Bio-Skin: A Cost-Effective Thermostatic Tactile Sensor with Multi-Modal Force and Temperature Detection

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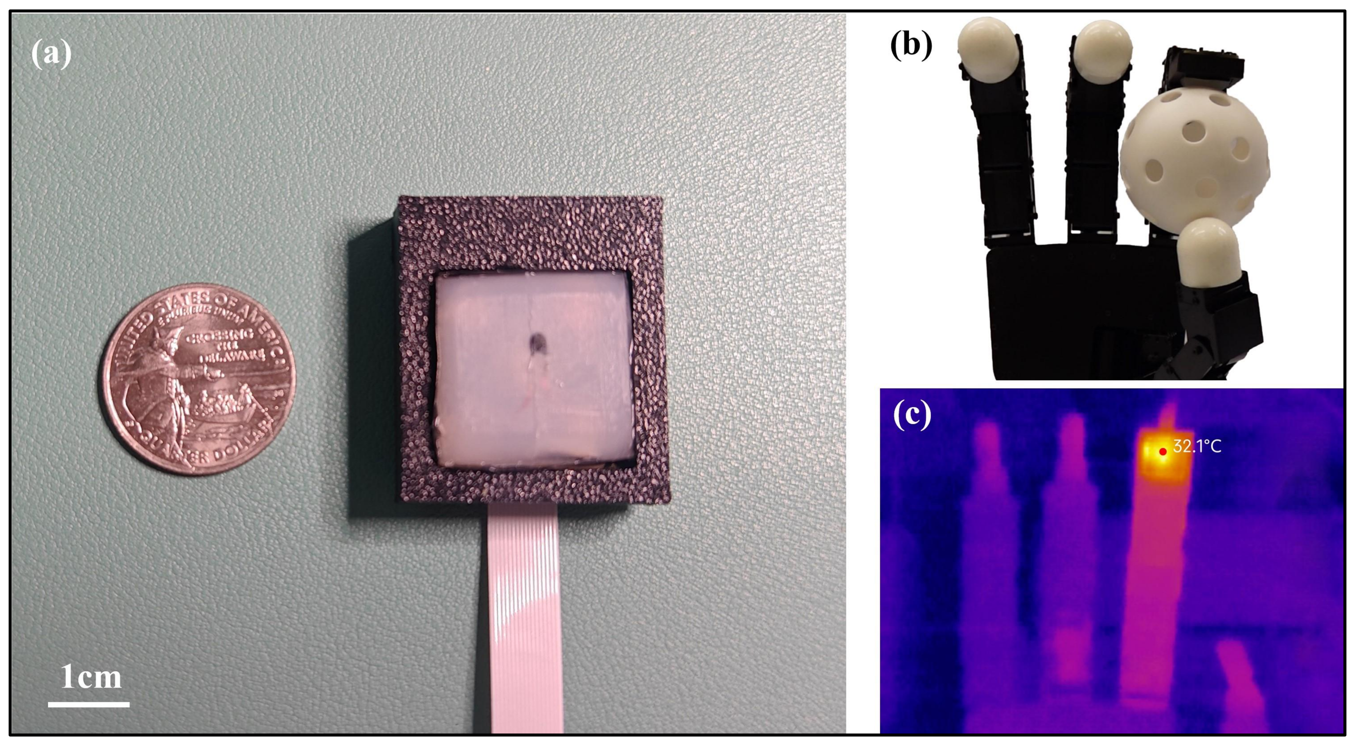
Motivations

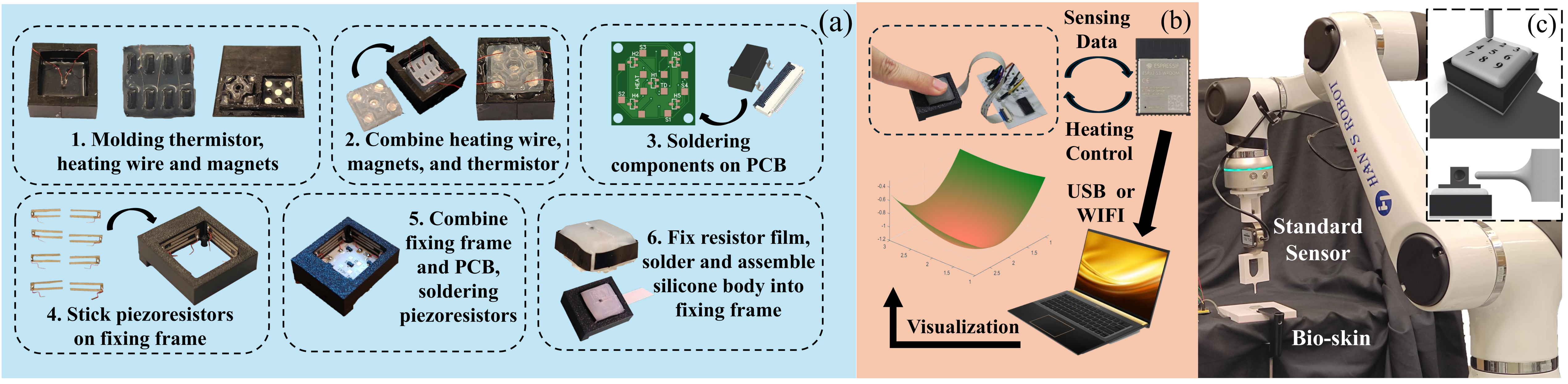
- Humanoid robots require cost-effective, multi-modal tactile sensors with temperature sensing and regulation for safe and adaptive human interaction.
- Current multi-modal sensors often prioritize performance over cost, leading to complex integration and large sensor sizes, limiting widespread adoption.

Key Contributions

- 🔨 Cost-Effective Multi-Modal Sensing: We present a tactile sensor utilizing single-axis Hall-effect sensors for normal force and bar-shape piezoresistors for shear force, significantly reducing costs while offering multi-modal and anti-interference ability.
- 🚨 Integrated Thermostatic Function: A thermistor and heating wire are integrated into a silicone body for temperature sensation and thermostatic control, mimicking human skin.
- 🏭 Bio-Skin's multi-layer design allows for sequential manufacturing and integration, enabling a fast production pathway.



Methodology

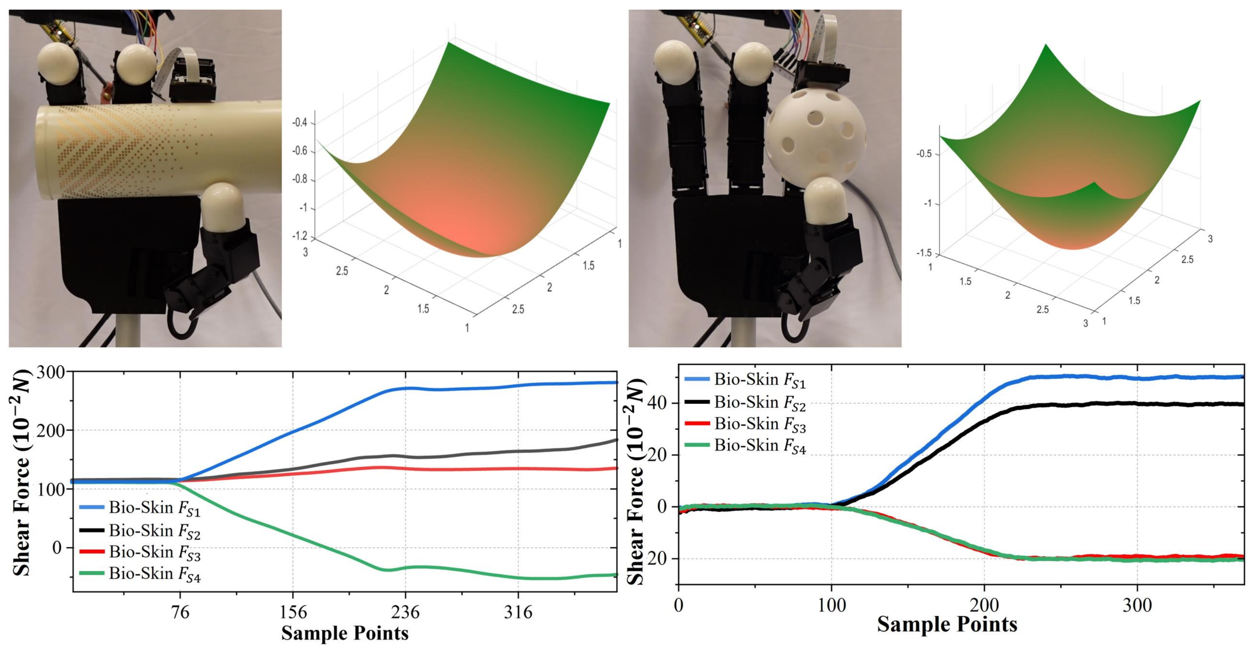


(a) Step-by-step fabrication process of Bio-Skin, including molding, assembly, and integration of key sensing components. (b) System architecture demonstrating real-time sensing, heating control, and data transmission via wired or wireless communication. (c) Calibration setup for collecting data of normal and shear force. Surface of Bio-Skin is divided into 1~9 positions and a direction converter is fixed on Bio-Skin to calibrate shear force.

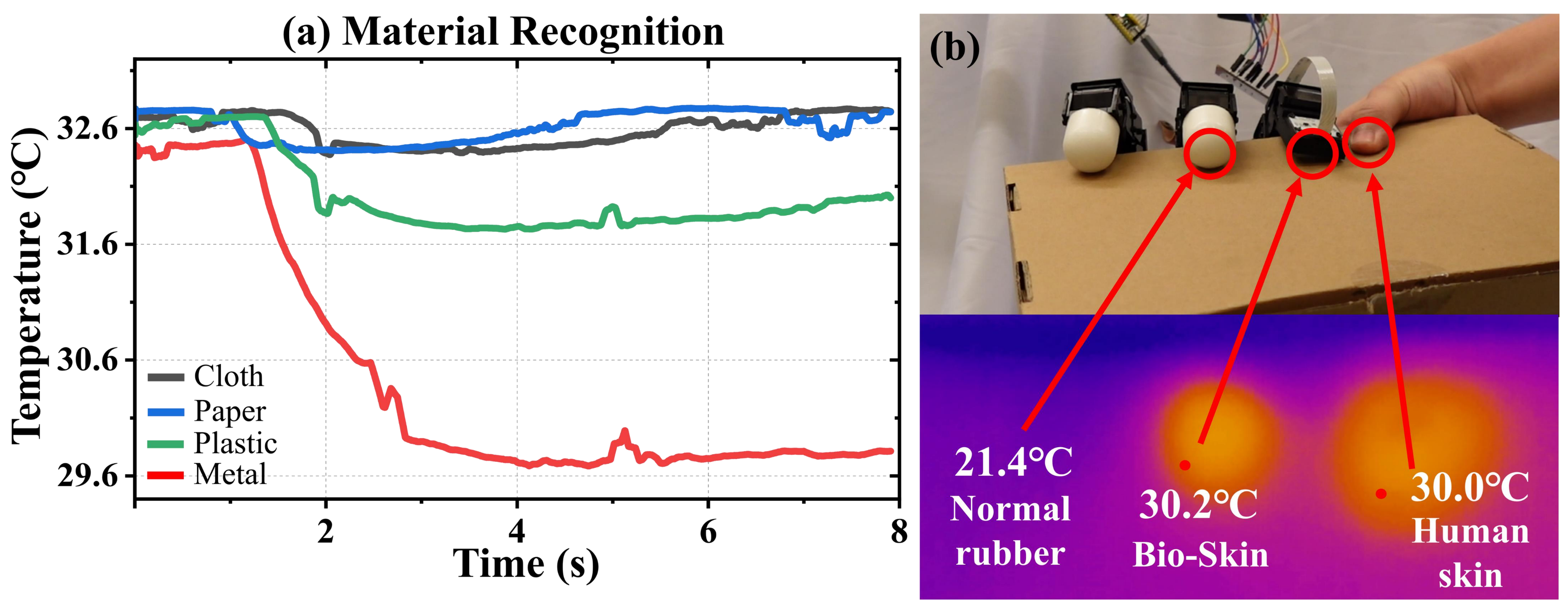
Heating Wire	Controller	Magnet	3D Print
138.8Ohm/M ($0.1/each sensor)	ESP32-S3 ($2.4/each sensor)	Neodymium 5x2mm ($1/each sensor)	eSun PETG (($1/each sensor)
Mux	**Silicone Gel**	**PCB**	**Thermistor**
CD74HC4067M96 ($0.35/each sensor)	Dragon Skin 10 Fast ($0.5/each sensor)	JLC PCB ($2/each sensor)	100kΩ ($0.2/each sensor)
Hall-effect Sensor	**Conductive Film**	**Other Components**	**Labor Cost**
DRV5056A4QDBZR ($1.5/each sensor)	Velostat ($0.1/each sensor)	($1/each sensor)	4~10h ($60~150/each)

The total material cost for each Bio-Skin sensor is under $10, excluding labor. This significantly lower cost, at least one-tenth of existing tactile sensors, paves the way for mass production and widespread adoption in humanoid robotics.

Experimental Results



The force visualization of Allegro Hand fingertip with Bio-Skin while grasping a plastic ball (right) and a metal cup (left), showing distinct normal force distribution and shear force changing.



(a) shows the temperature changing after Bio-Skin touch different materials with temperature regulation on. (b) shows temperature retention by comparing Bio-Skin, human skin and normal rubber.

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