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Flexible magnetic force sensors: manufacture, mechanisms, and applications

Key words: Magnetic film; Sensor; Microstructure; Decoupling; Performance; Super-resolution; Robotics

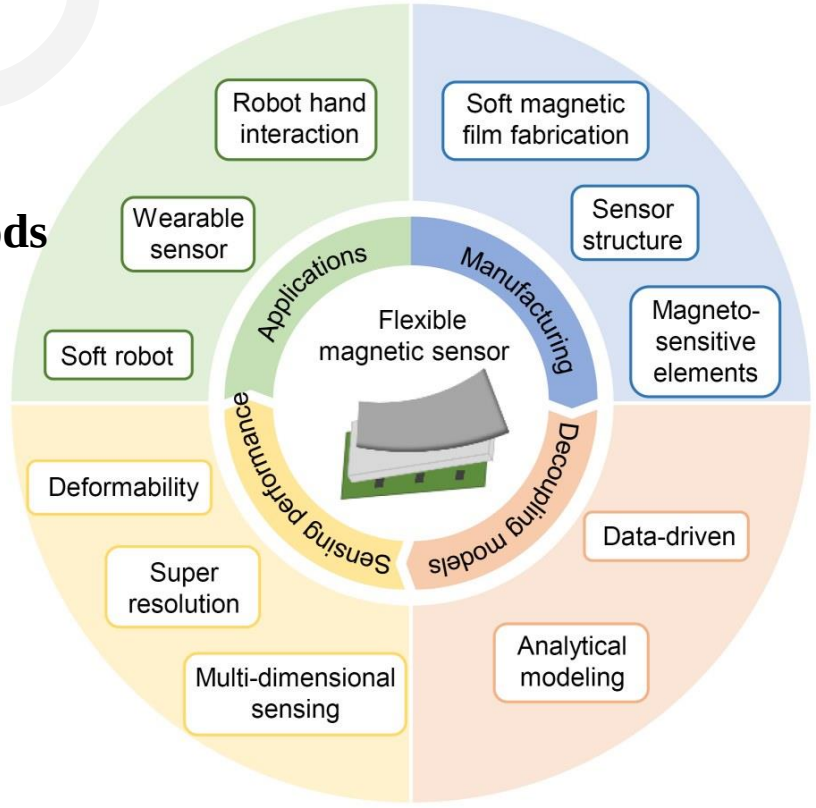
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Review summary

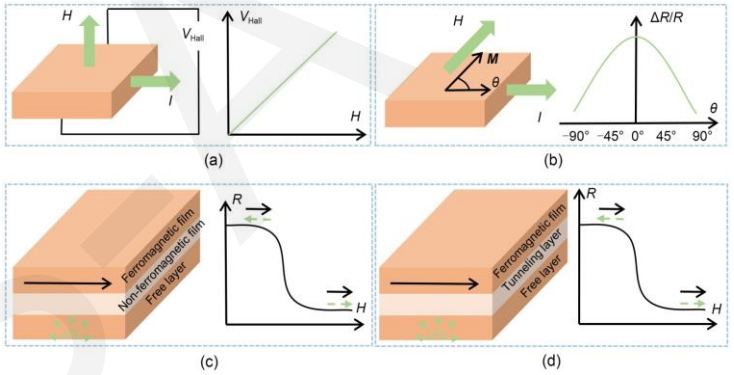
This review addresses fabrication, force-decoupling methods, performance, and applications of flexible magnetic force sensors, along with challenges and AI-driven future directions.

- **Manufacturing engineering**
- **Force–magnetic field decoupling methods**
- **Sensor performance**
- **Applications**

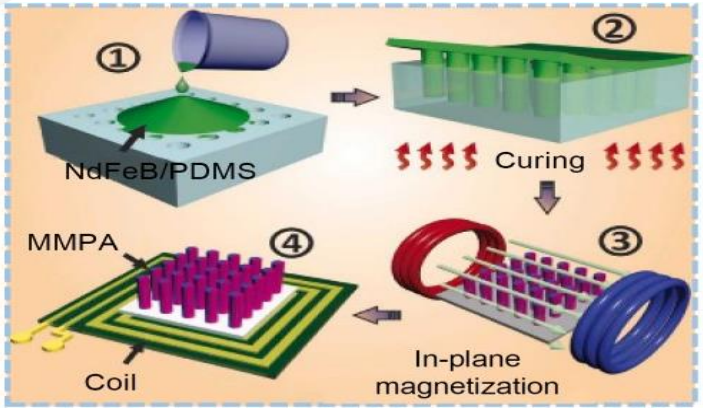


Innovative Points

- **Investigated flexible magnetic films as core elements for force-magnetic transduction including diverse fabrication techniques and magnetosensitive components**



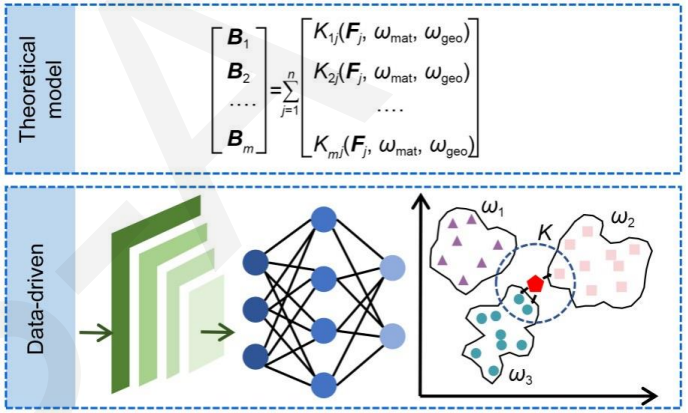
- **Analyzed the enhancement in magneto-mechanical coupling sensitivity and multi-axial force self-decoupling induced by surface microstructures**



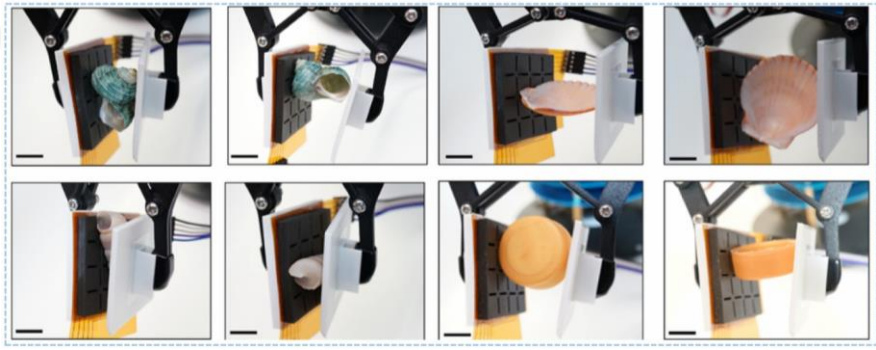
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Innovative Points

- **Summarized magnetic-signal decoupling schemes (physical models / data-driven algorithms) to reconstruct force magnitude, direction and contact position**



- **Reviewed sensor advantages of super-resolution perception, multi-dimensional force detection and deformability, together with their applications in wearables, robotic-hand interaction and soft robotics**



Challenges and Future Trends

- **Identified key bottlenecks that hinder the practical large-scale deployment of flexible magnetic force sensors. Inhomogeneous dispersion of magnetic particles produces uneven magnetic-field responses over sensor surfaces and imposes labor-intensive calibration requirements; signal drift occurs after repeated cyclic mechanical loading; meanwhile, high computational cost constitutes another major obstacle for real-world application.**

- **Future research directions :combining artificial intelligence, low-power edge computing and stable material systems. Together with bio-inspired structural optimization, these strategies can effectively improve the long-term reliability and practicality of flexible magnetic force sensors.**