Research Statement
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With the introduction of humanoid robots like Tesla's "Optimus" and Boston Dynamics' "Atlas," the interaction between robots and humans is becoming more prevalent. It is visible that the inclusion of tactile sensors is necessary to enhance the safety of human-robot interactions. Consistently immersed in research projects related to magnetic flexible tactile sensors during my undergraduate and postgraduate studies, I clearly saw the promising potential applications of this sensor in future human-machine interactions and humanoid robot tactile perception. As a passionate and driven individual, I am captivated by the potential of flexible robotics and its profound impact on society, fueling my desire to delve deeper into this field in PhD studies.

I participated in a joint undergraduate program between Zhejiang University and University of Illinois Urbana-Champaign, and I spent my junior year studying at UIUC. During this period, I seized the opportunity to join Professor E. T. Hsiao-Wecksler's lab and conducted research on building an extrusion-based 3D printer. Continuing my graduate study at Zhejiang University for a master's degree in Mechanical Engineering, I served as the research assistant to supervise three undergraduate students in a summer research project exploring encapsulation technology for flexible electronics using a 3D printer. Under my guidance, they successfully built a PDMS extrusion-based 3D printer to achieve the encapsulation of flexible electronics with optimal mechanical performance. This project greatly honed my leadership and mentoring capacities.

Preliminary Try: Internship

My enlightenment to scientific research was when I participated in the Magnetic flexible tactile sensor via direct ink writing project in my freshman year. After studying the principles and equipment requirements of 3D printers through literature research, I successfully designed and assembled an FDM 3D printer using components from the laboratory. To achieve the transition from FDM printing to a DIW extrusion-based printer, I purchased the corresponding squeeze needle and air compressor for extrusion head modification based on the corresponding Nature cover paper. During the equipment setup process, I also dealt with many technical issues. To overcome nozzle blockage issues, I implemented an automatic layered heating approach. Specifically, I designed the printer control program to print one layer of the pattern, raise the nozzle to allow for heating and solidification of the material, and then continue with the next layer. This modification ensured both stable multi-layer printing and smooth extrusion from the nozzle. After completing the equipment setup, I explored using negative Poisson's ratio structures as the design for our soft magnetic sensors, aiming to achieve linear compression curve variations. Additionally, I delved into the programming aspect of 3D printing, specifically the G-code language used to control the printer to achieve specific printing shapes. This project allowed me to better understand the printer's operation and enabled me to write custom G-code scripts to control the printer's movements. **As an undergraduate, I published this work as a second author in the SCI journal Sensors and Actuators A: Physical.**

Deeper Understanding: Find the Direction, Super-resolution tactile sensing

During my graduate studies, I continued the research on magnetic flexible tactile sensors. Unlike my previous study’s primary focus on optimal magnetic film material, we now placed greater emphasis on achieving super-resolution perception of the overall sensor through learning algorithms. We achieved super-resolution magnetic sensors by combining computational algorithms with innovative magnetic materials. First, I used COMSOL to conduct the magnetic film simulation experiment with different magnetization arrangements and finally chose the symmetrical magnetization arrangement. Regarding the algorithmic research and exploration phase, we combined the KNN clustering algorithm with Kriging interpolation to fully cover large-area high-resolution tactile sensing using real-time deformation magnetic field signals obtained through pressing. Additionally, we innovatively employed a disjointed structure design, allowing the magnetic film to achieve tactile sensing in deep water and conform to any part of the human skin. We also ensured the sensor could reach accurate point sensing even under external substantial magnetic interference or partial area damage through algorithm optimization. After completing the overall sensor construction, the sensor was placed on a humanoid robot's skin to showcase real-time perception as part of the robot's skin. The sensor was also placed on a human hand for real-time control to precisely manipulate the robotic arm for object grasping demonstrations. This project was incredibly intriguing and challenging, and **I published this work as the first author in the SCI TOP journal ACS Nano.**

Based on this project, I expanded the sensing area of the previous magnetic sensor to six times its original size, forming a large sensor plane, which I referred to as magnetic skin. By using more high-dimensional effective magnetic field signals from the array of 4*4 taxels, our magnetic skin can achieve more precise pressure sensing and multi-point and multi-scale tactile sensing through pressing. Combined with neural network algorithms, we demonstrate the promising potential of the proposed magnetic skin in intelligent control by simultaneously controlling two vehicles with trajectory mapping on the magnetic skin. I submitted this work as **the first author to the SCI TOP journal Advanced Science**, and I am currently awaiting reviewer feedback. Throughout these two significant research projects in my master's program, I further developed my research skills. I gained expertise in utilizing AI to produce exceptional graph representations of my work, and I became proficient in using PR software to process experimental videos. Additionally, I acquired a deep understanding of real-time image visualization using the Matplotlib library in Python and developed programs in Python for tasks such as K-nearest neighbors (KNN) clustering and neural networks.

Cross-disciplinary collaborative: Learn additional skills

With research experience continuously accumulated, I joined a cross-disciplinary collaborative project titled Mechanical Properties Changes of Hydrogels under High Pressure. My main task was to incorporate the magnetic film synthesized in our laboratory into the provided hydrogel materials to achieve magnetic manipulation of the hydrogels. By applying a magnetic field from the external three-dimensional Helmholtz coil through the control program, we could wirelessly drive the deformation of the hydrogel materials and explore their mechanical properties under extremely high pressures in the diamond anvil cell equipment. Subsequently, I also went to Professor Tiefeng Li’s laboratory, where I learned how to prepare hydrogels and achieve sparser molecular chain structures by altering material ratios. After that, I went to Prof. Yuanliu Chen’s lab and utilized a femtosecond laser device to precisely cut the hydrogel-magnetic film samples into micron-level specimens, ensuring the formation of intact cross-shaped pieces while preserving the magnetic film on both sides. Finally, the synthesized materials were subjected to increased internal pressure in a diamond anvil cell device in Prof. Yang Gao’s lab to explore the changes in the mechanical properties of hydrogels. I reinforced my interdisciplinary learning and collaboration skills through immersive participation in this project, as it involved research in various fields, including materials science, physics, and engineering.

Conclusion

Throughout my academic journey, I have undergone a series of systematic research training and found great joy. The sense of accomplishment I feel when achieving the goals of an experiment and completing a demo is genuinely fulfilling. I am eager to share and discuss my findings with others, as I believe collaboration and knowledge exchange are essential for advancing scientific discovery. My future plan is to continue cultivating my research abilities during my PhD studies, focusing on the research on smart materials, flexible sensing and soft robotics. I aim to develop actural tactile skin for the next generation of robots, enabling safe and reliable interactions with humans. Ultimately, I aspire to become an exceptional scientist in this field, contributing to the advancement of robotics and making a meaningful impact on society.