic threshold logic, and while some use machine learning, they often skip the hard work of fitting it onto small hardware [4].

There's a stubborn contradiction running through the literature about machine learning. It gets pitched as the answer to false positives and poor detection, and sometimes complex models do boost performance on

carefully curated datasets. But those models usually need way more computing power than wearables or cheap IoT devices can provide. Some researchers keep things simple to fit the hardware, but then lose out on accuracy and adaptability. This tug-of-war between smarter algorithms and real-world feasibility is still unsolved—especially for pediatric use, where seizure types and patient data are all over the map, and labeled datasets are hard to come by [5].

Most researchers tend to overlook the role of environmental context. Only a handful of studies mention that things like temperature, air quality, noise, or lighting can affect seizure risk or what happens after an event. When they do, they usually treat environmental sensing as an afterthought, not a core part of detection. So, most monitoring systems remain blind to anything outside the body. That's a real problem, especially for kids at home—environmental hazards during or after a seizure can be dangerous, sometimes even life-threatening. The research community still hasn't agreed on how to weave environmental data into detection or alerting strategies. This is a glaring gap in the field.

Cost and accessibility split existing solutions even further. The clinical-grade systems chase accuracy, but that usually means they're expensive and hard to get. Wearable devices try to keep things affordable, but that comes at the price of limited functionality. Some IoT-based prototypes claim to be cheap and practical, but hardly any studies dig into what happens when you actually use them long-term at home: How do they hold up? What about maintenance, or reliability outside the lab? This gap between what's proven in prototypes and what works in real life keeps much of the research from making a real difference.

Put simply, progress across the field is scattered. Clinical systems nail accuracy but can't deliver continuous monitoring. Wearables give you continuity but often fall short on reliability. IoT prototypes try to tie everything together, but real-world challenges hold them back. Right now, nobody offers a unified approach that's built for children, aware of real-world context, and ready to be deployed at scale. Fixing this isn't just about adding more sensors; it means rethinking how we balance sensing, processing, and alerting, all while dealing with the messy realities of embedded systems and pediatric care at home.

METHODOLOGY

This work centers on building and testing a real-time IoT-based epilepsy monitoring system designed specifically for children. The goal is simple: keep the device running smoothly outside of hospitals, keep the hardware easy to manage, and deliver alerts that actually matter — all while working within the limits of embedded systems and the unpredictability of real-world conditions.

System Design Approach

The system relies on a layered embedded-IoT architecture. It splits into data acquisition, on-device processing, communication, and application layers. This setup doesn't just look nice on paper — it keeps time-sensitive tasks local. Seizure alerts get generated right on the device, no matter if the Wi-Fi drops. Every design choice pushes for predictability and clear, explainable behavior, avoiding mysterious or resource-hungry models.

Sensor Selection and Data Acquisition

Single-sensor setups miss too much, so this system uses several. A pulse sensor tracks heart rate and oxygen saturation, two key signals that often change during seizures. A three-axis accelerometer picks up on odd movements or sudden falls. Environmental sensors add extra context: temperature, humidity, air quality (CO₂), sound intensity, and light levels. These sensors aren't just picked for precision — they're chosen because they're available, don't waste power, and actually matter for child safety.

All sensors connect directly to the ESP32 microcontroller. Sampling rates strike a balance between detail and battery life, so the system can monitor around the clock without draining power. The device normalizes and timestamps sensor data right at the point of collection.

On-Device Processing and Detection Logic

All the processing happens right on the microcontroller. This keeps things fast and doesn't depend on the cloud. First, the device filters out noise and smooths the signals, ironing out sensor glitches and movement artifacts. Detection logic combines simple threshold rules with lightweight pattern recognition. It doesn't panic over a single weird reading — it looks for clusters, like abnormal movement plus a spike in heart rate or a drop in oxygen.

This rule-based approach isn't an accident. Machine learning models are tempting, but they eat up resources, require lots of training data, and can act like a black box. For a low-power device meant for kids, predictability and easy calibration matter more. This way, the system stays responsive and transparent.

Alert Generation and Fail-Safe Mechanisms

When the system spots something off — a pattern that crosses set thresholds — it triggers a loud local buzzer. Caregivers nearby get notified immediately, even if the network's down. At the same time, the device flags the event and preps the data for remote upload. To avoid overwhelming caregivers, it filters out fleeting glitches and doesn't send repeated alerts for the same event.

Communication and Cloud Integration

The ESP32's Wi-Fi handles data transmission to the cloud. Instead of flooding the network with raw data, it sends real-time readings and event markers, which saves bandwidth. The cloud platform handles data visualization, logs history, and sends mobile notifications to caregivers. Communications are asynchronous — if the connection drops, local alerts still work.

Evaluation Strategy and Constraints

Testing focuses on whether the system works as intended, not on making medical diagnoses. Trials simulate real-world use: controlled movement, forced sensor readings, and changing environmental conditions. The team measures how quickly the system responds, how accurately it flags events during normal activity, and how stable it stays over time. The approach openly admits its limits — sensor accuracy, no access to clinical seizure datasets, and no long-term field trials yet. Overall, this methodology puts practical use ahead of theoretical perfection. By combining sensor fusion, on-device processing, and real-world alerting within embedded system constraints, the team delivers a working framework for continuous pediatric epilepsy monitoring — not a certified diagnostic tool, but a real step toward safer everyday care.

RESULT

The system ran smoothly through long testing sessions, showing that it's practical to pull data from several physiological and environmental sensors using just one embedded platform. The ESP32 microcontroller managed everything at once — grabbing sensor readings,

cleaning up the data, running detection algorithms, and sending information wirelessly. No crashes, no memory issues. That's impressive, especially given the hardware's low-power limits, and it backs up the choice to process data on the device itself instead of depending on the cloud.

Looking at physiological sensing, heart rate and SpO₂ readings stayed steady whether the subject was at rest or moving around. The system's signal smoothing and filtering did a good job at cutting out noise from motion, especially during moderate activity. It caught abnormal states—like sudden spikes in heart rate or drops in oxygen saturation—almost right away and flagged them. At the same time, it didn't overreact: if something odd popped up in one reading but not in others, the system held back on alerts. That cuts down on false alarms and makes the results more trustworthy.

Motion analysis with the accelerometer painted a clear picture. Everyday activities—walking, sitting—showed up as low or moderate acceleration, well below alert levels. But when test subjects simulated falls or seizure-like movements, the accelerometer picked up sharp, unmistakable spikes across several axes. The system consistently recognized these patterns. If an odd motion wasn't backed up by physiological changes, it didn't send an alert. This cross-checking approach really helps keep false positives in check.

Environmental sensors added another layer. Temperature and humidity stayed within expected ranges, and the system accurately tracked CO₂ changes during tests that simulated shifts in ventilation. It picked up loud noises and sudden drops in light, logging these as contextual events. While environmental data by itself didn't trigger seizure alerts, it gave extra information that could help caregivers make sense of what happened after an event.

When it came to alerts, the system responded quickly. The buzzer went off almost instantly when thresholds were crossed. Remote notifications sent through the IoT platform had slight delays, depending on network speed, but always stayed within a reasonable window for caregiver response. Crucially, local alerts didn't depend on internet access, so the system kept working even if the network went down.

Testing at the system level showed it could keep monitoring non-stop without draining power or overheating. By only sending updates when something

noteworthy happened, instead of streaming raw data all the time, the system used bandwidth efficiently. While this isn't a clinical diagnostic tool for seizures yet, the results show that a setup like this—combining multiple sensors, handling data on-device, and using IoT for notifications—can deliver reliable, real-time monitoring in real-world settings.

All told, the results back up the main idea: that combining physiological, motion, and environmental data right on the device leads to better, more reliable detection than just using one type of sensor. Of course, there are limits. The tests used simulated scenarios, and there's still no clinical validation. So, while the system proves itself technically and functionally, there's more work ahead to move from feasibility to full medical reliability. This lays the groundwork for future trials and system improvements.

CONCLUSION

This work shows that it's actually possible to build an IoT-based epilepsy monitoring system for children—one that runs around the clock, understands context, and sends real-time alerts when it matters. By pulling together physiological, motion, and environmental data on a single embedded device, the system breaks free from the usual limits of single-sensor monitoring. The results make it clear: you spot seizure-related problems more reliably when you look at several signals at once, not just one, especially in unpredictable home environments.

Looking at the bigger picture, this project proves that low-cost microcontrollers really can handle real-time health monitoring—if you set your priorities straight. Running detection and alerts locally, right on the device, cuts down response time and keeps the system reliable even if the network drops. Many cloud-based systems lose precious seconds because they send everything away for processing; this design avoids that pitfall. It's a real demonstration that smart decisions can happen at the edge, without needing heavy-duty computing power.

Adding environmental sensors isn't just a technical flourish; it actually brings an extra layer of awareness that most pediatric epilepsy systems overlook. These data points don't directly trigger seizure alerts, but they give caregivers valuable context when something goes wrong and help make sense of incidents after the fact.

This wider lens fits better with what families actually need, since risks during or after a seizure can be just as serious as the event itself.

Of course, the study doesn't shy away from its limits. The seizure detection relies on simple thresholds and lightweight inferences—not on clinically validated models. That makes sense for something running on embedded hardware, but it doesn't replace a medical diagnosis or EEG confirmation. There's also no real-world seizure data or long-term testing yet, so it's hard to say much about accuracy or how well the results would generalize. These gaps make it clear: there's a big difference between a system that monitors functionally and one that guides clinical decisions.

All things considered, this system offers a solid, practical way to monitor pediatric epilepsy outside the hospital. It fills the gap between clinical diagnostics and unreliable manual checks, giving caregivers faster alerts and better information. The next step is clear: clinical validation, smarter thresholds, personalized settings—these are needed to boost accuracy and cut down on false alarms. With these improvements, IoT-based monitoring could become a real tool for pediatric epilepsy care, not just a technical experiment.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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