Printed Piezoresistive Sensors for Self-Aware Wings

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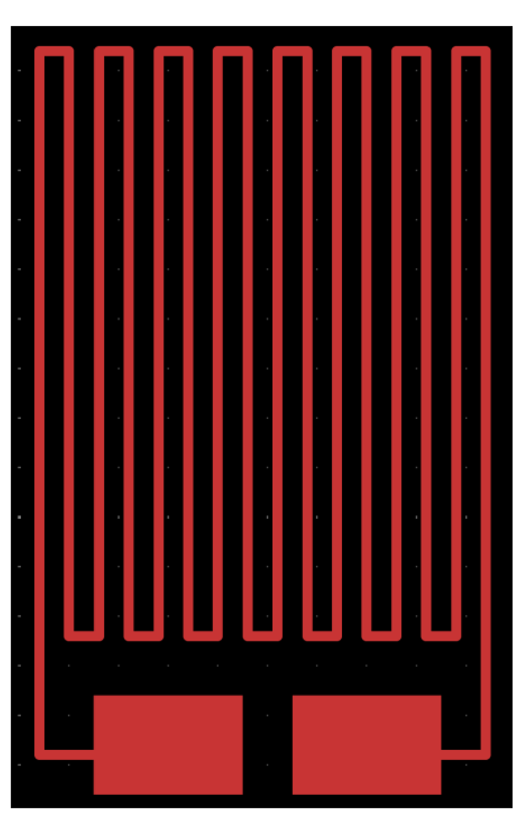
Introduction

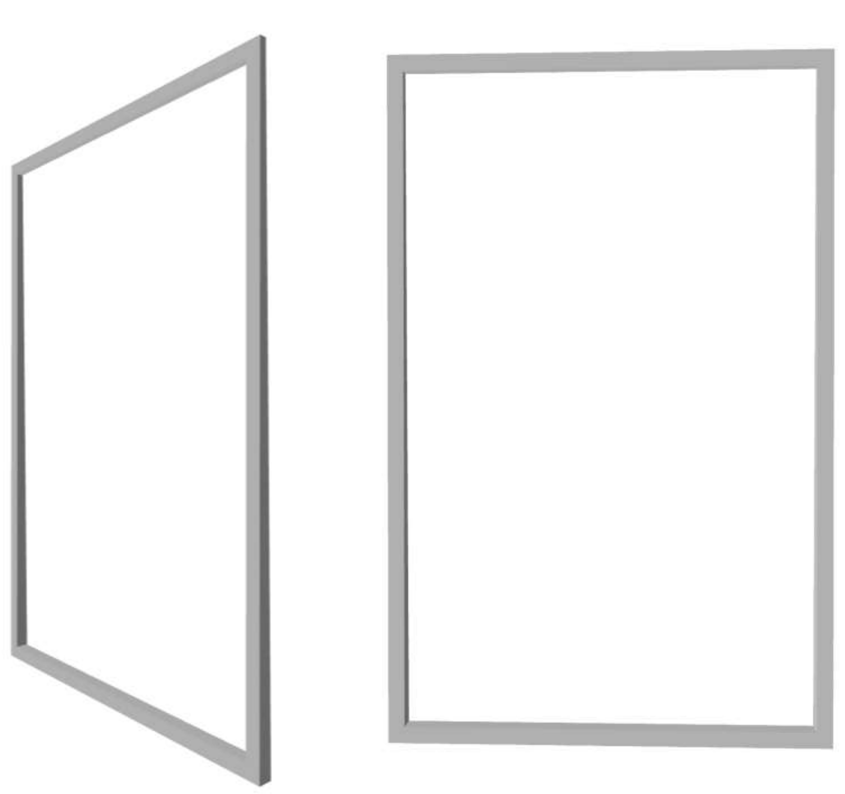
- Piezoresistive strain sensors measure strain based on changes in electrical resistance. The proposed system seeks to embed sensors onto wax paper sheets. As the paper is bent, the sensor structure stretches. The deformation of the sensor's geometry causes a change in the material's resistivity, thus allowing the applied stress to be quantified.
- This project aims to advance the development of a self-sensing flapping wing by identifying wing design, sensing material, and construction methods that facilitate reliable strain monitoring.

Methods

- Conductive traces are designed in KiCad to fit inside an 80 mm x 50 mm rectangle wing frame.
- Sensors are printed onto wax paper in a serpentine path using conductive ink and the Voltera One PCB printer.
- The ACI SC1502 stretchable carbon ink, ACI FS0142 semi-sintering conductive silver ink, and ACI SC1109 stretchable silver ink were all used to print separate models of sensors.
- Carbon 1502 and Silver 1109 are cured at 120°C while Silver 0142 is cured at 150°C.
- The frame is then 3D printed on top of wax paper using PETG to complete the wing.



KiCad serpentine conductive trace path



Side and front view of tapered wing design

Results

- Carbon 1502 sensors had extremely high resistances, often too high for the PXIE machine to register. Shorter sensor lengths and wider trace widths were most effective in offsetting this.
- Silver 0142 sensors exhibited low resistance across a variety of trace lengths and widths, allowing for greater versatility in sensor geometry.
- Silver 1109 sensors showed dense signals ranging from -200 Ω to 360 Ω, regardless of bending state or trace geometry.
- Wings with a tapered geometry experience a more uniform bend across the wax paper substrate.
- 3D printing the wing onto the wax paper first and then printing the trace resulted in crinkled wax paper and frame warping as the PETG used for the wing melted at the ink's curing temperatures.
- Printing the frame after the trace was printed and cured kept the wax paper taut and wing frame free from structural deformities.

Initial tear drop shape design with melted wing frame, causing frame deformities and wax paper detachment

New rectangle frame with tapered sides and serpentine conductive trace pattern printed with Silver 0142 ink. Wax paper is taut and frame is flat.

Significance

- Identified wing design that better distributes strain across the sensing region.
- Identified sensor geometry and ink selection parameters that produced more consistent resistance signals.
- Supports the feasibility of future applications of embedded printed sensors for a self-aware wing

Conclusion

- The tapered wing geometry promoted more uniform bending and strain distribution across the sensor.
- Carbon 1502 and Silver 0142 both showed clear piezoresistive responses, distinguishing between static and bending states.
- The lack of distinguishable separation between bending stages and the negative resistance values suggests that the Silver 1109 ink is incompatible with this project's purposes.
- No perfect prototype has been achieved as gradual drops in resistance, conductive trace peeling, and wax paper-frame separation occur over time.

Next Steps

- Enhance the bond between wax paper and wing frame to ensure continued adhesion over time.
- Fabricate more Silver 0142 sensors to further evaluate its suitability as the leading candidate for self-sensing wing applications.
- Begin testing wings with a MTS machine to evaluate durability and sensing capabilities under increased aerodynamic stress.

References

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