A Wearable Positioning Device Using LoRa Technology with the Thermoelectric Effect

WEI-YU HUANG(黃韋昱), GUAN-LIN WU(吳冠霖)，WEI-DA CHEN(陳韋達), KAI-YOU ZHANG (張凱祐)and CHIH-YUAN LIN(林之淵)
Department of Physics, Soochow University

Abstract

a body-heat-powered wearable using a thermoelectric generator and LTC3108 boosting to 3.3 V into a 0.22 F supercapacitor, targeting LoRa beacons every 30 min to ~1 km from ~5 °C gradients for battery-free tracking

Introduction

GPS struggles in remote, long-term, low-power settings; LoRa—long-range, low-rate, low-power—uses sub-GHz spectrum to link sensors, gateways, and servers for IoT.

Leveraging LoRa, we design a self-powered wearable positioning system for remote or harsh environments. Using the thermoelectric (Seebeck) effect, the body-ambient temperature difference powers the device.

The device could help lost mountaineers, dementia patients, and elder-monitoring systems, and integrate with medication dispensers to ensure on-time dosing and prevent over- and underdosing.

LoRa Technology

LoRa uses Chirp Spread Spectrum (CSS) to enable long-distance transmission in low SNR, with CSS improving interference and multipath resistance for reliable communication. Positioning methods include ToA, TDoA, RTT, AoA, RSSI, and fingerprinting, each with different accuracy and applications; filtering and time synchronization are crucial for accuracy and reliability.

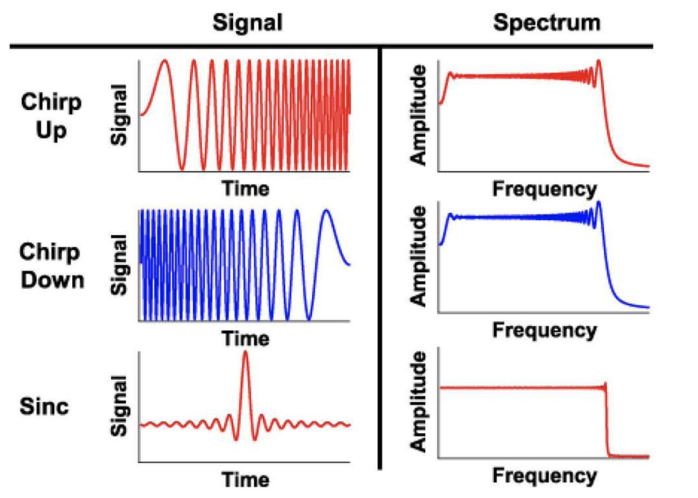


Figure 1. Chirp signal characteristics [ref. 1].

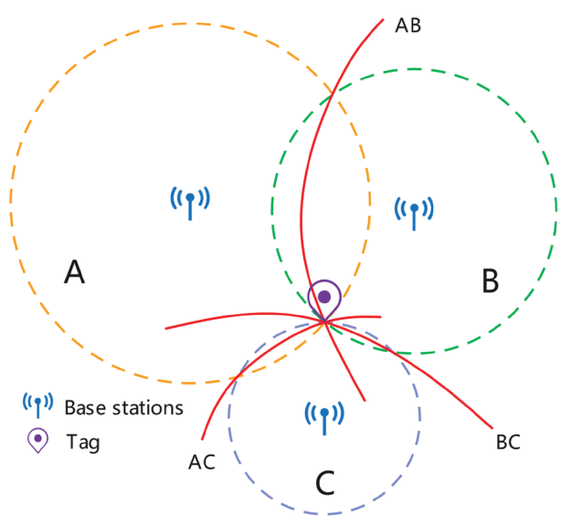


Figure 2. TDoA (Time Difference of Arrival) locates a transmitter by measuring signal arrival-time differences at multiple receivers and computing its geometric position relative to them..

Thermoelectric/Seebeck effect

The thermoelectric effect, discovered by Thomas Seebeck in 1822, is the direct conversion of a temperature difference into voltage in a closed circuit of two dissimilar conductors or semiconductors. Hot-side carriers gain kinetic energy, diffuse to the cold side, creating an electric field that drives current when the circuit is closed.

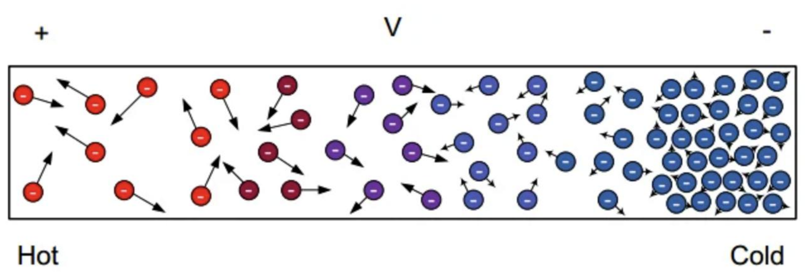


Figure 3. Temperature differences affect electron distribution from hot to cold [ref. 3].

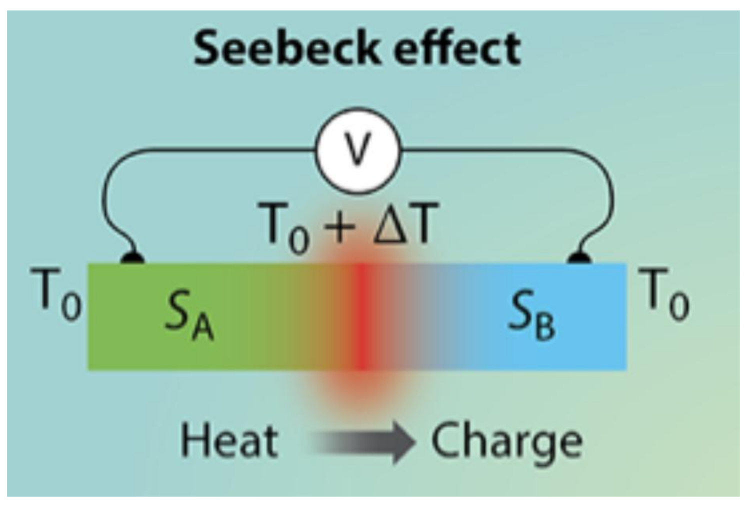


Figure 4. A temperature difference ΔT at the interface of two materials with different Seebeck coefficients SA and SB generates a voltage V [ref. 4].

The Seebeck voltage generated by a specific temperature difference is influenced by the properties of the material. To evaluate the effectiveness of the Seebeck effect in any material, the Seebeck coefficient is defined as:

$$S = \frac{\Delta V}{\Delta T} = \frac{V_{cold} - V_{hot}}{T_{hot} - T_{cold}} \quad or \quad S = \frac{dV}{dT}$$

Methodology

1. Hot side on hot plate, cold side with heatsink + thermal interface to maximize usable ΔT.
2. Sample every 5 °C: log ΔT, V_{OC} ,J_{SC} ;derive $R_{int} = V_{OC}/I_{SC}$;plot IV and Power–ΔT.
3. Power path: TEG → harvester + supercap → 3.3 V rail; verify stability across sleep/RX/TX.
4. Firmware/link: STM32 (TX) + ESP8266 (RX/UI) for LoRa P2P; track RSSI/SNR and packet integrity.
5. Energy budget guides reporting interval (e.g., +17 dBm ≈ 85.8 mJ, +13 dBm ≈ 36.3 mJ); TDoA slated for future hardware.

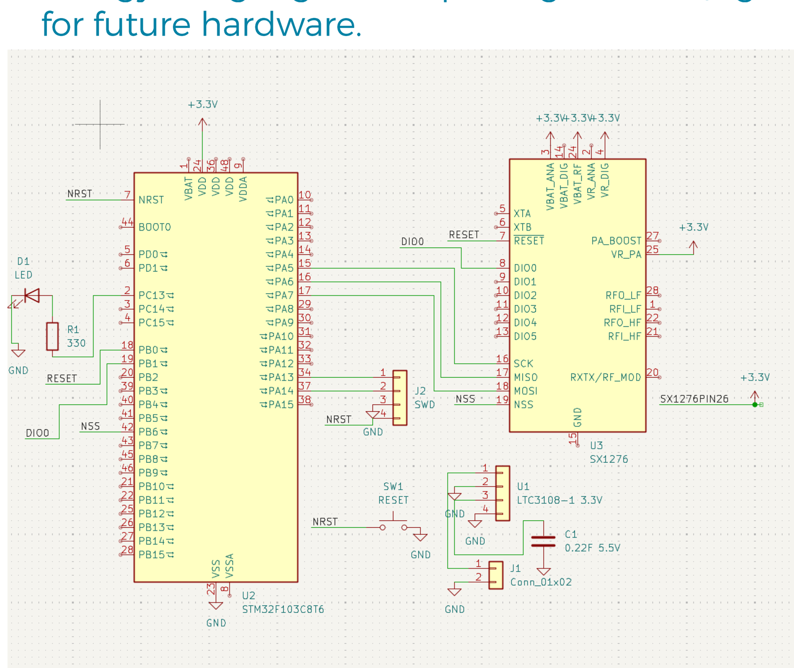


Figure 5. Transmitter Node Schematic STM32F10+ SX1276 LoRa + LTC3108 Energy Harvester (3.3 V).


Figure 6. Experimental Setup for Measuring Loaded Voltage and Current.

Simulation Results

Power Relationship with Load:

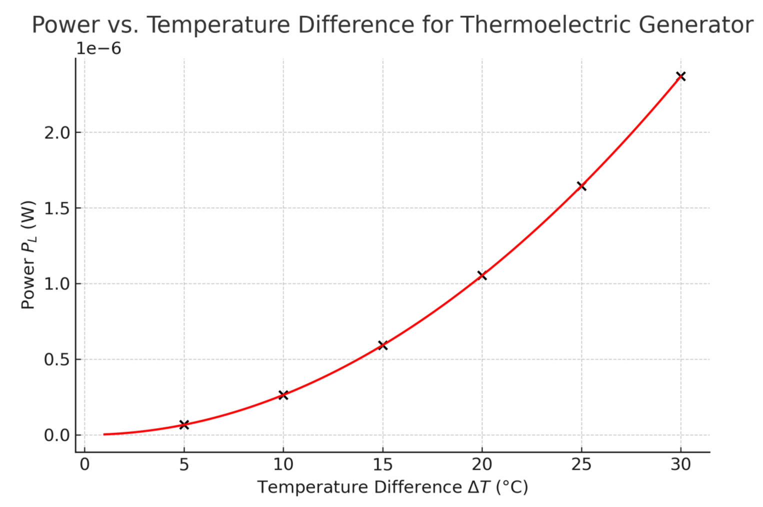
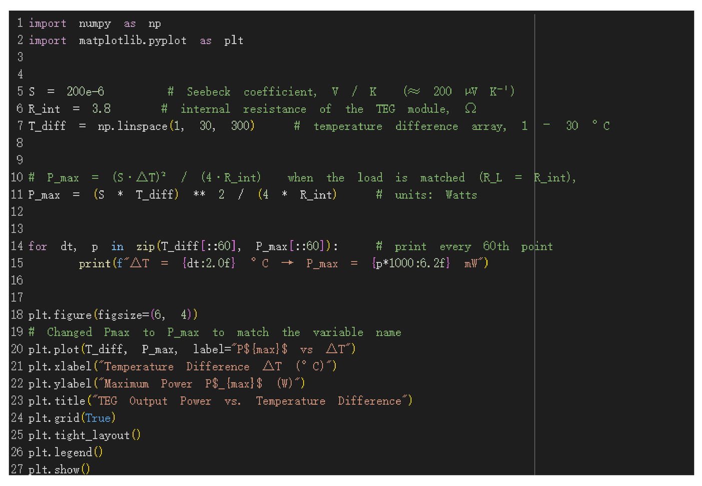


Figure 7.. Python simulation with fixed load R_L = 3.8 Ωshows TEG power increases nonlinearly with ΔT, following a quadratic trend ($P_L \propto \Delta T^2$).



$$P_L(\Delta T, R_L) = \frac{V_{OC}^2(\Delta T) R_L}{(R_{int} + R_L)^2}$$

$$V_{OC} = S\Delta T$$

LoRa Simulation UI

Figure 8. LoRa Simulation UI: send control and real-time receive console.

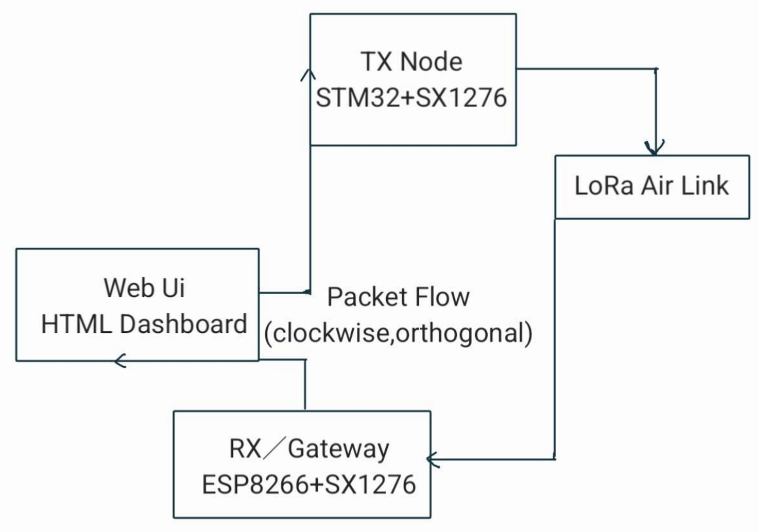


Figure 9. LoRa Packet Flow Diagram

Results

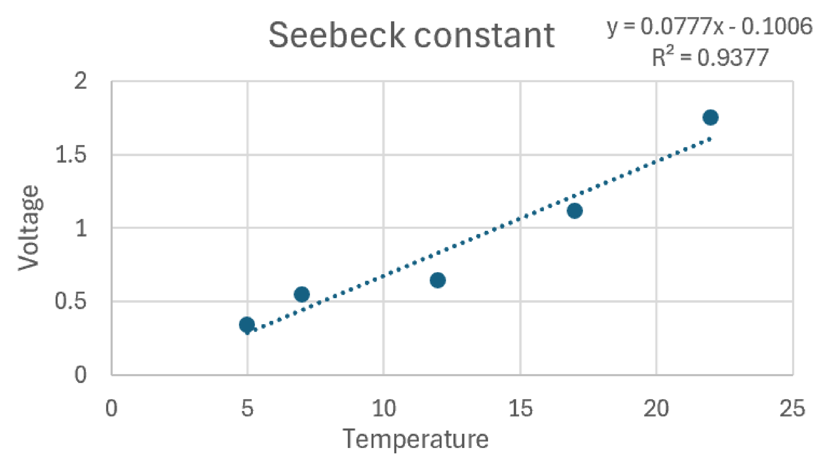


Fig 10. Voltage v.s temperature

溫差(ΔT)	電壓(V)	S (V/K)
5	0.34	0.068
7	0.545	0.078
12	0.645	0.054
17	1.114	0.066
22	1.75	0.080

Seebeck constant=$\frac{\Delta V}{\Delta T} = s$ =77.7mV/K

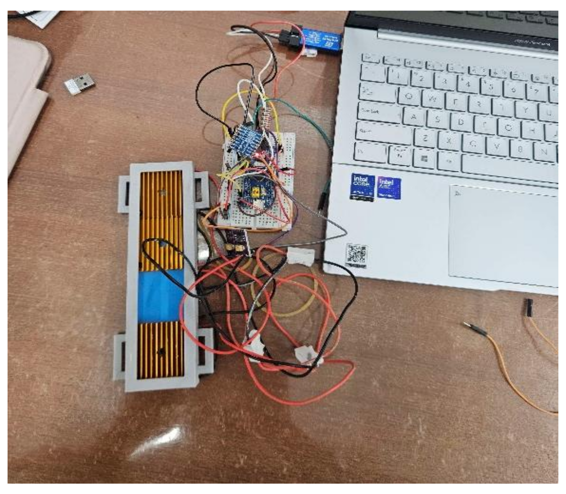


Figure 11. Transmitter Setup


Fig. 12. Transmitter Code

溫差 (ΔT)	功率 (mW)
5	5.525
7	10.1479
12	15.2607
17	69.7364
22	123.2

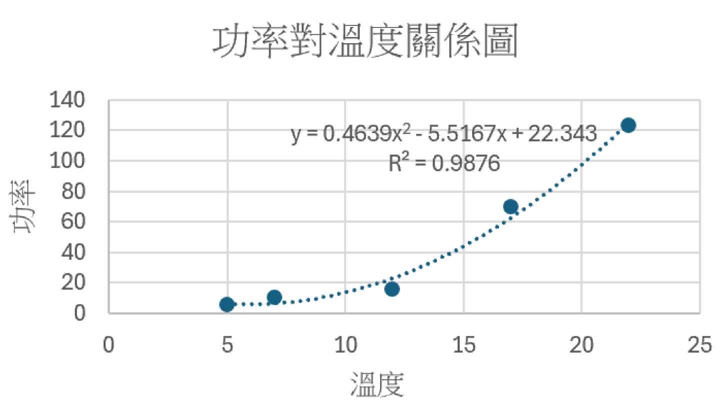


Fig. 13. Power v.s temperature difference

Conclusion

This study successfully achieved thermoelectric self-powering and reliably transmitted positioning information using LoRa technology. Even with a temperature difference as small as 5°C, the system can generate a stable voltage, highlighting its potential applications in areas such as wearable health monitoring, medical positioning for mountain rescue, electronic ankle bracelets, and more. Future work will concentrate on miniaturizing the system and expanding its applications into disaster relief and smart healthcare.

References

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