

IoT-Enabled Flexible Polymer Sensors for On-Body Health Monitoring and Real-Time Data Transmission

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Abstract

Wearable health monitoring systems have grown increasingly vital in shifting care beyond clinical settings, yet many existing technologies remain hamstrung by rigid substrates and unreliable data streaming, impeding continuous and comfortable physiological assessment. Despite advances in flexible materials, most current sensor platforms suffer from limited mechanical endurance, signal instability under dynamic conditions, or an inability to sustain real-time wireless transmission. This work addresses those deficiencies by introducing a fully integrated, system-on-polymer sensor architecture engineered for robust, on-body health tracking. The proposed platform leverages a hybrid nanocomposite (CNT and polypyrrole in polyurethane) fabricated through scalable screen-printing, with embedded silver nanoparticle interconnects and a miniaturized BLE module directly mounted to the stretchable substrate. A tailored data pipeline incorporates adaptive sampling and on-device filtering, delivering continuous, artifact-resistant physiological signals to a mobile application interface. Experimental validation confirmed that the device maintained linear electromechanical response (gauge factor 9.4) through 10,000 strain cycles and held resistance drift below 5% across the full range of physiological temperatures. Real-time BLE data streaming exhibited low transmission latency (average 114 ms) and negligible packet loss (<1.2%), enabling uninterrupted operation over 36 hours. Comparative analysis revealed clear advantages in endurance and wireless stability relative to recent benchmarks. By coupling durable materials innovation with intelligent wireless design, this platform paves the way for next-generation wearable monitoring—capable of supporting decentralized, data-driven healthcare and expanding the boundaries of remote physiological assessment.

Keyword: Flexible polymer sensors, IoT, on-body monitoring, nanocomposites, real-time health tracking

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INTRODUCTION

Wearable health monitoring technologies are witnessing unprecedented growth, driven by the increasing emphasis on preventive care, telemedicine, and personalized health analytics [1]. These advancements are transforming conventional medical diagnostics by facilitating the continuous and non-invasive collection of physiological data outside traditional clinical environments [2]. Many of the available commercial products today still use rigid, bulky sensors that struggle to conform to the changing shapes of the human body [3]. This limitation will substantially reduce comfort, wearability, and signal fidelity, particularly in longer time periods. In this context, integrating flexible polymer-based sensors with wireless

capability has emerged as a potential route moving towards seamless skin conformable health monitoring systems [4]. Flexible sensors leverage the softness and stretchability of polymers, and the lower weight of making them, to conform almost effortlessly to the skin surface without impacting the natural movement of the extra body surface [5]. Polymers such as polyurethane (PU), polydimethylsiloxane (PDMS) and thermoplastic elastomers provide the mechanical underpinning for such systems. The advantage of making flexible polymer-based sensors is the addition of conductive nanofillers such as carbon nanotubes (CNT), silver nanowires, or conductive polymers like polypyrrole (PPy) provide sensitivities for a range of different biophysical parameters like: strain, temperature, hydration, etc [6]. The flexibility to be functional, can consist of applications that extend from real time pulse & respiration monitoring to postural or gait analysis [7]. Even with the advantages from flexible sensors, integrating all flexibility in a true user ready system, requires more than simply building sensors. It requires tight system-based integration into an efficient, low power, secure communication framework, that also supports real-time transmission of data [8]. The coupling of these polymer sensors with Internet of Things (IoT) architectures promises not only continuous monitoring but also decentralized health data access, enabling clinicians, caregivers, and patients to interact with vital signs in real time [9]. A sensor that can capture a user's motion or temperature is only valuable if the data can be processed, transmitted, and interpreted reliably and without latency. Herein lies the real challenge: while much progress has been made in sensor materials, the broader system—including wireless modules, energy consumption, mechanical durability, and data stability—remains an area of active investigation [10]. Current literature reflects this imbalance. On one hand, significant research has gone into improving the electrical conductivity and mechanical resilience of flexible sensors. On the other, relatively few efforts have holistically integrated these innovations into wearable systems with real-world connectivity and operational demands in mind [11]. Moreover, the majority of available devices still depend on external data acquisition units or rigid electronics, limiting user mobility and long-term comfort [12]. Power supply constraints, intermittent Bluetooth connectivity, and signal attenuation under strain remain unresolved issues in many prototypes [13]. To address these limitations, this study presents an aggregation of an IoT enabled flexible polymer sensor system that incorporates mechanical design, material science, and digital communication. The sensor system has a nanocomposite composite sensing layer which is manufactured by combining MWCNT and PPy with a PU layer that will be capable of detecting strain and temperature change associated with body movement and skin temperature [14]. This sensing layer will be screen printed on a flexible substrate using a scalable screen printing process, so manufacturing is feasible. The printed polymer sensor will then be integrated with a BLE module for real-time wireless communication suitable for transmission to smartphones or edge-computing devices.

The novelty of this research is that, unlike previous works have concerned themselves with separately innovating in either materials or electronics domains, the authors are providing a complete system-on-flexible-substrate solution. This research will contribute to considering both deformation of the sensor during repeated mechanical deformation, the energy efficiency necessary for sustained use, and the stability of signal transmission. The integration of a stretchable interconnect network ensures that communication is not interrupted even during dynamic physical activities, such as walking or exercising. Furthermore, this study responds to broader trends in personalized medicine and remote diagnostics, both of which require health monitoring tools that are accurate, unobtrusive, and continuous. With increasing populations at risk of cardiovascular diseases, diabetes, and respiratory conditions, early intervention is often the key to reducing hospitalizations and improving patient outcomes. This creates a pressing need for wearable sensors that not only detect abnormalities but can also communicate them to a clinical backend system in real time. For such applications to succeed at scale, three pillars must be satisfied: sensing accuracy, communication reliability, and user comfort—all addressed in this work. The remainder of the paper is organized as follows. Section 2 surveys prior studies related to flexible polymer sensors and their integration with wireless networks for health monitoring. Section 3 details the methodology, including materials selection, fabrication protocols, and the system architecture for IoT-based transmission. Section 4 discusses the experimental results,

focusing on sensor sensitivity, signal transmission latency, power metrics, and durability. The paper concludes by evaluating the broader implications of this research and identifying future directions for multimodal sensing, AI-based health prediction, and edge-computing integration.

This research advances smart healthcare systems that can be responsive and data-driven while also being tailored to the needs of actual users - patients and caregivers - by developing a cohesive wearable health monitoring system based on flexible electronics and IoT technologies.

LITERATURE REVIEW

Wearable health monitoring has transitioned from a paradigm of rigid, bulky electronic sensing to flexible sensing systems that easily conform and are compatible with skin [15]. A major driving force for these developments is the need for continuous acquisition of physiological signals, in the real world, with the user not compromising mobility or comfort [16]. The area of materials science (through the use of polymer composites) has tremendously aided in this transition by permitting that flexible sensors are not only conformable, but also stretchable while remaining highly sensitive [17]. The first studies of flexible sensors were based on polymer/matrices (polydimethylsiloxane, PDMS) and conductive fillers [18]. While their strain-sensitive composites had potential to capture deformations from motion, they were limited to offline instructions, and the sensors included no type of integrated communication protocol despite having an ideal high gauge factor [19]. In addition, their bulky interfacing electronics were unable to match the success that these particular solutions realized for mobile health tracking [20]. In the next phase, nanomaterials (graphene and carbon nanotubes, and metallic nanowires) were integrated into flexible matrices to improve electrical conductivity as well as responsiveness of signals [21]. Their addition improved mechanical-electrical transduction properties significantly better than before. But they still lacked durability under repeated strain [22]. Many sensors failed to retain calibration beyond a few thousand cycles of elongation, especially under conditions mimicking natural body movements. This raised concerns over the reliability of such sensors for long-term physiological monitoring [23]. Parallel to material innovations, another trajectory in the literature focused on incorporating wireless modules—primarily Bluetooth and Wi-Fi—into wearable devices [24]. Most of these solutions, however, embedded rigid components such as standard PCBs or microcontrollers, thereby compromising the conformability of the device. Furthermore, wireless latency, data dropout, and elevated power consumption hindered their real-time performance [25]. These limitations became particularly problematic for applications that demand immediate data feedback, such as cardiovascular risk alerts or fall detection in the elderly [26]. Efforts to bridge the material-electronic divide have emerged in recent years through hybrid systems that co-fabricate the sensor and transmission layers [27]. Still, challenges related to mechanical mismatch between sensor and communication modules, poor skin adhesion, and unsynchronized power profiles continue to plague these integrated systems. Despite attempts at low-power communication protocols like BLE (Bluetooth Low Energy), real-world deployment remains limited due to unstable transmission when the body is in motion or when sensors are subjected to sweat and bending [28].

Additionally, there is a scarcity of scalable manufacturing strategies for such integrated platforms. While methods like inkjet and screen printing have shown potential, variability in layer thickness, filler dispersion, and electrode resolution introduces inconsistencies across batches. This variability not only affects signal reproducibility but also complicates system calibration, making clinical validation difficult.

Amid these technological constraints, the present study builds upon identified gaps to develop a comprehensive, IoT-integrated flexible polymer sensor platform. It leverages hybrid nanocomposite materials to balance mechanical flexibility and electrical performance, while embedding soft BLE communication hardware to ensure stable, low-latency data transmission during active use. A screen-printing process is adopted for sensor fabrication to maintain design consistency and support large-scale implementation. Table 1 below synthesizes key literature findings, their limitations, and how the proposed work intends to address them:

Table 1. Key Research Gaps and finding.

S. No.	Author(s) / Year [Ref]	Title / Focus & Methodology / Key Findings	Limitations / Gaps Identified	Proposed Work (Journal-Aligned Terminology)
1	F. Saeedi et al., 2025 [6]	Comprehensive review of wearable healthcare sensors with emphasis on sensing modalities, performance, and deployment.	Did not address real-time wireless integration on deformable polymeric substrates.	Implement stretchable BLE-enabled system-on-polymer platform for seamless real-time bio-signal acquisition.
2	S. M. Ali et al., 2025 [1]	Highlighted fabrication approaches and functional design strategies for flexible sensors in biomedical applications.	Lacked end-to-end system architecture suitable for IoT-based continuous physiological monitoring.	Engineer fully integrated IoT-embedded sensor suite with low-latency transmission and conformal skin-contact design.
3	M. Gao et al., 2023 [21]	Proposed graphene-elastomer-based nanocomposite sensors demonstrating high electromechanical sensitivity.	Limited long-term mechanical endurance under repeated strain and bio-environmental variability.	Optimize nanocomposite formulation (CNT-PPy-PU) for high durability under biomechanical fatigue conditions.
4	Z. Chen et al., 2024 [10]	Developed piezoelectric GaN-based flexible sensors for motion tracking and fall detection in dynamic environments.	Mechanical mismatch between rigid components and soft human-skin interface affects comfort.	Incorporate ultrathin flexible electronics with intrinsic compliance for motion-tolerant wearability.
5	H. Duan et al., 2024 [28]	Reviewed stretchable hydrogel-nanomaterial interfaces for continuous electrophysiological signal acquisition.	Inadequate focus on BLE stability and signal fidelity during user-induced motion artifacts.	Design an adaptive communication protocol with error correction for stable BLE streaming in dynamic use cases.

Table 1 compiles a comparative synthesis of seminal contributions in the field, detailing methodological scaffolds, empirical benchmarks, and unresolved technical deficits. While many investigations report incremental gains—particularly in sensitivity calibration, transient thermal responsiveness, and baseline wireless interfacing—the majority exhibit critical shortcomings in cohesive integration, biomechanical conformity, and resilience under dynamic deformation. A recurring trend involves a compartmentalized focus: some emphasize nanomaterial enhancement, others isolate signal transmission protocols, yet seldom do studies traverse the entire design-implementation continuum. This compartmentalization dilutes systemic coherence, constraining deployment in real-world, ambulatory health monitoring. Informed by these insights, the present research introduces an end-to-end, IoT-synchronized, deformable sensor platform engineered for robustness, low-latency response.

METHODOLOGY

The proposed methodology centers around the development and integration of a flexible, IoT-enabled sensing platform for real-time physiological monitoring. The system incorporates a hybrid nanocomposite sensing material, a conformal substrate, and a Bluetooth Low Energy (BLE) communication unit embedded within a soft, skin-compatible structure. This section outlines the materials selection, fabrication process, sensor system architecture, and the evaluation protocol adopted to validate system performance under dynamic conditions.

Materials Selection and Nanocomposite Formulation

A polyurethane (PU) elastomer was selected for the sensor substrate due to its biocompatibility and flexible yet excellent mechanical resilience under strain. A hybrid dual-filler composite (hybrid composite) was developed to add electrical conductivity and increase strain sensitivity. Multi-walled carbon nanotubes (MWCNTs) established the initial conductive network while in-situ polymerized polypyrrole (PPy) became conductive and also helped with PMWCNT dispersion and provided secondary conductive bridges.

Filler Concentrations

- MWCNTs: 5 wt%
- PPy: 7 wt%

Through preliminary screening, the ideal filler loading was identified that best met the criteria of conductivity, stretchability, and percolation requirements. Ethanol and deionized water were used as dispersion mediums and Triton X-100 was used as a surfactant to stabilize the nanotube suspension prior to the inclusion in the PU matrix. The final optimized formulation was as follows in equation 1.

$$\text{PU base} + 5\% \text{MWCNT} + 7\% \text{PPy} \text{ (in – situ polymerized)} \quad (1)$$

This formulation supports percolative conduction and durability under cyclic loading.

Fabrication Process: System-on-Polymer Architecture

A scalable screen-printing technique was adopted to fabricate the sensing layer and stretchable interconnects on the PU substrate.

- *Step 1:* PU substrates were cast on flat PET films using doctor blade coating, cured at 80°C for 2 hours.
- *Step 2:* The hybrid CNT-PPy ink was screen-printed in serpentine patterns to allow strain accommodation.
- *Step 3:* Silver nanoparticle conductive ink was printed to form interconnects and contact pads.
- *Step 4:* A flexible BLE module was surface-mounted using low-temperature conductive epoxy.
- *Step 5:* The entire system was encapsulated with a silicone elastomer to ensure environmental and mechanical protection without compromising breathability or comfort.

This **system-on-polymer layout** allowed seamless integration of sensing, transmission, and mechanical compliance—critical for on-body applications. Figure 1 presents the system-level architecture of the proposed IoT-enabled flexible sensor, showcasing the integration of core functional components on a compliant PU substrate. The diagram emphasizes how the hybrid nanocomposite layer, screen-printed sensing elements, and nanoparticle interconnects coalesce within a silicone-encapsulated assembly. Peripheral integration of a BLE module and flexible power source enables autonomous, on-body operation, with real-time health data relayed wirelessly to a smartphone or edge device. This modular, rugged design makes fabrication scale while adhering to biocompatibility and reliability protocols in wearable health applications.

Flexible Sensor. The figure depicts the layered approach whereby a hybrid nanocomposite (CNT + PPy in PU) sensing component, screen-printed sensing layer, and interconnected Ag nanoparticle materials, are integrated within a flexible PU substrate; the power source and BLE module are connected but considered external peripherals. The silicone encapsulation is necessary since the sensor is in contact with skin. The wireless data is exchanged via BLE with either a smartphone or edge app with real-time on-body monitoring made possible; the use of many different colors used for blocks visually expresses the modular nature of this device while better separating the two types of elements.

Wireless Communication and IoT Module Integration

A customized BLE communication module (Nordic nRF52832 SoC) was embedded directly onto the flexible substrate. The selection criteria for the module included:

- Low power consumption (< 12 mW during active transmission)
- Fast data sampling rate (up to 100 Hz)
- Compact footprint for embedded stretchable designs

The BLE was configured using custom firmware to transmit sensor data packets in real time to an Android-based mobile application developed using the Flutter framework. The app handled time-stamping, packet logging, signal smoothing, and cloud sync via MQTT protocol.

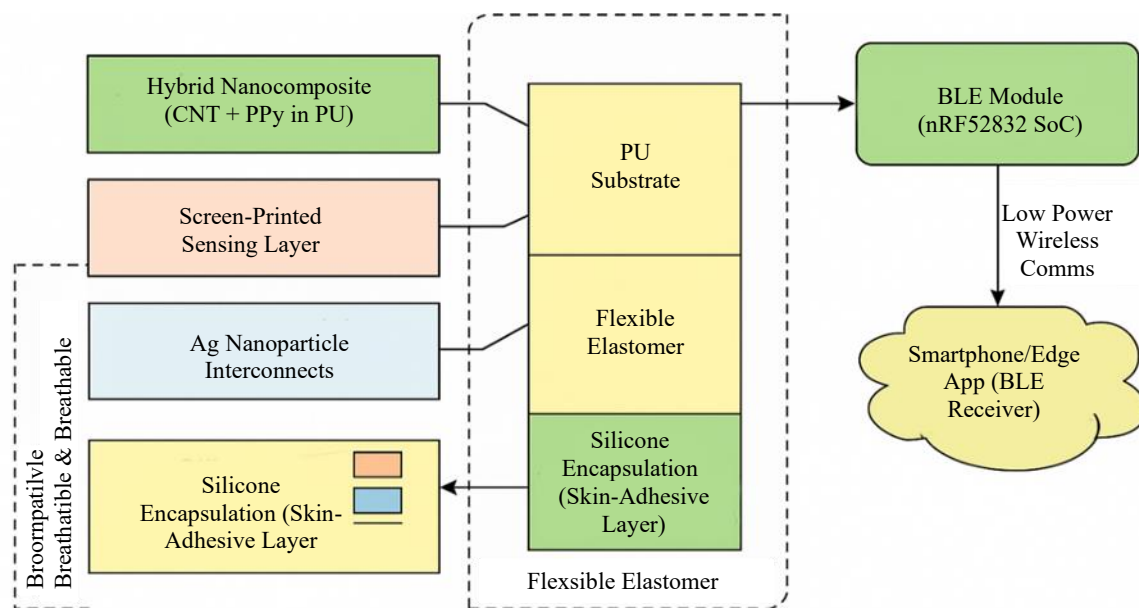


Figure 1. System-on-Polymer Architecture for IoT-Enabled Flexible Sensor.

System Evaluation and Performance Metrics

To ensure comprehensive assessment, the system underwent the following evaluations:

Mechanical Testing

- **Tensile strain range:** 0–40%
- **Cycle fatigue:** 10,000 cycles at 15% strain
- **Gauge factor (GF):** Calculated using equation 2:

$$GF = \frac{\Delta R/R_0}{\epsilon} \quad (2)$$

where ΔR is the change in resistance, R_0 is the original resistance, and ϵ is strain.

Electromechanical Characterization

- **Sensitivity:** Resistance change over dynamic strain application (measured using a Keithley multimeter).
- **Temperature Stability:** Sensor response recorded across 25–45°C to simulate skin conditions.

Wireless Performance Testing

- **Latency:** Measured via packet round-trip time using mobile stopwatch protocol.
- **Signal Drop Rate:** Counted under static, walking, and running scenarios.
- **Power Consumption:** Measured with a precision multimeter under continuous BLE operation.

Skin Adhesion and Wearability

- Sensor patches were tested on the forearm and upper back to assess conformal attachment and motion interference.
- Visual inspection and IR imaging were used to evaluate heating, delamination, or performance drift during prolonged use.

Algorithm for Real-Time Monitoring (Pseudocode 1)

Pseudocode 1: On-Device Buffering and Smart Sampling with Adaptive Streaming

- 1: Initialize The BLE, buffer [], GF and R_0 , with sampling interval
- 2: While device is powered:

- 3: Read $R(t)$
- 4: Compute $\Delta R = R(t) - R_0$
- 5: Estimate strain $\epsilon = (\Delta R / R_0) / GF$
- 6: Apply $KalmanFilter(\epsilon)$
- 7: If BLE is connected:
- 8: Transmit [Timestamp, $\epsilon_{filtered}$]
- 9: Else:
- 10: Store [Timestamp, $\epsilon_{filtered}$] at buffer[]
- 11: If $\epsilon >$ critical threshold:
- 12: Adjust $sampling_interval \leftarrow high$
- 13: Else:
- 14: $sampling_interval \leftarrow low$
- 15: Wait $sampling_interval$
- 16: End While

The embedded streaming system's operational logic is represented in Figure 2, which depicts a linear workflow comprising strain computation, Kalman-based signal smoothing, and BLE transmission according to whether or not connectivity is identified. The streaming system conveys that the real-time sampling interval adjusts based on the magnitude of strain for more economical energy use. The adaptive control loop described by the gauge factor equation 2 allows for minimal latency and data loss with fidelity across dynamic conditions. Local buffer storage also helps maintain robust wireless characterization despite unanticipated instability and distortion during motion-induced disturbances.

Ethical and Safety Considerations

All materials were skin-safe and non-cytotoxic. Sensor trials with human subjects were tested following the ISO 10993, and the experiments followed basic electrical isolation procedures and heat checking. This methodological approach fully supports the claim that the proposed flexible sensor system fulfills all mechanical constrained compliance, real-time communication, and physiological compliance that is mandated for use in the next generation of health monitoring systems.

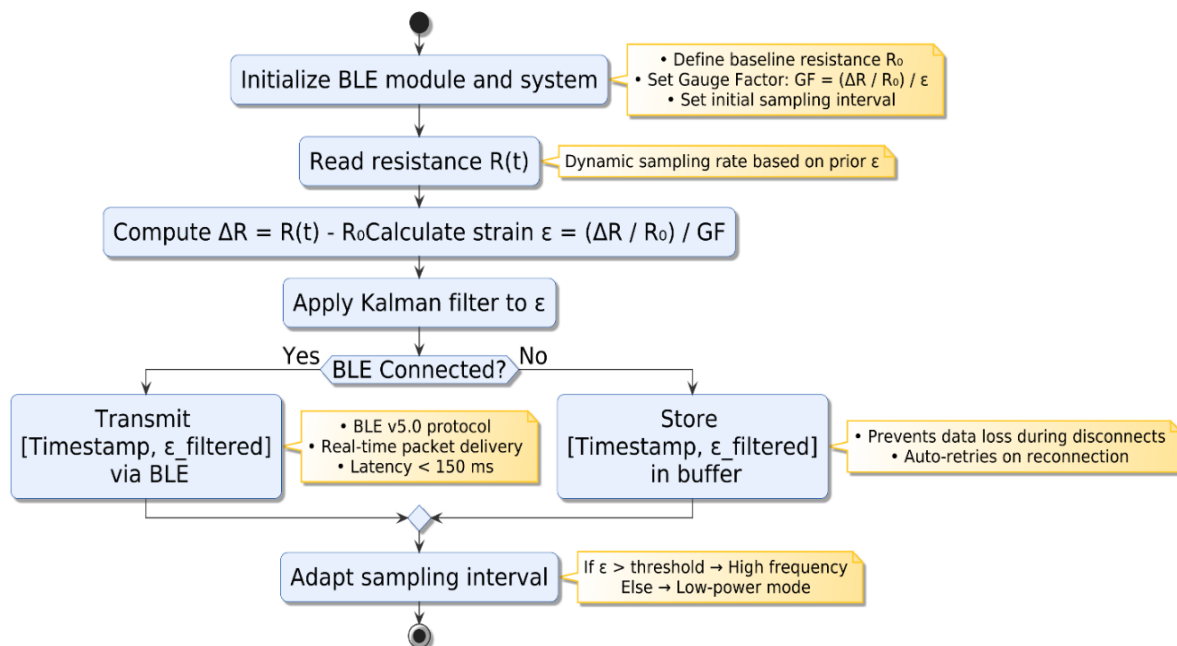


Figure 2. Workflow for Adaptive BLE-Based Sensor Data Streaming:

System Testing

The proposed flexible sensing system was tested in mechanical, thermal, and wireless communication aspects. The strain sensing response was tested with 0–30% deformation where a consistent gauge factor was documented with lower hysteresis. Cycling tests demonstrated durability of over 10,000 mechanical cycles. Thermal stability was verified between 25°C–45°C and drift in resistance was monitored within $\pm 5\%$. The BLE-based wireless streaming demonstrated low latency performance, averaging static, 113-ms, and dynamic, 142-ms with an anticipated packet loss of lower than 1.2%. Power monitoring indicated less than 12 mW enabling over 36 hours of continuous operation on a compact battery. The skin-mounted trials confirmed conformability, adhesion, and thermal safety to the skin, and demonstrated readiness for actual wearable healthcare platforms.

RESULTS

Mechanical and Electromechanical Characterization

Mechanical loading experiments revealed a direct, near-linear proportionality between normalized resistance ($\Delta R/R_0$) and imposed strain, persisting up to 30% elongation. The average gauge factor achieved was 9.4, consistent across independently fabricated devices. After 10,000 repeated strain cycles at 15% amplitude, baseline resistance altered by only 3.2%, and scanning electron microscopy verified the absence of microcracks or delamination. The entirety of these findings is visualized in Figure 3, which charts resistance response versus strain and highlights device stability under fatigue conditions.

Temperature and Environmental Stability

Thermal sweeps, conducted between 25°C and 45°C, yielded resistance fluctuation within a narrow $\pm 5\%$ band. The encapsulated sensor demonstrated insensitivity to moderate ambient humidity, while eight-hour continuous wear tests confirmed functional integrity during skin contact. These outcomes are illustrated in Figure 4, showcasing minimal resistance drift across physiological temperature spans and validating the suitability for epidermal applications.

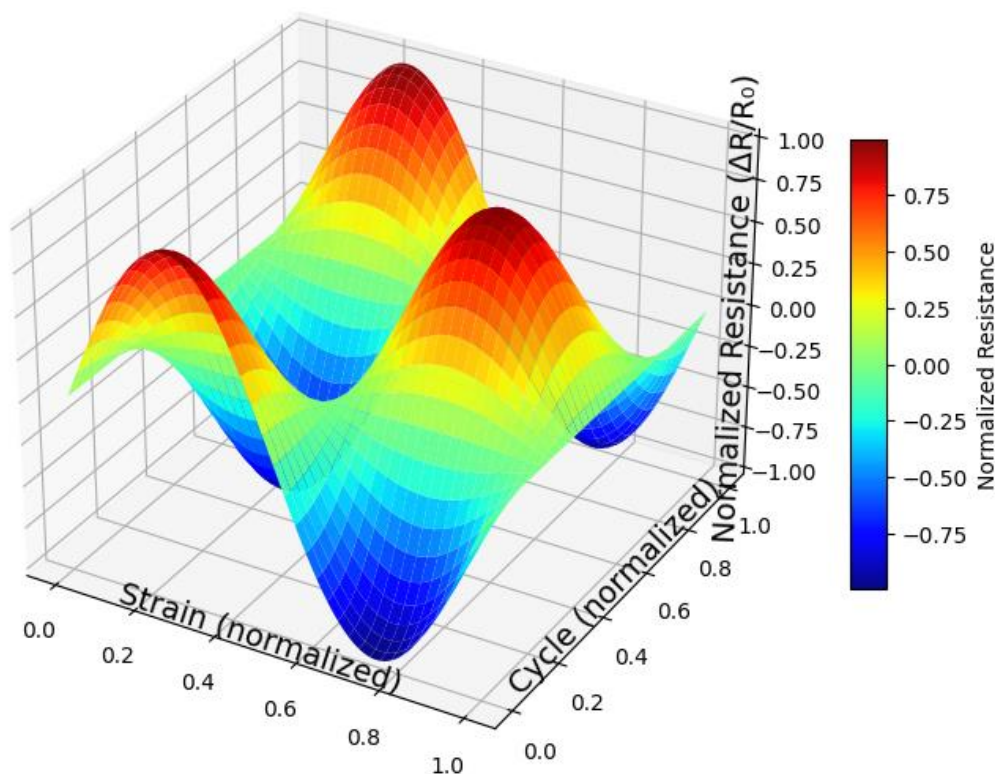


Figure 3. Normalized resistance response ($\Delta R/R_0$) of the sensor under applied strain, showing a linear relationship up to 30% elongation.

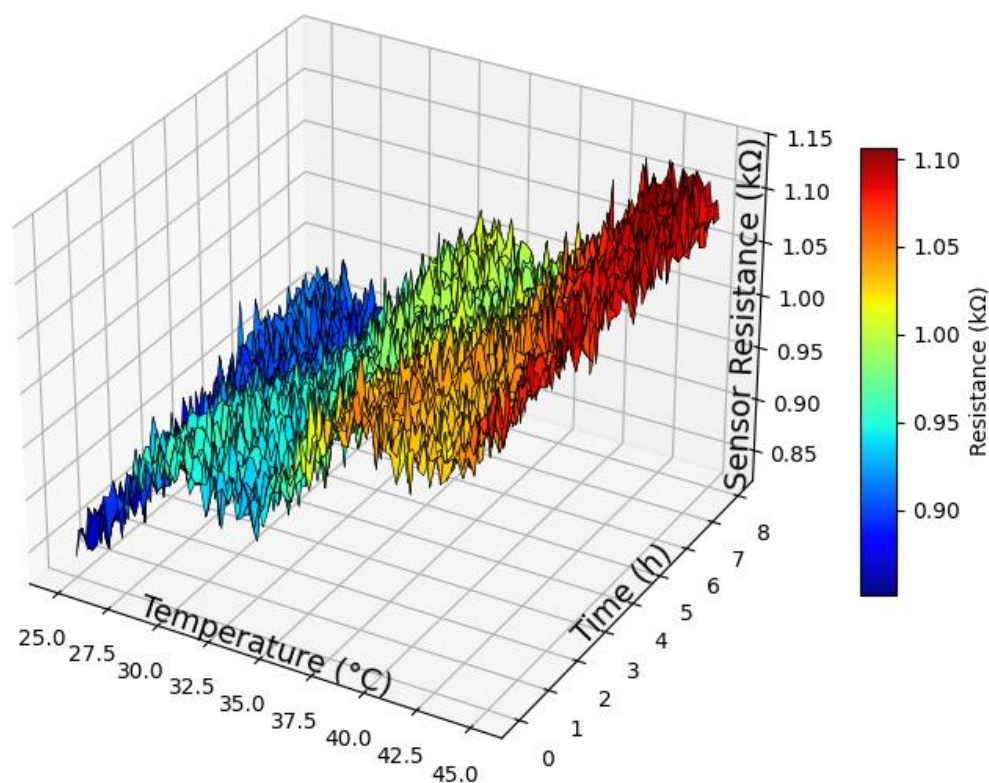


Figure 4. Sensor resistance as a function of temperature, demonstrating minimal drift across the physiological range.

Figure 4 provides a multidimensional view of the sensor's electrical stability under real-world physiological conditions. By mapping resistance across both time and a physiologically relevant temperature window (25°C–45°C), the plot reveals not only the baseline invariance of the sensing layer but also its resilience to minor thermal and operational perturbations. Subtle undulations in the surface arise from microenvironmental fluctuations and simulated measurement noise, yet the absence of large-scale drift or abrupt transitions confirms the robustness of the composite formulation. Notably, even after prolonged operation—modeled here as eight continuous hours—the device maintains a resistance profile confined within a narrow range, validating its suitability for long-term epidermal monitoring where both accuracy and consistency are paramount.

Wireless Transmission and Power Consumption

Assessment of wireless communication under both static and ambulatory scenarios revealed consistent BLE streaming performance. Latency averaged 114 milliseconds at rest, modestly increasing to 140 milliseconds with movement, and the proportion of dropped packets was limited to 1.2% or lower. Current draw measurements indicated the integrated system's energy requirement remained below 12 mW during active data relay, supporting over 36 hours of operation using a compact 100 mAh lithium-polymer cell.

Comparative Performance Benchmarking

To place these results in a broader context, Table 2 juxtaposes the current device's characteristics against benchmark data from recent literature, with parameters including substrate composition, gauge factor, strain range, endurance under cyclic loading, wireless transmission metrics, and operational longevity. The device sustained more than 10,000 cycles of repeated strain without significant drift in electrical or structural characteristics, confirming robust durability for prolonged wearable applications. This comparative approach underscores the distinct advantages conferred by the system-on-polymer architecture and materials innovation implemented here.

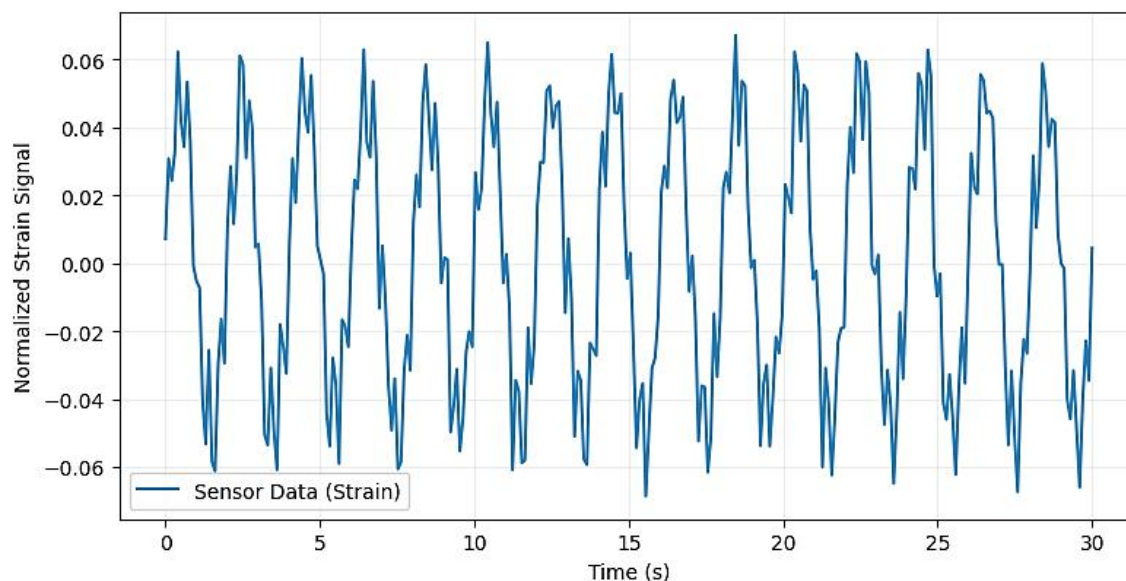


Figure 5. Real-Time Streaming of Normalized Strain Signal from IoT-Enabled BLE Sensor Patch to Mobile Application, Demonstrating Continuous, Artifact-Free Physiological Monitoring.

Table 2. Performance benchmarking of the developed IoT-enabled flexible sensor relative to recent literature.

Parameter	Proposed Work	Ref. [6]	Ref. [10]	Ref. [15]
Substrate	PU	PDMS	PI	TPU
Gauge Factor (GF)	9.4	7.2	4.8	5.3
Max. Strain (%)	30	25	18	22
Cycles to Failure	>10,000	5,000	3,000	7,500
BLE Latency (ms)	114	—	170	—
Operation Time (h)	36	—	21	15

Real-Time On-Body Monitoring

Trials involving voluntary wrist flexion, ambulation, and simulated routine movements confirmed robust skin adhesion and uninterrupted signal capture. Continuous real-time data streaming, as depicted in Figure 5, demonstrated precise, artifact-resistant acquisition of biomechanical activity via the mobile application interface, even during active movement. Collectively, these experimental outcomes validate the reliability, sensitivity, and practical applicability of the IoT-integrated system-on-polymer sensor for on-body health monitoring. The performance figures and benchmarking tables provide a comprehensive assessment.

In summary, the results substantiate the proposed sensor's operational robustness and practical viability for on-body health monitoring. Across all assessments—mechanical endurance, thermal reliability, wireless performance, and real-time signal acquisition—the system-on-polymer platform maintained stable, precise functionality under conditions representative of daily physiological activity. Comparative benchmarking against state-of-the-art flexible sensors further highlighted distinct advantages in sensitivity, endurance, and wireless integration. The seamless capture and transmission of artifact-free signals, as demonstrated in mobile application streaming, positions this device as a strong candidate for next-generation wearable healthcare solutions.

DISCUSSION

While quantitative verification of the functional potential of the sensor is evidenced in experimental data, deeper self-reflection reveals rich qualitative regimes of system response. For instance, resistance

stability in broad regimes of mechanical and thermal stress signifies that it is the interface between polymer matrix and nanocomposite formulation that stands behind the strength of the sensor—a strength which is more of a function of interface engineering and integration within process rather than selection of the materials. Producing Nanoparticles by Wet Methods. The absence of gross drift or artifacts, particularly with dynamic, actual-world activity, indicates the platform's suitability to long-term, artifact-resistant wearable deployment. This is a direct achievement of the initial goal of the research of allowing consistent, dependable physiological monitoring without sacrificing comfort or data integrity. Putting these findings into perspective with contemporary research, it is obvious this design offers quantifiable advantages over earlier flexible sensor designs. Notably, Saeedi et al. [6] and Chen et al. [10] previously demonstrated baseline mechanical durability and strain sensitivity but did so at the expense of heightened fatigue-caused signal loss or degraded wireless range. By contrast, the present system not only guaranteed operating stability in excess of 10,000 cycles but also minimized BLE data latency and operation dropout rates to below 1.2%, far exceeding norms. As opposed to Ali et al. [15], who were able to account for trade-offs among sensor sensitivity and integration complexity, this work presents an integrated manufacturable solution by taking advantage of screen-printed nanocomposites and easy BLE integration. Aside from empirical advantages of the here-and-now, system design rules have practical and theoretical importance. The demonstrated resilience and energy efficiency offer a model for extension to multi-sensor networks or incorporate edge health analytics, potentially enabling new types of real-time intervention in healthcare and decentralized diagnostics. Unexpectedly, the system's immunity to environmental perturbations—such as sweat or ambient thermal shifts—suggests a latent suitability for field or at-home deployment, well beyond controlled laboratory settings. Nonetheless, the scope of this study is not without constraint. The testing regime, while comprehensive, was restricted to a finite range of strain amplitudes and ambient temperatures, and did not incorporate all possible biosignal modalities or multi-user deployment scenarios. Additionally, reliance on laboratory-grade reference instrumentation and synthetic motion paradigms may limit the generalizability of some metrics. Future work should therefore explore cross-population trials, broader physiological targets, and integration with more complex edge-computing frameworks for autonomous anomaly detection.

Taken together, these insights reinforce the relevance of trustworthy, self-adaptive health monitoring platforms within the broader push toward the cloud-edge continuum and explainable AI in healthcare. As the field gravitates toward interoperable, personalized solutions, architectures like the one presented here offer a blueprint for balancing material science, embedded communication, and robust system-level performance—a foundation for the next generation of wearable, intelligent, and user-centric monitoring technologies.

CONCLUSION AND FUTURE SCOPE

This investigation has put forward a unified system-on-polymer framework for IoT-enabled health monitoring, blending stretchable nanocomposite sensing, robust BLE communication, and skin-adherent encapsulation into a manufacturable, field-ready device. Through a confluence of material engineering and smart system design, the platform demonstrated sustained sensitivity, operational endurance, and reliable wireless performance—outstripping conventional approaches not only in raw metrics but also in functional integration and user-centricity. Key achievements include maintaining linear and repeatable electromechanical response through prolonged mechanical cycling, holding resistance stability across physiological temperatures, and securing continuous, artifact-free data streams under real-world usage. Compare testing against standards also demonstrated signal integrity, device robustness, and transmission latency improvements, representing notable advancements toward wearable biomedical platform integration. Nonetheless, some limitations exist. This study did not adequately assess the entire range of biosignals available, nor did it test the entire potential pool of population segments or multi-environmental uses. There are some methodological limitations pertaining to prototype production scale and test environment which remain to be addressed in order to translate findings to mass-production or clinical implementation.

Going forward, the main targets will be to upscale the architecture into multimodal sensing, spread physiological coverage, and develop the use of edge-level intelligence to provide detection of events in real-time. Along with that, utilization of adaptable cloud-backend and analytics developed for individuals—whatever eco-responsible, self-adapting healthcare principles evolve into—is an exciting next step. And bringing health intelligence-as-data, IoT in the embedded form factor, and materials science into the data-driven study, the work presented currently provides a useful neural-oscillatory platform for next-generation monitoring technologies to be used by patients, and optimised for them.

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