Hybrid integration of flexible temperature and humidity sensors with crosstalk decoupling for wearable physiological monitoring

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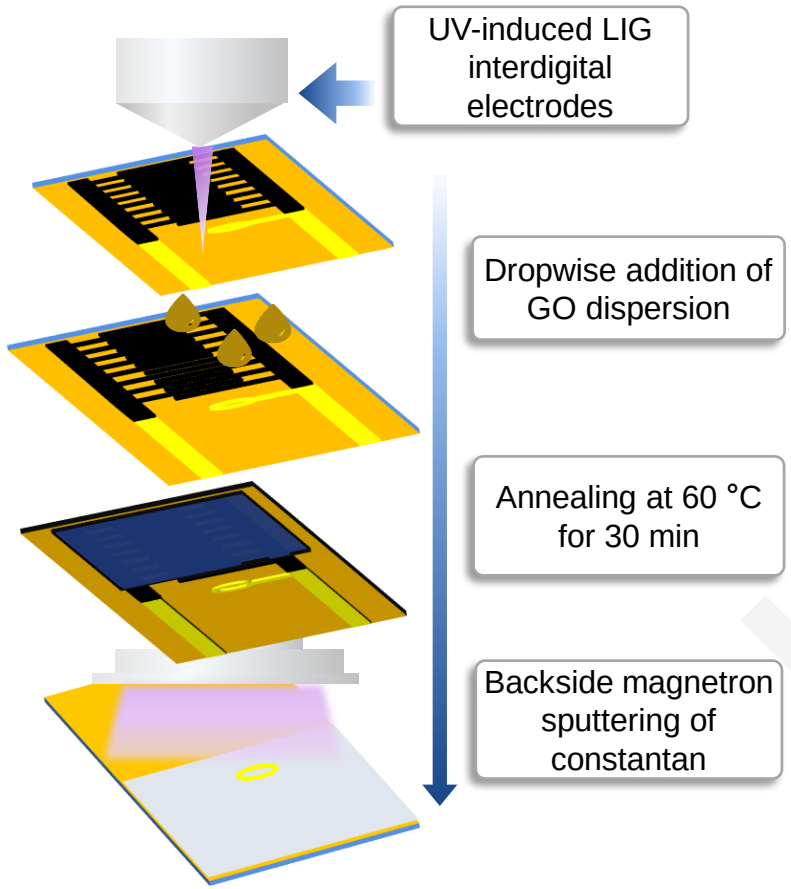
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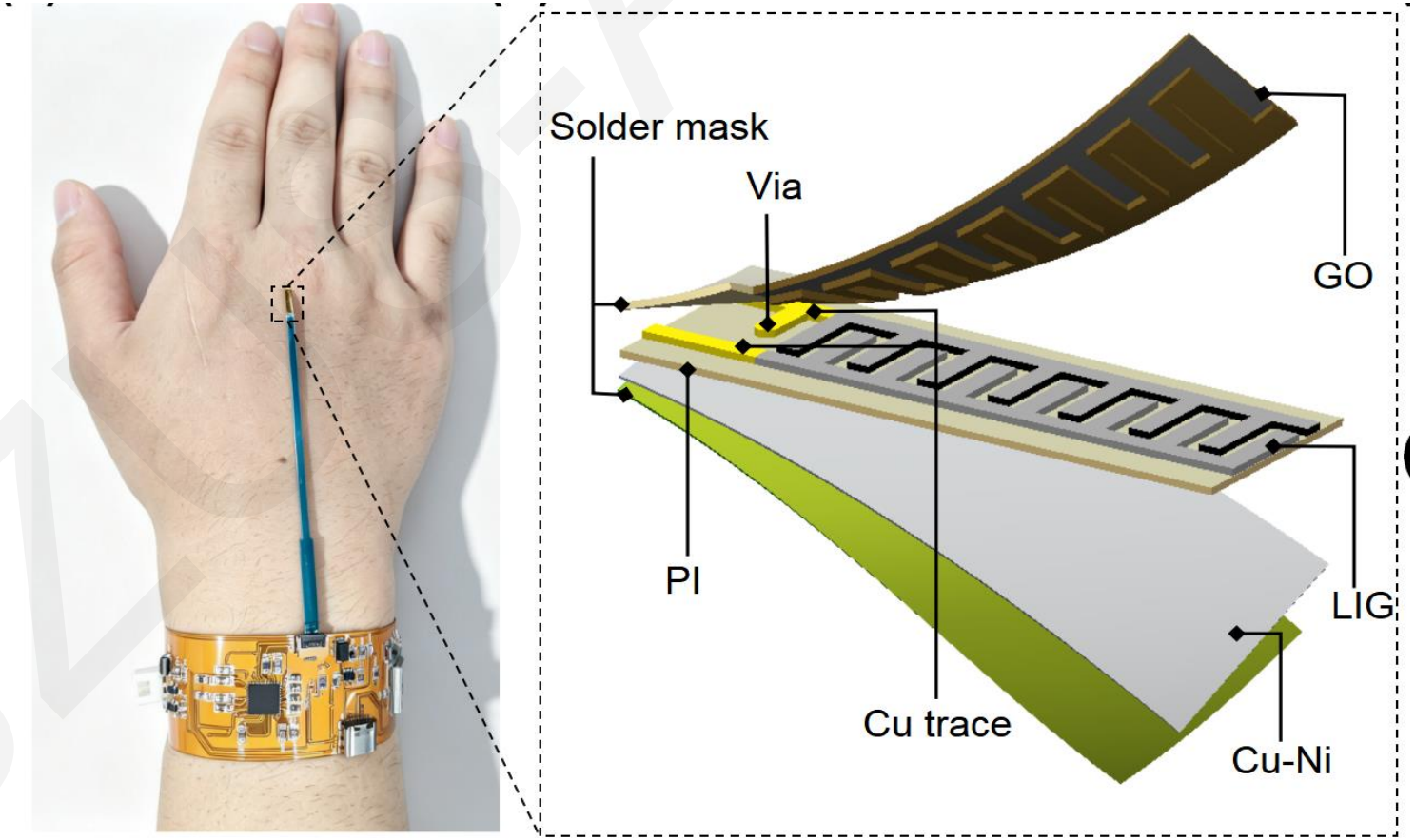
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Device Architecture and Fabrication

Fabrication Process



Device Structure and Wearable Integration

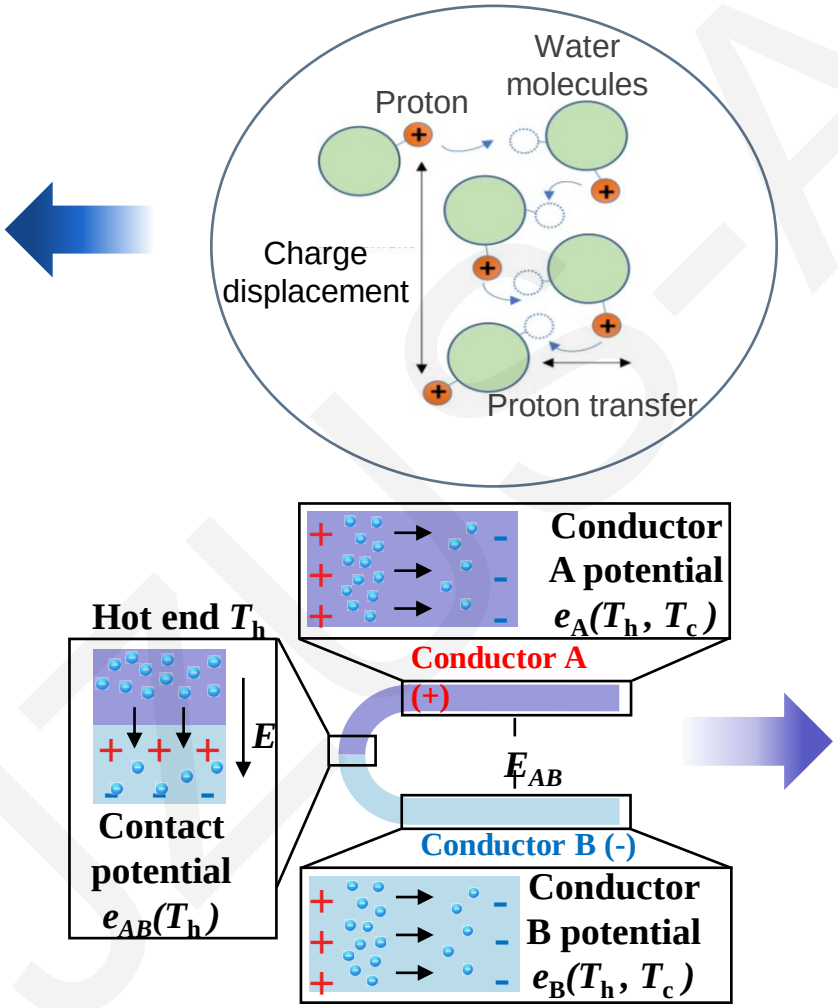


Thermoelectric temperature sensing and GO/LIG capacitive humidity sensing are integrated on a flexible PI substrate.

Temperature and Humidity Sensing Mechanisms

Humidity Sensing Mechanism

- **Grotthuss proton-hopping ionic conduction**
  - Mechanism: Water intercalation in GO induces proton conduction
  - Transmission along hydrogen bonds improves capacitance
  - Capacitance humidity model follows $C = \varepsilon_0 \varepsilon_r \cdot A/d$
- **Sensing mechanism**
  - Humidity sensing ionic conduction

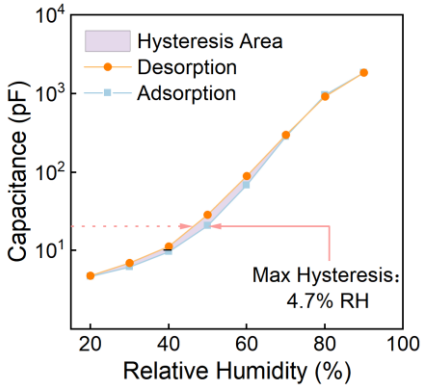


Temperature Sensing Mechanism

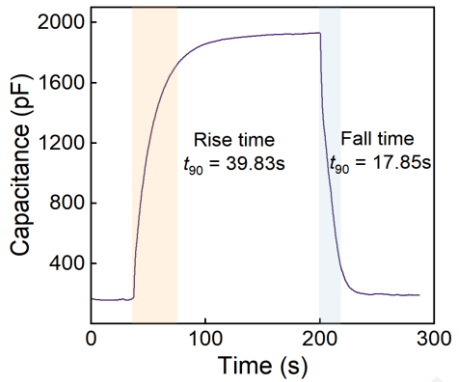
- **Seebeck effect electronic conduction**
  - Mechanism: Temperature difference drives thermoelectric potential
  - Thermoelectric model follows $E_{AB} = S_{AB} * (T_h - T_c)$ (S_{AB}: copper-constantan Seebeck coefficient)
- **Sensing mechanism**
  - Temperature sensing electronic conduction Seebeck effect

Sensor Performance Characterization

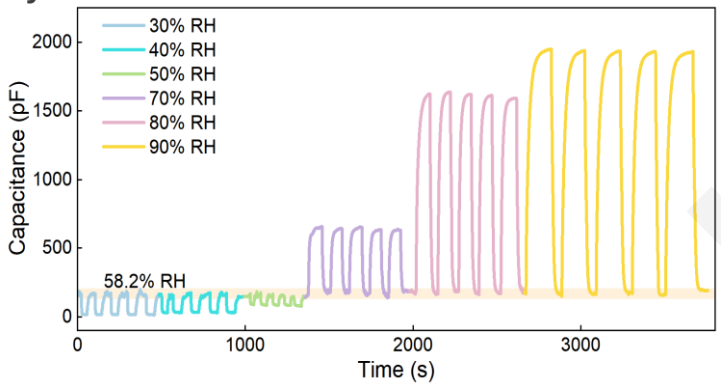
Humidity response calibration



Hysteresis characteristics



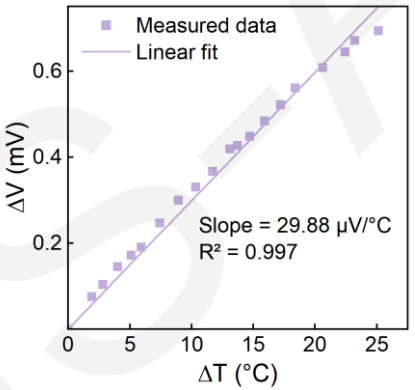
Transient response



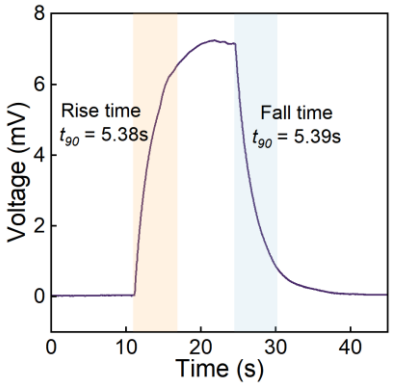
Step tracking



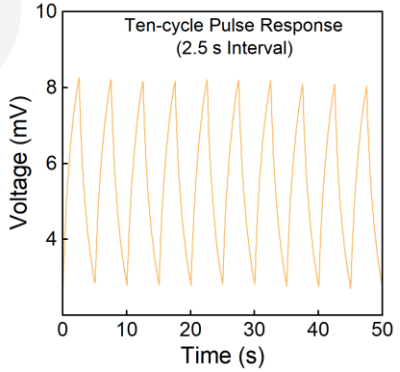
Temperature thermoelectric calibration



Calibration curve



Transient response



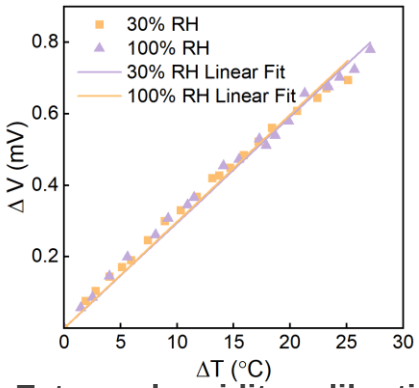
Cyclic stability



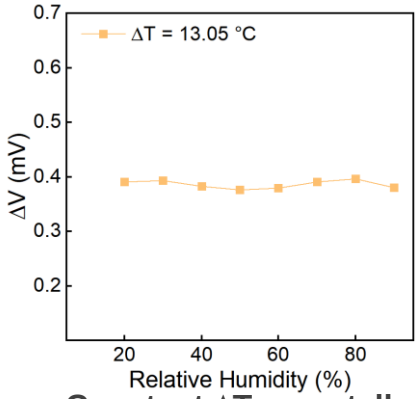
High bimodal sensitivity low hysteresis and extremely stable dynamic baseline

Crosstalk Characterization and Compensation

Humidity-to-temperature crosstalk

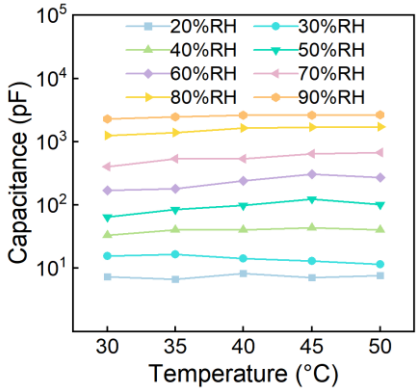


Extreme-humidity calibration

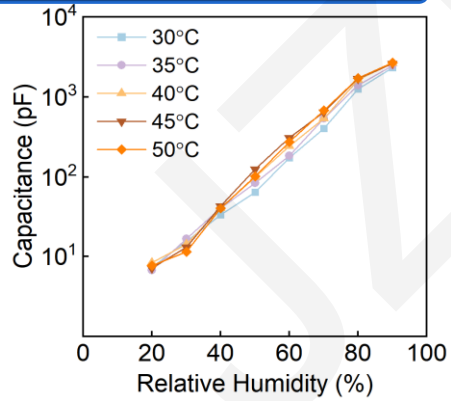


Constant ΔT crosstalk

Temperature-to-humidity crosstalk



Iso-humidity thermal drift



Broad-temperature response





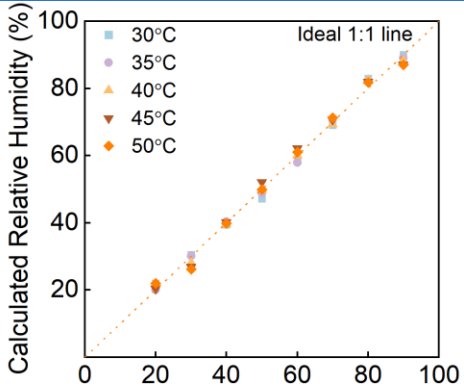


$$\ln C = \beta_0 + \beta_1 \cdot RH + \beta_2 \cdot T + \beta_3 \cdot RH^2 + \beta_4 \cdot RH \cdot T + \beta_5 \cdot T^2$$

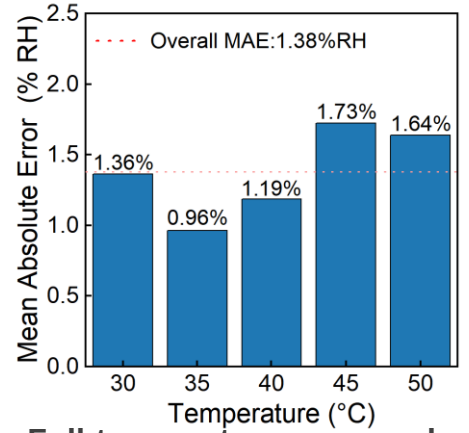
Polynomial decoupling

Unidirectional temperature crosstalk

Decoupling performance evaluation



Ideal baseline regression

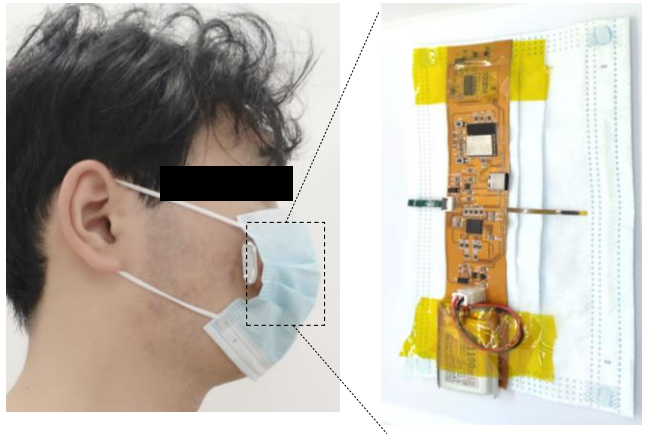


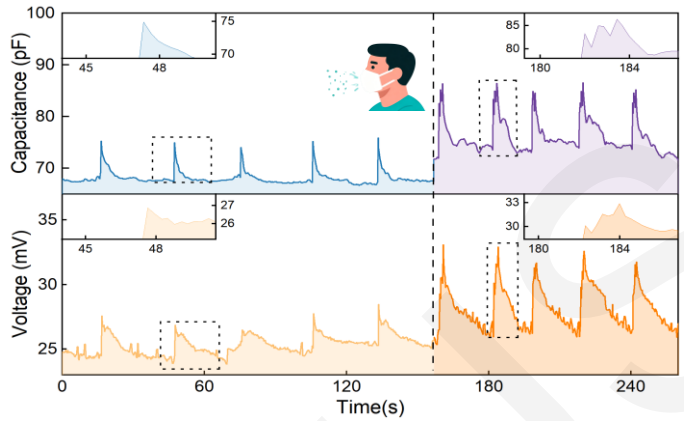
Full-temperature error analysis

Second-order polynomial effectively suppresses unidirectional thermal drift reducing global MAE to 1.38%RH

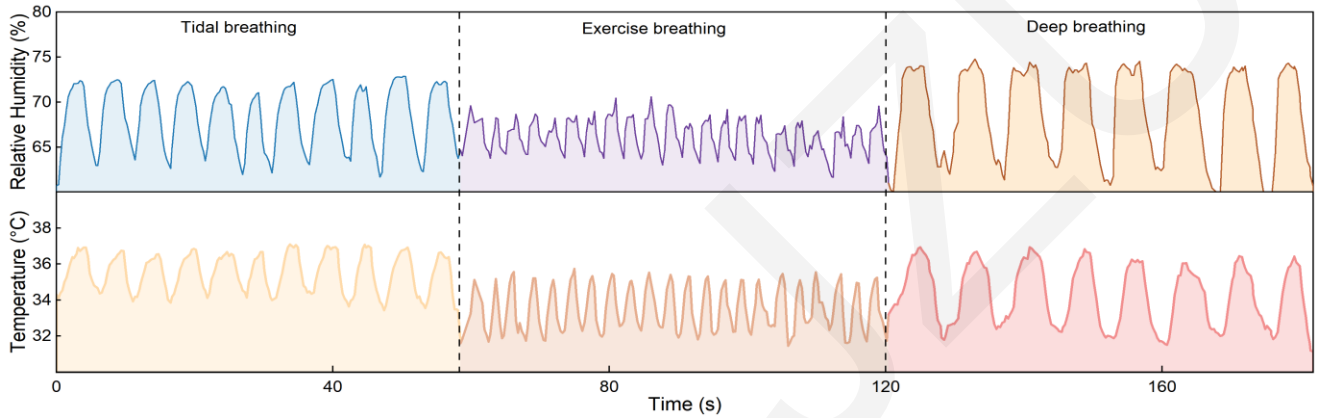
Wearable Physiological Monitoring

Mask-integrated monitoring



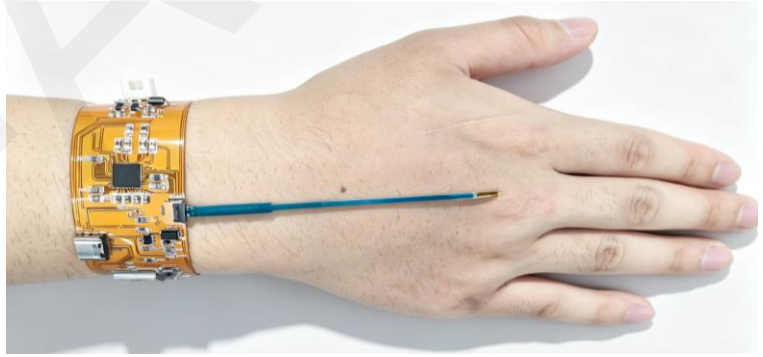


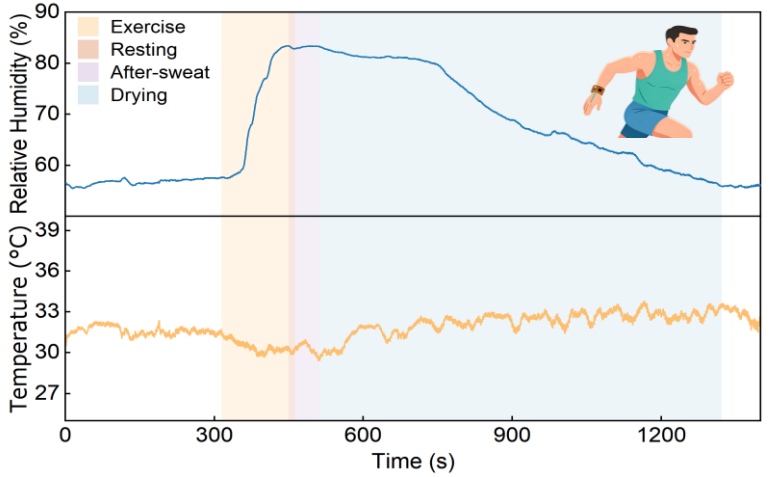
Cough disturbance capture



Multi-mode breathing recognition

Epidermal exercise monitoring





Full-cycle exercise tracking

Decoupling algorithm enables dynamic physiological parameter monitoring exhibiting excellent system stability and anti-crosstalk capability

Conclusion and Outlook

Flexible Hybrid Sensor Integration

A flexible sensing platform integrating GO/LIG capacitive humidity sensing and thermoelectric temperature sensing was successfully developed.

Reliable Dual-Parameter Sensing and Crosstalk Decoupling

The temperature sensor exhibited a sensitivity of 29.88 μV/°C (R^2 = 0.997). Second-order polynomial compensation achieved an overall humidity estimation MAE of 1.38% RH.

Wearable Physiological Monitoring

The integrated system demonstrated the capability to monitor breathing patterns, cough disturbances, and exercise-related temperature and humidity variations.

Future Perspectives

Further improvements in long-term stability, wearing comfort, and real-world monitoring performance will support practical wearable applications.