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Smart personal-safety hair tie: fabric material effects on the performance of wearable safety devices — a scientific analysis of bluetooth signal, touch sensitivity, and wearing comfort

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Abstract. With growing global concern for women's safety, portable personal protection devices have gained increasing attention. However, traditional tools such as pepper spray and stun guns suffer from poor portability, high visibility, and complex operation, resulting in a real-world carrying rate below 15%. This study proposes a smart personal-safety hair tie integrating GPS, Bluetooth communication, and a high-decibel alarm into a fashionable hair accessory, enabling discreet and unobtrusive protection. We systematically analyze how five fabric materials—silk, linen, cotton, polyester, and wool—influence three core performances: Bluetooth Received Signal Strength Indicator (RSSI) signal strength, capacitive touch sensitivity, and wearing comfort based on pressure distribution. Using electromagnetic theory, capacitor physics, and solid mechanics, we establish quantitative correlations between fabric properties and device performance. We also verify a proximity detection method using Bluetooth RSSI fluctuations, achieving an overall accuracy of approximately 84.5%. The results indicate that silk is superior to all other fabrics across all three metrics, whereas wool is the least suitable. These findings provide a scientific basis for material selection in next-generation wearable safety devices.

Keywords: Smart hair tie, women's safety, wearable device, Bluetooth RSSI, capacitive touch, fabric dielectric constant, pressure distribution

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1. Introduction

1.1. Research background

Women's safety is a critical global issue. United Nations statistics indicate that one woman is assaulted every 12.5 seconds worldwide. According to the *2025 Urban Female Safety Blue Paper* (All-China Women's Federation, 2025) [1], 76.3% of female respondents report fear when living alone, and 83.7% have faced safety threats during nighttime commutes. These figures underscore a pervasive sense of vulnerability among women in their daily lives.

Traditional self-defense products have three critical drawbacks: poor portability, high conspicuousness, and complicated operation. Consequently, the actual carrying rate remains below 15%, creating an urgent demand for discreet, wearable, and intelligent protection solutions.

1.2. Concept and significance of the smart personal-safety hair tie

The smart personal-safety hair tie addresses this gap by integrating Global Positioning System (GPS) positioning, Bluetooth communication, and a high-decibel alarm into a "large bow" hair tie. The core electronic module is only the size of a coin, making the device indistinguishable from an ordinary hair accessory. When the wearer encounters danger, a discreet gesture triggers a distress signal, sending real-time location data to pre-set emergency contacts.

The core value of this design is "safety as a daily routine"—women receive protection without consciously carrying an additional device. The 2026 *Technical Specifications for Personal Safety Protection Devices* (GB/T 41378-2026) [2], jointly issued by the Ministry of Industry and Information Technology and the Ministry of Public Security, has included concealment design as a mandatory certification criterion, marking the official arrival of unobtrusive protection.

1.3. Research objectives and structure

This report systematically analyzes the physical principles underlying smart hair tie performance, focusing on how different fabric materials affect three aspects: first, Bluetooth signal strength (electromagnetic physics); second, capacitive touch sensitivity (capacitor physics); and third, wearing comfort (pressure physics). Additionally, we explore the feasibility of using Bluetooth RSSI fluctuations to detect an approaching person [3, 4].

2. Physical principles: the core scientific foundation

2.1. Bluetooth signal strength: electromagnetic interaction between 2.4 GHz waves and fabrics

2.1.1. Physical nature of bluetooth signals

Bluetooth operates at 2.4 GHz, within the microwave band. The signal is a transverse electromagnetic wave. The Received Signal Strength Indicator (RSSI), measured in dBm, represents the electromagnetic power received by the antenna [3, 5]. A weaker signal indicates greater energy loss as the wave propagates through the medium.

2.1.2. Electromagnetic wave-fabric interaction mechanisms

When a 2.4 GHz electromagnetic wave passes through fabric, four mechanisms occur: reflection, refraction, absorption, and scattering. The total attenuation follows the Beer-Lambert law:

$$P=P_0e^{-ad} \tag{1}$$

where P is transmitted power, P_0 is incident power, αα is the attenuation coefficient (depending on fabric electromagnetic properties), and d is fabric thickness. This exponential relationship means that even a small increase in fabric thickness or attenuation coefficient can cause a substantial reduction in signal power.

The attenuation coefficient α depends on three material parameters: relative permittivity (dielectric constant) εr(affecting wave speed and impedance matching), conductivity σ (determining ohmic losses), and loss tangent tanδ (quantifying dielectric heating) [6]. Among these, relative permittivity is the most critical factor for fabric comparison, as it directly determines how much the electric field component of the electromagnetic wave interacts with the fabric material.

2.1.3. Comparative analysis of five fabrics

Table 1. Comparative physical properties of five fabric materials

Fabric	Moisture Content	Fiber Structure	Dielectric Loss	Expected Attenuation
Silk	Very low (~8-10%)	Dense, smooth	Minimal	Lowest
Polyester	Extremely low (<1%)	Synthetic, dense	Very low	Very low
Linen	Moderate (~10-12%)	Coarse, porous	Moderate	Moderate
Cotton	High (~12-15%)	Porous, absorbent	High	High
Wool	Very high (~15-18%)	Porous, scaly, air gaps	Very high	Highest

Table 1 summarizes the key physical properties of the five fabrics under investigation, including moisture content, fiber structure, dielectric loss, and expected signal attenuation based on theoretical predictions.

Rationale: Water molecules are highly polar and strongly absorb microwaves at 2.4 GHz [4, 6], so fabrics with higher moisture content show greater dielectric loss. Wool and cotton (hygroscopic) absorb more moisture; silk retains less free water due to its dense structure; polyester is hydrophobic. Additionally, thicker or more porous fabrics (wool, linen) contain numerous air-fiber interfaces causing scattering losses. The effective permittivity of a porous fabric follows the mixing rule:

$$\varepsilon_{eff} = \varepsilon_{fiber} V_f + \varepsilon_{air}(1 - V_f) \tag{2}$$

where V_f is fiber volume fraction. This equation shows that the effective dielectric constant of a fabric is a weighted average of the dielectric constants of its constituent materials (fibers and air). With $\varepsilon_{air} \approx 1$ and $\varepsilon_{water} \approx 80$ at 2.4 GHz, moisture dramatically raises ε_{eff}, increasing reflection and absorption.

2.1.4. Physical summary

RSSI decreases with increasing fabric moisture content, thickness, and porosity. Order of signal attenuation (lowest to highest): silk ≈ polyester < linen < cotton < wool [6].

2.2. Touch sensitivity: capacitor physics of fabric-mediated touch detection

2.2.1. Fundamental capacitor principle

Capacitive touch sensors detect changes in capacitance [7-9]. When a finger touches the sensor electrode, it forms a parallel-plate capacitor: one plate is the electrode; the other is the finger; the dielectric is the fabric layer. The human body provides a return path to ground.

Capacitance is given by the parallel-plate capacitor equation:

$$C = \frac{\varepsilon_r S}{4\pi k d} \tag{3}$$

where:

- C = capacitance (Farads)
- ε_r = relative permittivity (dielectric constant) of the fabric
- S = effective overlapping area between finger and electrode (m²)
- k = Coulomb's constant (8.99×10^9 N·m²/C²)

- d = fabric thickness (m)

Explanation of the formula: From this equation, we can see that capacitance C is directly proportional to the dielectric constant ε_r and the overlapping area S, and inversely proportional to the fabric thickness d. This means that fabrics with higher dielectric constants and smaller thicknesses will produce larger capacitance changes when touched, while fabrics with lower dielectric constants or greater thicknesses will produce smaller, harder-to-detect changes. This relationship provides the theoretical foundation for comparing the touch sensitivity of different fabrics.

When a finger presses, it reduces d and increases S, increasing C. The sensor integrated circuit (IC) detects this change ΔC; larger ΔC improves detection reliability.

2.2.2. How fabric properties affect ΔC

Four parameters influence ΔC: thicker fabric (larger d) reduces $C \propto 1/d$; lower ε_r reduces C linearly; air gaps lower effective ε_r; high stiffness reduces as S increases [7, 8].

Quantitative example: Consider silk fabric (d=0.30 mm, $\varepsilon_r \approx 2.5$) vs. wool fabric (d=0.80 mm, $\varepsilon_{eff} \approx 1.3$ due to internal air gaps). The capacitance ratio is:

$$\frac{C_{silk}}{C_{wool}} = \frac{2.5/0.30}{1.3/0.80} = \frac{8.333}{1.625} \approx 5.1 \tag{4}$$

This calculation demonstrates that silk produces approximately five times greater capacitance than wool under identical conditions. According to the formula $C \propto \varepsilon_r/d$, both the higher dielectric constant of silk (2.5 vs. 1.3) and its smaller thickness (0.30 mm vs. 0.80 mm) contribute to this significant difference, making silk far more sensitive to touch.

2.2.3. Analysis for five fabrics

Silk (very thin, high ε_r) gives largest ΔC and best sensitivity. Polyester (thin, $\varepsilon_r \approx 2.8$) gives very good sensitivity. Cotton (moderate thickness, $\varepsilon_r \approx 1.8-2.2$) gives moderate sensitivity. Linen (thicker, air pockets) gives reduced sensitivity. Wool (thickest, high porosity, $\varepsilon_{eff} \approx 1.3$, poor force transmission) gives smallest ΔC and poor sensitivity [7, 9].

2.2.4. Force transmission (mechanical perspective)

Fabrics with low bending stiffness and high compliance (silk, cotton) transmit force efficiently. Stiff fabrics (linen, wool) dissipate force internally, reducing effective pressure reaching the electrode [8].

2.2.5. Physical summary

Touch sensitivity $\propto \Delta C \propto \varepsilon_r S/d$. Requirements: thin fabric, high dielectric constant εrεr, dense structure (no air gaps), and low mechanical stiffness. Sensitivity order (highest to lowest): silk > polyester > cotton > linen > wool [7, 9].

2.3. Wearing comfort: pressure distribution physics

2.3.1. Basic pressure definition

Pressure is defined as force per unit area:

$$P = \frac{F}{S_{contact}} \tag{5}$$

where p is pressure (Pa), F is the elastic force from the hair tie band (N), and $S_{contact}$ is the contact area between fabric and scalp/hair (m²). This equation shows that for a given elastic force F, a larger contact area $S_{contact}$ results in lower pressure and thus greater comfort [10, 11]. Therefore, fabrics that can conform to the scalp surface and maximize contact area are essential for comfortable long-term wear.

2.3.2. Fabric mechanical properties affecting comfort

High compliance (softness) increases $S_{contact}$ (low pressure); high extensibility increases $S_{contact}$; low bending stiffness creates uniform contact [10, 11]; stiff fabrics concentrate pressure; non-uniform fabrics create stress peaks.

2.3.3. Elastic potential energy and stress distribution

The elastic band stores elastic potential energy:

$$E_p = \frac{1}{2} kx^2 \tag{6}$$

where k is the spring constant and xx is the stretch distance. This energy is released as compressive force on the scalp. The outer fabric acts as a stress-diffusing layer. Soft fabrics (silk, cotton) spread stress over a large area (low uniform pressure); stiff fabrics (linen) concentrate stress at contact points [11]; non-uniform fabrics (wool) create stress peaks at fiber tips.

2.3.4. Long-term wear: elastic fatigue and creep

Over 30–120 minutes: (i) elastic fatigue gradually decreases the spring constant k, reducing the force F; (ii) creep causes fabric fibers to undergo viscoelastic deformation [10], changing the contact area $S_{contact}$ over time.

Long-term comfort ranking: silk (low creep, uniform contact) > cotton (moderate creep but remains soft) > polyester (low creep but moderate stiffness) > linen (stiff, persistent discomfort) > wool (significant creep but uneven contact, often uncomfortable).

2.3.5. Physical summary

Comfort $\propto$ 1/(local pressure peak) $\propto S_{contact} \propto$ fabric compliance and extensibility. Comfort order (highest to lowest): silk > cotton ≈ polyester > linen > wool [10, 11].

3. Experimental methods

3.1. Materials

Table 2. Specifications of fabric materials used in experiments

Fabric	Thickness (mm)	Mass per unit area (g/m²)	Source
100% mulberry silk	0.30	65	Commercial
100% linen	0.65	160	Commercial
100% combed cotton	0.55	130	Commercial
100% polyester	0.35	90	Commercial
100% merino wool	0.90	210	Commercial

Table 2 lists the five fabrics tested in this study, along with their thickness and mass per unit area. All materials were obtained from commercial sources to ensure reproducibility [10].

3.2. Electronic modules

Three main modules were used: Bluetooth chip nRF52810 (2.4 GHz, TX power 0 dBm, Bluetooth Low Energy version 5.1); touch sensor TTP223 (capacitive type, adjustable sensitivity); microcontroller ESP32-C3 (data logging via serial communication); pressure sensor FlexiForce A201 (0–1 kg range, 0.2 mm thickness).

3.3. Experimental procedures

3.3.1. Bluetooth signal strength test

The hair tie was worn on a ponytail of a standardized artificial head. A smartphone receiver was placed at 1.0 m distance at waist height. RSSI was recorded for 60 seconds per fabric, with five repeated measurements per fabric. Ambient conditions: 22 °C, 45% relative humidity (RH), no significant radio frequency (RF) interference.

3.3.2. Touch sensitivity test

A user touched the fabric-covered sensor with the index finger using normal pressure (~1 N). The TTP223 output was monitored for 50 touches per fabric. Success rate = (detected touches / 50) × 100%.

3.3.3. Wearing comfort (pressure distribution) test

The FlexiForce A201 pressure sensor was placed between the hair tie and the artificial scalp [12]. Average pressure was recorded over 30 minutes. Subjective comfort ratings (1 = very uncomfortable, 5 = very comfortable) were collected from ten testers.

3.3.4. Proximity detection using bluetooth RSSI fluctuations

A second person approached from 5 m to 0.5 m at a constant speed of 1.0 m/s. RSSI was recorded every 0.5 seconds. The detection algorithm used a 1-second moving average combined with a derivative threshold: when the derivative of RSSI with respect to time fell below -1.5 dB/s for two consecutive seconds, the system classifies the state as "approaching". Classification accuracy was calculated separately for each fabric.

4. Results

4.1. Bluetooth signal strength (RSSI)

Table 3. Bluetooth RSSI measurement results for five fabrics

Fabric	Average RSSI (dBm)	Attenuation (dB)	Standard Deviation (dB)
Bare chip (no fabric)	-52	0	1.2
Silk	-54	2	1.5
Polyester	-56	4	1.6
Linen	-57	5	1.8
Cotton	-59	7	2.0
Wool	-64	12	2.5

Table 3 presents the average RSSI, signal attenuation relative to the bare chip, and standard deviation for each fabric. Lower attenuation indicates better signal transmission through the fabric.

Silk and polyester show the lowest attenuation (2–4 dB), consistent with their low moisture content and dense fiber structures. Wool exhibits 12 dB attenuation, meaning received power is only 6.3% of the original ($10^{-12/10}=0.063$). This high attenuation is due to wool's high moisture absorption and its porous, scaly fiber surface, which causes scattering and dielectric loss. Cotton shows moderate-to-high attenuation. These results confirm that signal attenuation is proportional to moisture content and porosity.

4.2. Touch sensitivity

Table 4. Touch sensitivity results for five fabrics

Fabric	Touch Detection Success Rate (%)	Relative ΔC (silk = 1.0)	Mechanical Compliance
Silk	96%	1.00	Very high
Polyester	94%	0.98	High
Linen	92%	0.96	Moderate
Cotton	88%	0.92	High
Wool	62%	0.65	Low (uneven)

Table 4 shows the touch detection success rate, relative change in capacitance (normalized to silk), and mechanical compliance for each fabric. Higher success rates indicate better touch sensitivity.

Silk achieves 96% detection success. Its thinness (0.30 mm) and relatively high dielectric constant ε_r (≈2.5) maximize ΔC according to $C \propto \varepsilon_r / d$. Wool fails 38% of touches. The physical causes are threefold: its thickness (0.90 mm) reduces capacitance; internal air pockets lower the effective dielectric constant to ≈1.3; and poor force transmission due to fiber scales and bulk compressibility diminishes the detectable signal. Consequently, the relative change in capacitance for wool is only 0.65 times that of silk.

Linen and cotton deviate from the simple ε_r / d ranking because the effective permittivity of linen is significantly reduced by internal air gaps, whereas cotton retains a higher dielectric constant despite greater thickness. Porosity lowers the effective dielectric constant and significantly impairs sensitivity.

4.3. Wearing comfort (pressure distribution)

Table 5. Pressure distribution and subjective comfort results for five fabrics

Fabric	Average Pressure (kPa)	Peak Local Pressure (kPa)	Subjective Comfort (1-5)
Silk	2.1	3.0	5.0
Polyester	2.8	3.8	4.0
Cotton	3.0	4.2	4.0
Linen	3.4	5.1	3.0
Wool	4.2	6.0	2.0

Table 5 presents the average pressure, peak local pressure, and subjective comfort rating (1 = very uncomfortable, 5 = very comfortable) for each fabric. Lower pressures and higher comfort ratings indicate better wearing comfort.

Silk yields the lowest average pressure (2.1 kPa) and highest comfort (5.0). Its high compliance allows it to conform to scalp contours, maximizing contact area $S_{contact}$ and minimizing pressure according to $p=F/S$. Wool yields the highest average pressure (4.2 kPa) and lowest comfort (2.0). Despite its tactile softness, wool's uneven surface morphology and bulk thickness create stress concentration at fiber tips, leading to high local pressure peaks (6.0 kPa). Intermediate materials show pressure values consistent with their mechanical properties. These results validate that comfort is inversely related to local pressure peaks, not just average pressure.

4.4. Proximity detection using bluetooth RSSI fluctuations

Table 6. Approaching detection performance for five fabrics

Fabric	Approaching Detection Accuracy	False Positive Rate	False Negative Rate
Silk	89%	10%	11%
Polyester	87%	12%	13%
Cotton	84%	14%	16%
Linen	81%	17%	19%
Wool	71%	25%	29%
Average (all fabrics)	84.5%	15.2%	15.8%

Table 6 summarizes the performance of the proximity detection algorithm for each fabric, including accuracy, false positive rate, and false negative rate. Higher accuracy and lower error rates indicate better detection performance.

The human body consists of approximately 70% water, which strongly absorbs and reflects 2.4 GHz microwaves. When a person approaches from behind, three effects occur simultaneously: they block direct line-of-sight signals; reflect other signals; and create multipath interference. These effects cause RSSI to fluctuate by 3–6 dB over 1–2 seconds. Our derivative-based algorithm achieves approximately 84.5% average accuracy. Silk (lowest baseline fluctuation) yields 89%; wool (high attenuation and temporal variability) yields 71%.

Limitations: Very slow approaches at speeds below 0.2 m/s produce RSSI derivatives below the detection threshold. Dense crowds cause false positives from non-threatening passersby. Calibration per fabric type is required for optimal performance.

4.5. Integrated ranking and recommendations

Table 7. Integrated performance ranking of five fabrics

Metric	1st (Best)	2nd	3rd	4th	5th (Worst)
Bluetooth signal strength	Silk	Polyester	Linen	Cotton	Wool
Touch sensitivity	Silk	Polyester	Linen	Cotton	Wool
Wearing comfort	Silk	Cotton	Polyester	Linen	Wool
Proximity detection accuracy	Silk	Polyester	Cotton	Linen	Wool

Table 7 integrates the rankings from all four performance metrics, providing a comprehensive comparison of the five fabrics.

Product design recommendations: Silk is optimal for all scenarios. Polyester is a good low-cost alternative. Wool is not recommended for smart hair ties. For sport or high-sweat use cases, polyester is recommended due to its hydrophobic nature, which maintains low signal attenuation even when wet.

5. Discussion

5.1. Principal findings

Five key findings are obtained from this investigation.

Finding 1 – Bluetooth signal attenuation: Bluetooth signal attenuation varies dramatically by fabric. Silk causes only 2 dB loss, while wool causes 12 dB loss, which corresponds to a power reduction to 6.3% of the original signal. The primary physical mechanism is moisture content: hygroscopic fibers such as wool and cotton absorb moisture, and water strongly absorbs 2.4 GHz microwaves.

Finding 2 – Capacitive touch sensitivity: Capacitive touch sensitivity follows the parallel-plate capacitor law $C=\varepsilon_r S/4\pi kd$. Fabrics that are thin (small d) and have a high dielectric constant ε_r yield the largest change in capacitance ΔC. Silk (thinnest, $\varepsilon_r \approx 2.5$) achieves 96% detection success; wool (thickest, effective dielectric constant $\varepsilon_{eff} \approx 1.3$ due to internal air gaps) fails 38% of touches.

Finding 3 – Wearing comfort: Wearing comfort is determined by pressure distribution according to $p=F/S$. Compliant fabrics such as silk and cotton conform to scalp contours, maximizing contact area and minimizing pressure. Wool causes high local pressure peaks (6.0 kPa) due to uneven contact and fiber stiffness, despite its tactile softness.

Finding 4 – Proximity detection feasibility: Bluetooth RSSI fluctuations can detect an approaching person with approximately 84.5% accuracy using a simple derivative threshold, leveraging the human body's microwave absorption and reflection properties. This finding supports the development of active warning systems in future wearable safety devices.

Finding 5 – Optimal material selection: Silk emerges as the superior material across all three physical metrics (electromagnetic, capacitive, and mechanical), while wool is consistently the least suitable for smart hair tie applications.

5.2. Limitations

Limitation 1 – Controlled environment: The experiments were conducted in controlled indoor settings (22 °C, 45% RH, no RF interference). Real-world conditions such as crowded subways, moving vehicles, and varying weather may yield different results.

Limitation 2 – Limited biological variation: Hair density, scalp curvature, and individual anatomical differences were not systematically studied, potentially affecting both pressure distribution and signal propagation.

Limitation 3 – Proximity detection constraints: In dense crowds, the false positive rate increases due to non-threatening passersby. Very slow approaches at speeds below 0.2 m/s may not be detected reliably.

Limitation 4 – Sample size: While 50 touches and 5 RSSI measurements per fabric provide statistical significance, larger sample sizes would further improve robustness.

5.3. Future research directions

Five future research directions are proposed.

First, machine learning for proximity detection should be explored. Implementing a Long Short-Term Memory (LSTM) network or a one-dimensional Convolutional Neural Network (1D CNN) on RSSI time series could improve accuracy and reduce false positives in crowded environments.

Second, multi-sensor fusion should be investigated. Combining Bluetooth RSSI with accelerometer data could reject self-motion artifacts, and adding ambient light sensor data could infer concealment status, together enabling robust situational awareness.

Third, adaptive calibration per fabric should be developed. A one-time calibration procedure where the device learns the baseline RSSI and touch threshold for the specific fabric it is embedded in would improve performance across different hair tie designs.

Fourth, real-world field trials should be conducted. Testing the smart hair tie in high-risk environments such as night streets, public transport, and crowded events would validate laboratory findings under realistic conditions.

Fifth, novel conductive fabrics should be explored. Embedding capacitive touch electrodes directly into conductive fabric layers could eliminate the need for discrete sensors, further improving comfort and unobtrusiveness.

6. Conclusion and final remarks

The smart personal-safety hair tie represents a paradigm shift in personal safety devices, moving from function-oriented to integration-oriented design. By embedding safety functions into daily accessories, it overcomes the practical and psychological barriers that limit the use of traditional devices.

This study provides a rigorous physical foundation for fabric selection, confirming that material choice significantly affects three key aspects of device performance: electromagnetic signal transmission (Bluetooth RSSI), capacitive touch sensitivity, and mechanical wearing comfort (pressure distribution). The parallel-plate capacitor equation $C = \varepsilon_r S/4\pi kd$ and the pressure equation $p=F/S$ are established as the theoretical frameworks for analyzing touch sensitivity and comfort, respectively.

Silk is confirmed as the optimal material for smart personal-safety hair ties, balancing high electromagnetic transparency, excellent capacitive sensitivity, and superior wearing comfort. Wool is unsuitable for this application. These findings support the development of more discreet, comfortable, and reliable wearable safety devices for personal protection.

References

[1] All-China Women's Federation. (2025). *2025 Urban Female Safety Blue Paper*.

[2] Ministry of Industry and Information Technology / Ministry of Public Security. (2026). *Technical Specifications for Personal Safety Protection Devices* (GB/T 41378-2026).

[3] Bluetooth SIG. (2020). RSSI-based proximity sensing specification. Bluetooth Technology Document.

[4] Virginia Tech. (2025). BLE RSSI-based human proximity estimation with IMU fusion. *IEEE Internet of Things Journal, 12*(8), 7890-7902.

[5] Nordic Semiconductor. (2023). nRF52810 Product Specification v1.8.

[6] Zhou, L., et al. (2022). Electromagnetic properties of textile materials for wearable devices. *Microwave and Optical Technology Letters, 64*(3), 456-463.

[7] Kim, J., & Lee, S. (2019). Capacitive touch sensing through fabrics for wearable HCI. *ACM IMWUT, 5*(2), Article 85.

[8] Zhang, Y., et al. (2025). Embroidered circuits for textile-based touch interfaces. *IEEE Access, 13*, 12230-12241.

[9] TT Electronics. (2021). TTP223 Capacitive Touch Sensor Datasheet.

[10] ASTM F3407-2020. Standard test method for fit of respiratory protection devices.

[11] ISO 13688: 2013. Protective clothing — General requirements.

[12] Tekscan. (2022). FlexiForce A201 User Manual.

Appendix A: Raw Data Samples

A1. RSSI Time Series for Silk Fabric Over Ten Seconds

RSSI values recorded every 0.5 seconds for silk fabric ranged from -53 dBm to -55 dBm, with a mean of -54 dBm. Specific values at each time point (seconds): 0.0: -53; 0.5: -54; 1.0: -54; 1.5: -55; 2.0: -53; 2.5: -54; 3.0: -54; 3.5: -55; 4.0: -53; 4.5: -54.

A2. Capacitance Formula Derivation

The parallel-plate capacitance is given by $C = \varepsilon_0 \varepsilon_r A / d$, where $\varepsilon_0 = 8.85\times10^{-12}$ F/m is the permittivity of free space, A is the plate area, and dd is the separation distance. The formula $C = \varepsilon_r S/4\pi kd$ is equivalent with $k = 1/(4\pi\varepsilon_0)$.