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The Contribution of Sensors to Haptic Feedback in Robotic Hand Control and Teleoperation

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Summary:
This paper investigates the importance of sensory feedback for a vibrotactile haptic interface. We propose our initial design with first functional tests using a bidirectional robotic hand. Finally, opportunities to improve the interface with the integration of additional sensors are outlined.

Keywords: haptic feedback, vibrotactile feedback, robotic hand, human-machine interfaces, force sensing

Introduction

The advancements in computing technology over the past decades has led to an increased presence of robotic devices in our everyday life, ranging from vacuum cleaning robots to robotic assistants. These robotic agents can be teleoperated from a distance, leading to applications in the field of tele-presence, tele-medicine, space exploration, and search and rescue operations etc. [1].

In the case of teleoperated robots, it is important for the operator to be aware of their environment for interacting in an efficient manner. The sense of touch is responsible for proprioception of the body (ability to sense movement, action, and limb location) leading to a feeling of presence in the environment [2].

In this work, we propose a wearable haptic feedback armband for bidirectional human-machine interaction with robotic devices that heavily relies on sensory data. To do this, we employ a wearable sensor glove to teleoperate a robotic hand (equipped with fingertip tactile sensing and an inertial measurement unit (IMU)), and using the haptic feedback armband, the operator can receive information regarding the forces exerted during the interactions or weight of the objects.

Background

Vibrotactile feedback is based on vibration motors that change their intensity proportional to the force typically measured at the fingertips. A study by Nabeel et al. [3] claims an improved performance in distinguishing different weights while using vibrational feedback. Seiler et al. [4] investigated the phantom tactile sensation with a vibrotactile interface. The study shows that two closely spaced actuators on the skin produce vibrations which are perceived as one single vibration in between. They found out that it is possible to distinguish between more than 32 different haptic sensations on the upper arm. Vibrotactile feedback is one of the most promising feedback systems so far [3] and is thus within the focus of this work.

Within another study, Clemente et al. [5] presented a device that is able to deliver short-lasting vibrotactile feedback to transradial amputees using commercially available myoelectric hands. By using the proposed feedback system participants improved significantly in handling fragile objects.

Beckerle et al. [6] conducted a study to investigate, which design solutions would increase embodiment during interactions with robotic anthropomorphic hands. Experts in robotic hand design and control systems were asked to develop a design concept for robotic hands as well as for their opinion on haptic feedback and feedback control. Most of the experts (84.62%) agree that the combination of feed forward and feedback control is the best choice. Finally, 76.92% of the experts agreed that force/torque is the quantity that should be controlled.

Sensor-Supported Haptic Feedback

Our system includes a 3D-printed robotic hand which is based on the model of the open-source project "exiii hackberry" by Mission ARM Japan

[7] with added force sensing in all five fingertips. These force sensors not only provide the necessary data for the haptic feedback interface but also allow force control. The robotic hand is controlled by a data glove that contains flex sensors to measure the joint angle of each finger and an IMU.

The vibrotactile feedback system is adapted from Seiler et al. [4]. Linear Resonant Actuators (LRA) are used which can modulate vibration intensity by changing the amplitude rather than frequency. The armband consists of five 3D printed modules, each containing one LRA. These modules are connected through an elastic cord, cables and a toggle drawstring to fit the armband to any arm circumference. Each LRA changes its vibration intensity individually according to the applied force on the corresponding fingertip. To assess the effectiveness of the armband, two studies are proposed. First study focuses on estimation of the weight of the objects being lifted by the robotic hand and the second study focuses on identifying the fingers of the robotic hand which touches the object.

First functional tests with the proposed vibrotactile feedback armband show the general functionality of the system. These tests indicate the possibility to localize vibration of individual modules correctly and thus the affiliation to the respective fingers which is in line with the findings of the study by Seiler et al. [4]. Initial findings also include the possibility to perceive different vibration intensities, depending on the applied force on the fingertips of the robotic hand, which partially matches the results by Nabeel et al. [3].

Conclusion and Outlook

The proposed haptic feedback system could help in distinguishing between different force levels applied on the fingertips of the robotic hand and provides the user, information on the localisation of the stimulation on the robotic hand. However, further large-scale user studies are necessary to draw firm conclusions.

The tightness of the armband affects the performance of the haptic feedback armband. This challenge could be overcome with the integration of FSRs to measure the force between the skin and each of the vibration modules to ensure a determined tightness of the interface. This could make the vibrotactile feedback more reliable across users and less prone to artefacts caused by displacements through motion. The sensory data could allow automatic user-based calibration and inform the user about the ideal tightness. With additional force measurements from the palm of the robotic hand to provide a feedback to the user, a higher dexterity could be achieved by assessing the grasp stability. Furthermore, in the future design we plan to include an IMU to the feedback armband. In combination with the IMU of the data glove, this would allow to control a robotic hand mounted to a robotic arm for teleoperation, while providing the user useful feedback about the applied force on objects.

Haptic interfaces are always reliant on sensory data. This goes beyond the sensory-based localization and intensity of the feedback and includes potential ways to improve the reliability and personalization of the system as well as the ability to control robotic arm/hand systems. These interfaces can be employed not only in case of providing feedback during the use of robotic control, but also with limb prostheses, where persons with limb amputations can receive feedback regarding the interactions for making the control more effective, intuitive, and embodied.

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