Wireless Triboelectric Wearable Sensors for Self-Powered Biomechanical Monitoring

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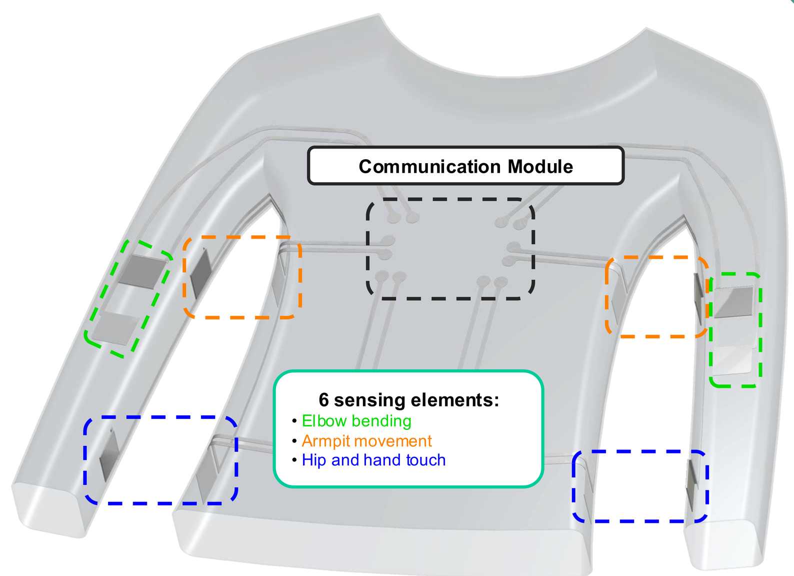
Motivation

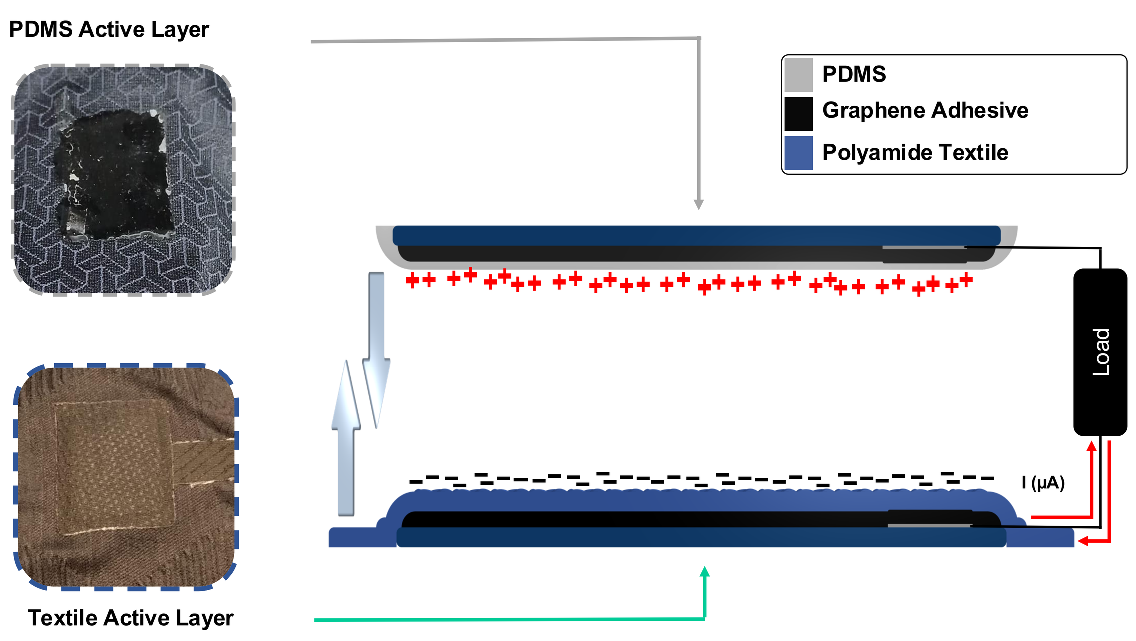
There is a growing demand for continuous, untethered motion tracking in rehabilitation, health and human–machine interaction. Flexible, durable, and self-powered sensors based on triboelectric nanogenerators (TENGs) offer a promising solution [1,2]. In this work, we use a textile-based TENG sensor capable of converting motion into electrical signals, designed for wearability in garment integration. However, seamless integration requires not only mechanical flexibility but also reliable, real-time, and energy-efficient wireless communication.

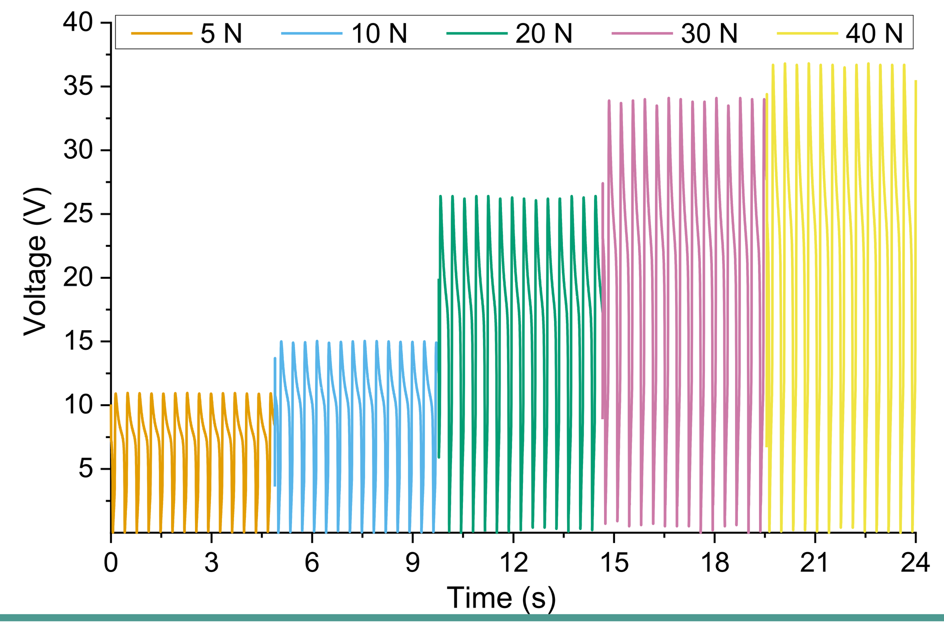
Bluetooth Low Energy (BLE) modules demand more power than TENGs can supply, preventing fully self-sustainable operation, as they require external power sources. To overcome this, we investigate a batteryless RFID communication [3], enabling energy-autonomous sensing, improving washability, and reducing environmental impact.



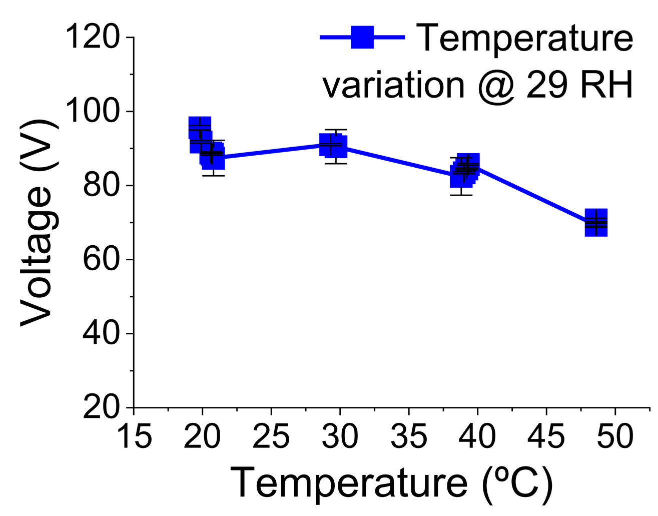
Sensor characterization

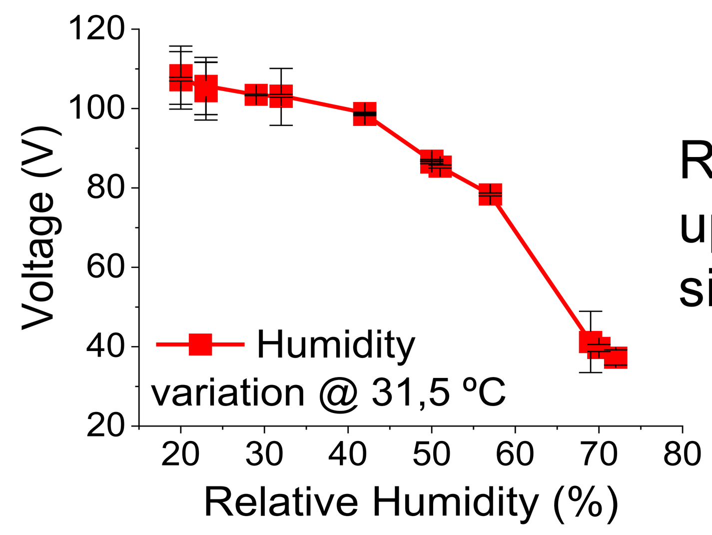
Real images and schematic representation of the triboelectric device in the vertical separation working mode. The pair is composed of one positive and one negative layer, with the textile acting as the negatively charged layer.





Output voltage at 3 Hz under contact forces ranging from 5 to 40 N measured for normal human motion - voltage amplitude increase with higher applied force.





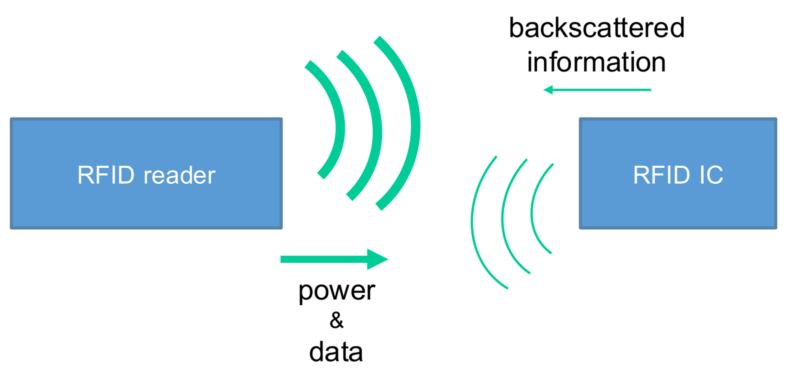
Output voltage variation:

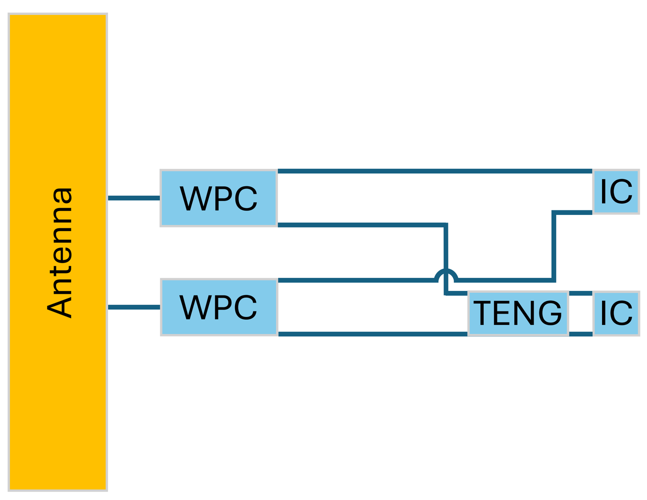
Temperature - decreases from 90 V to 70 V over a 30 ºC range, with negligible variation near body temperature;

Relative humidity (RH) - stable up to 45% RH, then decreases significantly at higher levels.

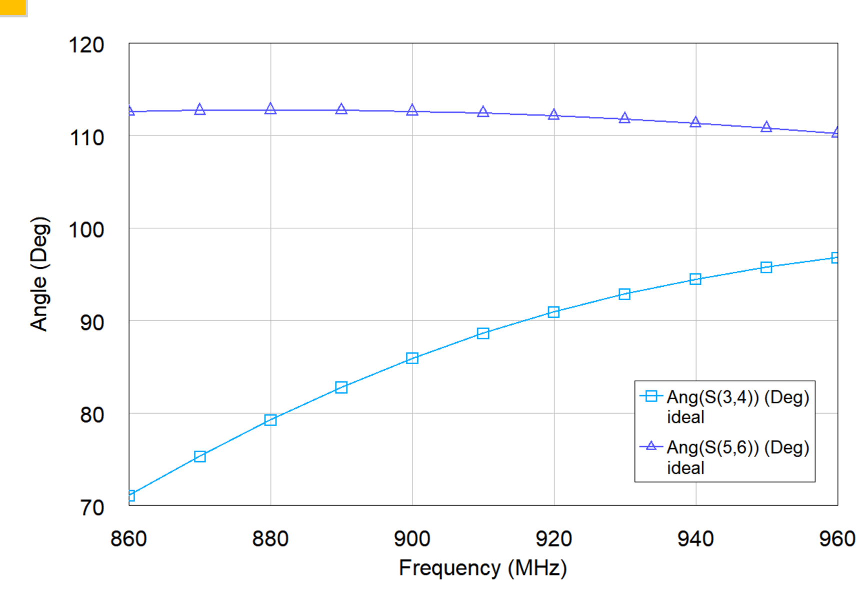
Radiofrequency Identification

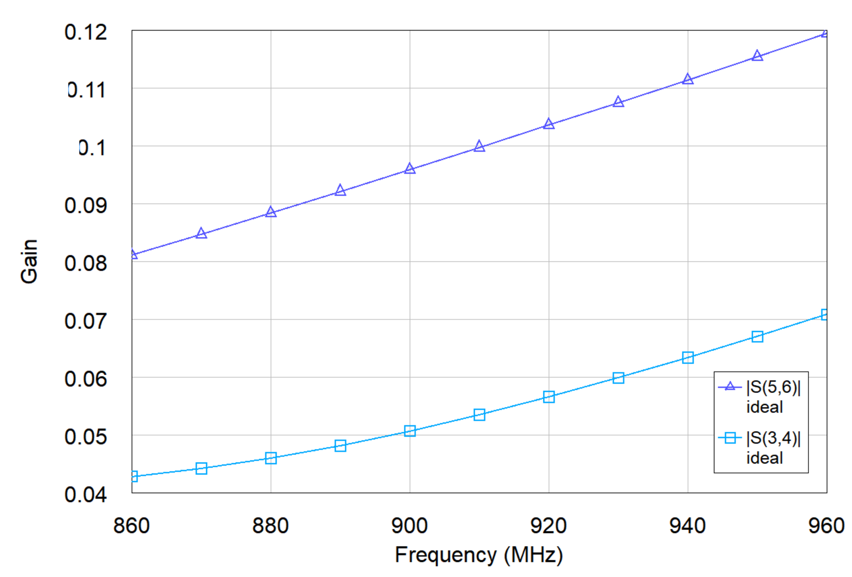
Passive RFID communication uses an emitter of EM waves carrying power and data to an Integrated Circuit (IC). Data stored in the IC's memory is returned by modulation of the backscattered signal through the circuit's impedance variation.





TENGs can introduce an impedance mismatch in the circuit to signal its on/off state. The twin-tag single antenna model was used with Wilkinson Power Combiners to equally divide the power between the two RFID ICs.

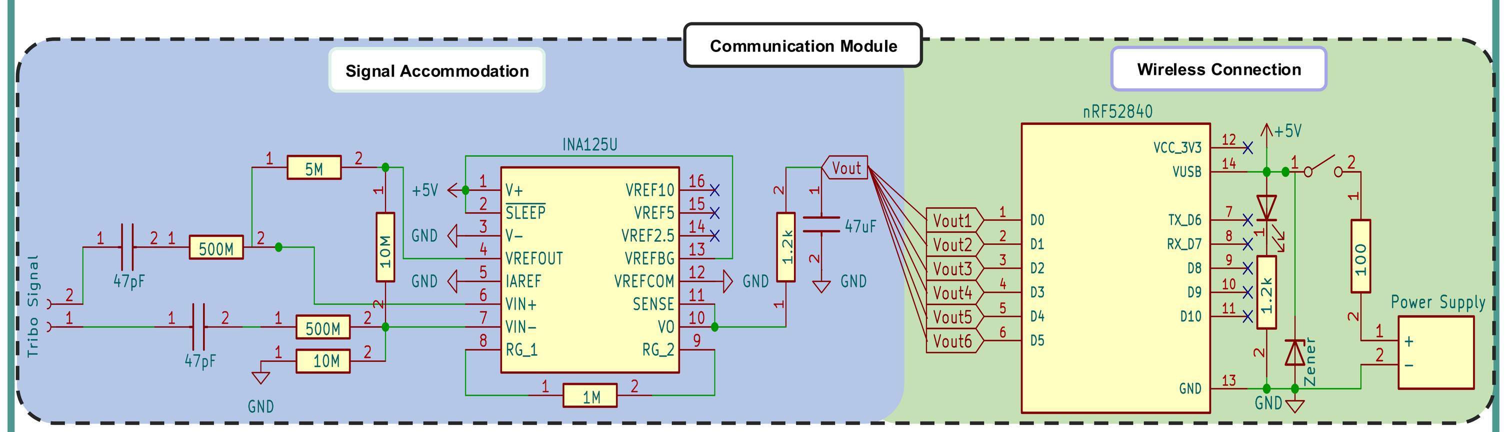




Simulation was performed using ports 3 and 4 (light blue), with impedance mismatch caused by the TENG sensor, and ports 5 and 6 (dark blue), for the unmodified branch.

Bluetooth Low Energy

BLE is the current communication technology implemented in a triboelectric sensing shirt. A 3D printed box enclosing the circuit is attached to the chest area, receiving data through highly conductive graphene electrodes.



Circuit diagram of the communication module, showing the signal conditioning stage (blue) with impedance matching and noise reduction, and the wireless module (green) with Bluetooth Low Energy capabilities.

Conclusions

A flexible, textile-embedded triboelectric sensor featuring graphene printed electrodes were developed for efficient human motion monitoring. Electrical characterization revealed an amplitude increase in voltage for higher applied force, a voltage decrease with relative humidity and a stable output for temperatures between 10 ºC and 50 ºC. A batteryless communication technology was tested, showing promising simulation results in phase and gain measurements, enhancing wearability. These devices hold potential for wireless wearable bioelectronics, utilizing cost-effective and scalable materials and processes.

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