CoaxHaptics-3RRR: A Novel Coaxial Spherical Parallel Haptic Device

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Abstract

Kinesthetic haptic devices are serial or parallel mechanisms. While serial mechanisms usually have larger workspace, parallel mechanisms can provide higher structural stiffness and lower dynamic inertia. For transparent haptic interaction, mechanisms with high stiffness in translational and rotational degrees of freedom (DoFs) and low dynamic inertia are crucial. There are haptic interaction devices based on parallel mechanisms, such as Omega.7 and Sigma.7. These specific devices, however, only realize translational DoFs by parallel mechanisms, while serial mechanisms are used for their rotational DoFs.

Spherical parallel mechanisms (SPM) represent a technical solution for parallel mechanisms for rotating DoFs [1]. They can provide higher structural stiffness and lower dynamic inertia also for the rotational DoFs. With SHaDe, Birglen et al. [2] introduced for the first time a haptic device based on an SPM. They argued that SPMs have very well-suited properties for haptic devices, specifically low dynamic inertia with a very low coupling between the DoFs, large workspace, and high acceleration capability.

This paper extends this solution and presents CoaxHaptics-3RRR, a concept for a novel haptic device with three rotational DoFs and the ability for unlimited roll motions (see Fig. 1a). CoaxHaptics-3RRR is a coaxial SPM specifically adapted for haptic applications and capable of generating haptic feedback to a human hand in the three Cartesian rotational DoFs.

The main contributions of this work are

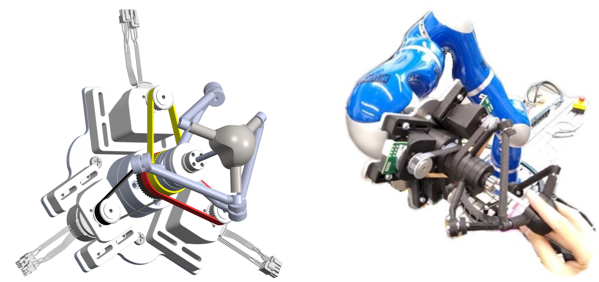
(i) proposal of a new concept for a spherical haptic device with large workspace, low inertia, and enhanced structural stiffness,

(ii) application of a multi-objective optimization method that simultaneously considers workspace, manipulability, dynamics, and structural stiffness of the device as objective functions [3], and

(iii) conducting experiments to identify the stiffness and validate the concept.

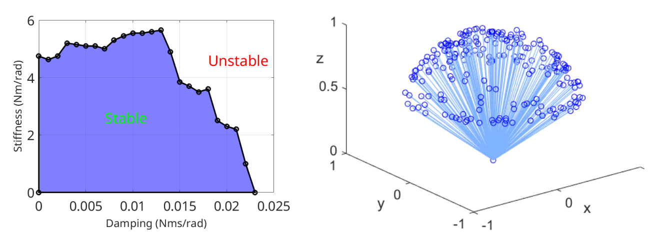
To reveal the dynamic range of stable impedances that the device can render, experiments were conducted. While the maximum renderable stiffness value without virtual damping is 4.75 Nm/rad, it can be increased up to 5.65 Nm/rad with virtual damping as shown in Fig. 2a. The workspace of the device is illustrated in Fig. 2b. It covers about 110° in x and y direction and is unlimited in z direction.

The developed system can be easily combined with another system to extend it to the translational Cartesian DoFs or to increase the rotational workspace of the other system and improve its dynamic characteristics. This combination turns the overall system into a macro-micro manipulator system, as exemplified in Fig. 1b using a DLR lightweight robot (LWR). Previous studies show that such macro-micro systems can also lead to improved position control.



(a) (b)

Fig. 1: (a) CAD model of the newly introduced CoaxHaptics-3RRR, and (b) assembly on a DLR LWR.



(a) (b)

Fig. 2: (a) Stable dynamic impedance range, (b) workspace of CoaxHaptics-3RRR.

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