Abstract

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.