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論文題目	Large-area Multimodal Soft Sensing Skin for Human-Robot Interaction		
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論文の内容の要旨

Soft-bodied robots with a sense of touch and multimodal sensing capabilities hold promise for the realization of fully autonomous, social, and human-friendly robotic systems. However, seamlessly integrating multimodal sensing functionalities into soft artificial skins remains a challenge due to compatibility issues between soft materials and conventional electronics. While vision-based tactile sensing has enabled efficient robotic touch, there has been limited exploration of this technique for intrinsic multimodal sensing in large-sized robot bodies. To address this gap, this study introduces a novel vision-based soft sensing technique, named *ProTac,* capable of operating either in tactile or proximity sensing modes, which relies on a soft functional skin that can actively switch its optical properties between opaque and transparent states. Compared to conventional sensing skins of various electronic elements, our system provides large-area multimodal sensing with a simple setup and minimal impact on the mechanical properties of the soft skin. Furthermore, this study proposes a novel learning mechanism to facilitate tactile inference on large-area robot bodies, alongside the development of a proximity sensing pipeline and multimodal sensing strategies. The effectiveness of the soft sensing technology is demonstrated through a soft *ProTac* link, which is integrated into newly constructed or existing commercial robot arms. Based on this framework, this study also explores the synergy between the robot's softness and its tactile-proximity sensing capabilities in facilitating task performance and enhancing safe interactions with the environment. Results suggest that robots integrated with the soft *ProTac* link, along with rigorous control formulation, are capable of mediating safe and purposeful control actions, which enhance safe interactions and facilitate motion control tasks that are challenging to achieve with conventional rigid robots.

Keywords: tactile sensing, multimodal perception, soft robotics, safety control, human-robot interaction.

論文審査の結果の要旨

Soft-bodied robots equipped with touch sensitivity and multimodal sensing abilities show significant potential for developing autonomous, social, and human-friendly robotic systems. However, integrating multimodal sensing into soft artificial skins poses challenges due to the incompatibility between soft materials and traditional electronics. Although vision-based tactile sensing has advanced robotic touch, its application in intrinsic multimodal sensing for large-scale robot bodies remains underexplored.

This study addresses this gap by introducing ProTac, a novel vision-based soft sensing technique that can operate in both tactile and proximity sensing modes. ProTac utilizes a soft functional skin capable of switching its optical properties between opaque and transparent states. Compared to traditional sensing skins that incorporate various electronic components, ProTac offers large-area multimodal sensing with a straightforward setup and minimal impact on the soft skin's mechanical properties. Additionally, the study proposes a new learning mechanism to support tactile inference across large robot surfaces, as well as a proximity sensing pipeline and multimodal sensing strategies. The effectiveness of this soft sensing technology is demonstrated through the integration of the ProTac link into both newly developed and existing commercial robot arms. The study further explores how the combination of the robot's softness and its tactile-proximity sensing capabilities can improve task performance and enhance safe interactions with the environment.

The findings suggest that robots equipped with the ProTac link, coupled with precise control mechanisms, can effectively manage safe and purposeful actions, thereby improving interaction safety and enabling complex motion control tasks that are difficult for conventional rigid robots to achieve. The student could prepare papers, thesis, and present the content in English without any problem. Therefore, this thesis is sufficient to be rewarded as doctoral thesis.