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論文題目	Development of a Large-Scale Vision-Based Tactile Sensing System for Robotic Links
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論文の内容の要旨

The sense of touch allows individuals to physically perceive and interact with their environment. Touch is even crucial for robots, as robots equipped with tactile sensation can more safely interact with their surroundings. The research describes the development of a vision-based artificial sensory system for robotic links, called TacLINK (see Fig. 1), which can be assembled to form a whole-body tactile sensing robot arm. The developed system is an elongated structure consisting of a rigid transparent tube covered by continuous artificial skin, which is soft, very safe, and comfortable to touch. When contacting with the surrounding environment (real-world objects and humans), TacLINK perceives tactile information through the three-dimensional (3-D) deformation of the skin that results from the tracking of an array of marker points sitting on its inner wall by two cameras installed at both sides of the transparent bone. Remarkably, a finite element model with shell structure for the skin body was successfully established to describe the relationship between applied forces and the displacements of these markers, allowing computation of tactile force. Thus, TacLINK provides simultaneous contact geometry and distribution of contacted force throughout the skin surface, regardless of the number of contact points and contact area with humans and various real-world objects. Besides, the artificial skin of TacLINK not only provides tactile force feedback but can change its form and nominal stiffness by providing air to inflate at low pressure (0-2.5 kPa).

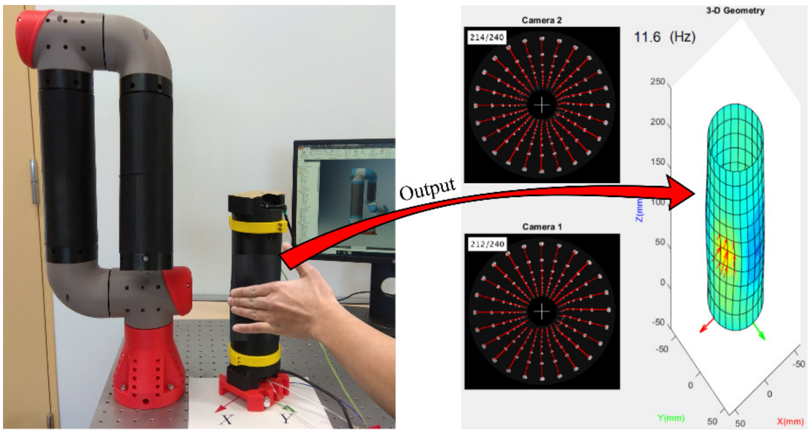

Fig. 1. The proposed TacLINK with tactile force sensing for robot links.

Contributions of the research:

1) A novel large-scale tactile sensing system at low cost for robot links: The research proposes an accomplished tactile sensing system for robot links with a large sensing area ~500cm^2 at low cost (about 150$). TacLINK is high sensing performance in both contact geometry and contact force upon interactions between the robot and surroundings.

2) An efficient vision-based tactile sensing system: The proposed vision system comprising two cameras with proposed algorithms tracks efficiently displacements of all the markers locating on the inner wall of the elonged skin surface. Vision-based sensing shows the advantages for developing large-scale tactile sensing systems, such as minimizing the challenges in wiring, the bulk of electronics, and the risk of damage.

3) The finite element method (FEM) for tactile force sensing: Previous research on vision-based force-sensing faced difficulty in establishing the relationship between force and displacement/deformation. This research utilized the FEM to derive the structural stiffness of the skin that is a key to calculate the contact force. Based on FEM, we could also characterize the skin to evaluate the design and choose suitable materials for a specified application.

4) A highly scalable structure for the development of the vision-based tactile sensing devices: The proposed artificial skin with markers is very simple and easily fabricated by the casting method. The shape and size are customizable for the specified applications. The FEM is generalized that the structural stiffness of the skin could be derived by using the analytical FEM. Vision technology now is powerful and small in size, thus a set of cameras can be set to track the displacements of the skin. The research expects to contribute significantly to the field of tactile sensing with a generalized method for designing vision-based tactile devices.

Keywords: Tactile sensing skin, vision-based force sensing, non-rigid registration, finite element method (FEM), soft robotics.

論文審査の結果の要旨

The sense of touch allows individuals to physically perceive and interact with their environment. Touch is even crucial for robots, as robots equipped with tactile sensation can more safely interact with the surroundings. Although in recent decades, tactile sensing technology has shown great advances in design, the main challenges relate to mimicking the inherent complexity of natural skin structure that has a particularly high density of mechanoreceptors with various types of receptors, e.g. mechanoreceptors (pressure and vibration sensing), thermoreceptors (temperature sensing), and nociceptors (pain and damage sensing). The conventional approach focused mostly on developing a skin-like structure with a small matrix of sensing elements without considering system-level design, such as the bulk of wires and electronic components, the complication of data processing and transmitting, and risk of damage.

The research describes the development of a vision-based artificial sensory system for robotic links, called TacLINK, which can be assembled to form a whole-body tactile sensing robot arm. The developed system is an elongated structure consisting of a skeletal transparent tube covered by a continuous artificial skin, which is soft and very safe and comfortable to touch and interact. When contacting with the surrounding environment (real-world objects and humans), TacLINK perceives tactile information through the three-dimensional (3-D) deformation of the skin that results from the tracking of an array of marker points sitting on its inner wall by two cameras installed at both sides of the transparent bone.

Also, a finite element model with shell structure for the skin body was successfully established to describe the relationship between applied forces and the displacements of these markers, allowing computation of tactile force. Thus, TacLINK provides simultaneous contact geometry and distribution of contacted force throughout the skin surface, regardless of the number of contact points and contact area with humans and various real-world objects. Besides, artificial skin of TacLINK not only provides tactile force feedback but can change its form and nominal stiffness by providing air to inflate at low pressure (0-2.5kPa).