Experimental Investigation of Printed Piezoresistive Sensors for Self-Aware Cellulose/Polymer Wing Structures

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ARTS-Lab
Adaptive Real-Time Systems Laboratory

Introduction

- Flexible strain sensors enable multi-directional characterization of large structural deformations, bypassing the limitations of conventional rigid electronics.
- Traditional strain sensors are limited to measuring small, unidirectional strains on rigid surfaces, making them incompatible with high-displacement, non-rigid structures.
- Research compares signal sensitivity, baseline stability, and trace geometries of three printed conductive ink materials, moving towards self-sensing cellulose/polymer wing structures.

Methods

- Three conductive inks tested:
  - Voltera Conductor 3 Silver Ink
  - ACI SS1109 Stretchable Silver Ink
  - ACI SC1502 Stretchable Carbon Ink
- Multiple sensor designs of various trace length and width.
- Resistance measured via 4-wire method; contact pads connected using copper adhesive strips with soldered lead wires.
- Hand-induced flapping across three bend depths (light, medium, heavy) and two speeds (slow, ~0.05 Hz, 5s holds at top/neutral/bottom; fast, ~0.5 Hz).
- Data acquired with NI PXI-4070 DMM.

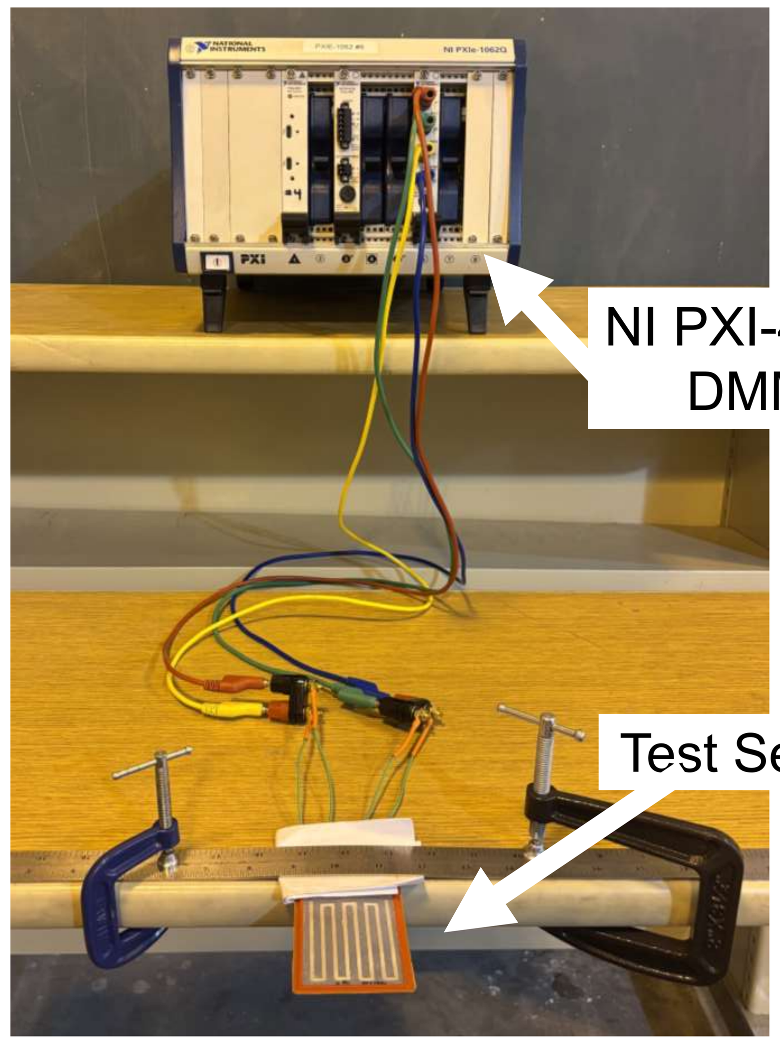

Figure 1: Experimental test setup.

Significance

- Integrating flexible strain sensors directly into cellulose/polymer wing structures provides the real-time deformation feedback necessary for closed-loop control, paving the way for advanced bio-inspired propulsion and autonomous aerodynamic steering for UAVs.

Figure 2: Labeled diagram of all three sensor materials and various designs.

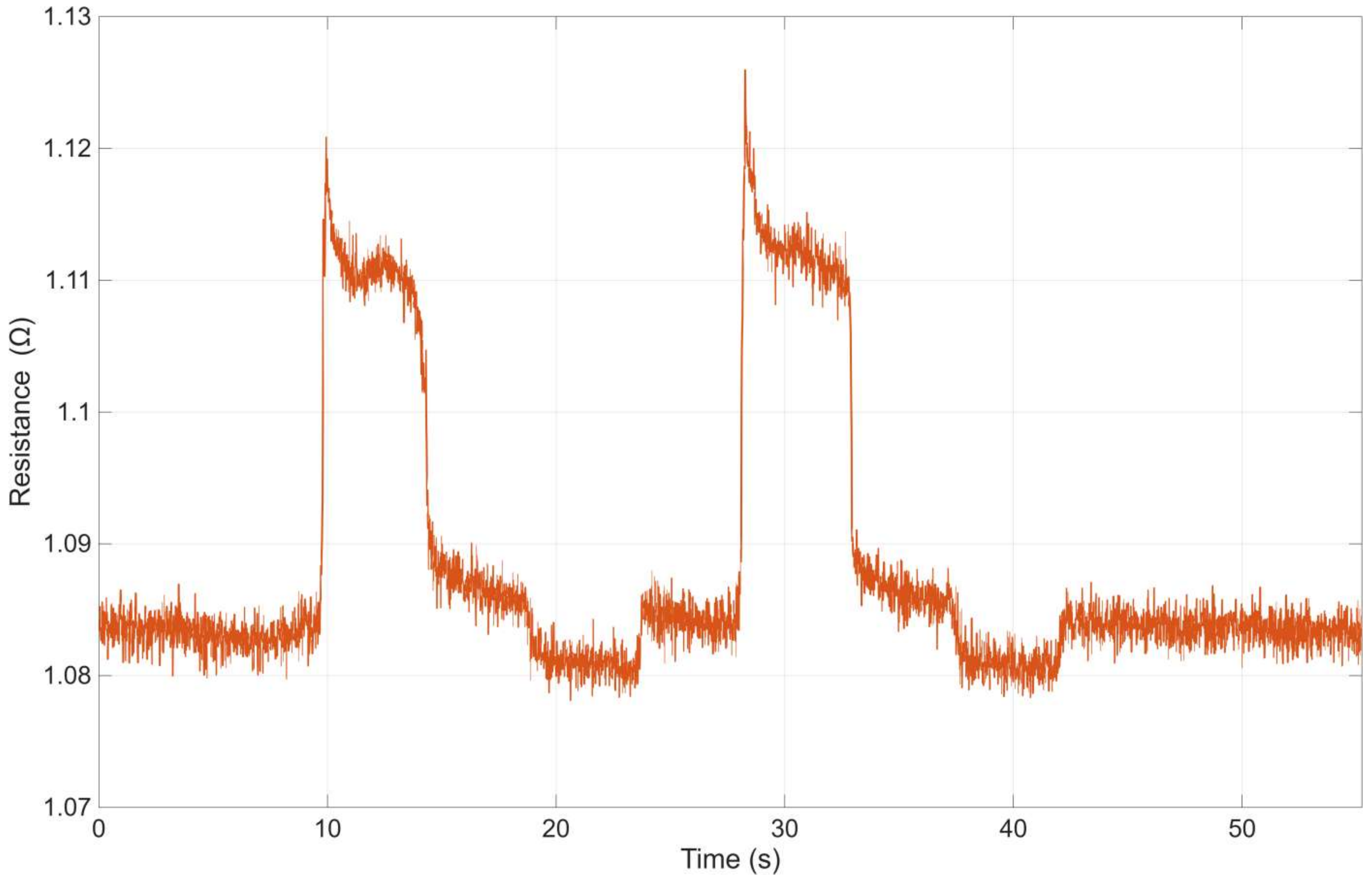

Figure 3: Plot of light bending test on V6, Conductor 3 Silver Ink. Displays 2 oscillations. Resistance increases during downward flap (tension), returns to baseline during 5 second hold at neutral position, and decreases during upward flap (compression).

Results

Voltera Conductor 3 Silver Ink
- Sensitivity to flapping improved significantly with increased trace length and decreased trace width.
- Successfully captured rapid flapping frequencies (~0.5Hz) via post processing.
- Stable baseline resistance maintained over extended cyclic testing.

ACI SS1109 Stretchable Silver Ink
- Results suggest that sensors are very responsive to deformation; however, static tests reveal significant, unpredictable baseline drift.

ACI SC1502 Stretchable Carbon Ink
- Results show very high noise levels, though faint signals are detectable in some tests.
- Results often exceeded the measurement capabilities of DMM.

Conclusions

- Longer and narrower traces yielded superior signal clarity across all three inks by accumulating structural strain across a longer conductive path.
- Voltera Conductor 3: Preferred. Demonstrated high reliability and low baseline drift across all flapping speeds.
- ACI SS1109: Rejected. Exhibited severe baseline drift, likely due to viscoelastic material relaxation.
- ACI SC1502: Rejected. High ink resistivity prevents geometric optimization (longer/narrower traces) because the resulting baseline resistance exceeds DAQ limits.

Next Steps

- Cantilever deformation testing under known strains to calculate individual sensor gauge factors (GF).
- Deploy calibrated sensors onto flapping wings to calculate real-time operational strain, where $\epsilon = \frac{1}{GF} \times \frac{\Delta R}{R}$.

References

- C. A. Smith and A. R. J. Downey, “Additively Manufactured Flexible Hybrid Electronic Sensor for Discrete Fatigue Crack Detection”, in *Proc. AIAA SciTech Forum*, National Harbor, MD, 2023, doi:10.2514/6.2023-2417.

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