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The DLR Bimanual Haptic Device with Optimized Workspace

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***Abstract*— This article accompanies a video that presents a bimanual haptic device composed of two DLR/KUKA Light-Weight Robot (LWR) arms. The LWRs have similar dimensions to human arms, and can be operated in torque and position control mode at an update rate of 1 kHz. The two robots are mounted behind the user, such that the intersecting workspace of the robots and the human arms becomes maximal. In order to enhance user interaction, various hand interfaces and additional tactile feedback devices can be used together with the robots. The presented system is equipped with a thorough safety architecture that assures safe operation for human and robot. Additionally, sophisticated control strategies improve performance and guarantee stability. The introduced haptic system is well suited for versatile applications in remote and virtual environments, especially for large unscaled movements.**

I. Introduction

Commercially available haptic devices are mostly desktop systems with limited workspace and force capabilities. On the other hand, some developments that aim for larger workspaces and forces appeared in recent years [1], [2]. This article accompanies a video that presents a multimodal Human Machine Interface (HMI) for bimanual haptic feedback (shown in Fig. 1), which targets at workspaces comparable to human arms.

The main components of the described system are two Light-Weight Robot (LWR) arms [3]. The intersection of the human and robot workspaces is maximized [4] and large unscaled movements can be performed. Additionally, the wide range of force and torque values that can be generated enable highly transparent interaction with remote and virtual environments. The introduced device is an optimization of the bimanual HMI presented in [5].

The remainder of this paper is distributed as follows: Section II describes the hardware components of the system, Section III discusses the optimized workspace offered by the device, Section IV introduces safety measures of the system, Section V discusses specific control issues, Section VI presents two possible applications in which the system can be used, and Section VII highlights the conclusions.

II. System Description

The haptic system is composed of two LWRs with adjustable mounting position. The columns to which the robots are attached can be rotated fitting the system to the user's size. The following subsections describe in detail the main system components.

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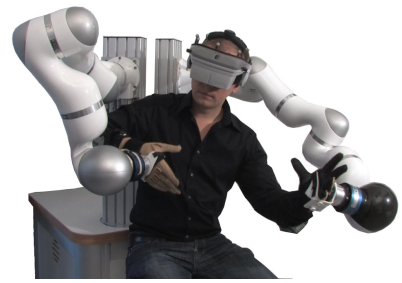

Fig. 1. The DLR bimanual haptic device.

Property	Value
Dynamic mass	2 × 14 kg
Peak force[1]	2 × 150 N
Maximum span	2 × 936 mm
Number of joints	2 × 7
Sensors on each end-effector	6-DoF force-torque sensor
Sensors in each joint	2 position, 1 torque sensor
Sampling rates	40 kHz current control
	3 kHz joint internal
	1 kHz Cartesian

TABLE I
Specifications of the haptic system

A. *Light-Weight Robot*

The LWR is a light-weight, flexible, revolute joint robot, which by its overall sensory equipment is especially suited for working in the area of human interaction [3]. The robot's size, power and manipulation capabilities, as well as its workspace are fairly similar to that of a human arm (see Section III). These properties turn the LWR into an appropriate haptic device for versatile applications.

The LWR is equipped with very light gears, powerful motors and safety brakes that are activated when power is not supplied. The electronics is integrated in each joint, including the power converters, torque and redundant position sensors. The robot can be operated for position, velocity and torque, at an update rate of 1 kHz, which allows for a highly dynamic behavior. Table II highlights the main technical specifications of the LWR.

Several handles can be used with the robot, such as joysticks, mock-ups, grasping interfaces with force feedback, and a magnetic safety clutch [5]. The latter is presented in the video. All available handles can be easily exchanged by a manual coupling flange.

The clamp of the magnetic clutch couples the human hand to the robot, such that all fingers can be moved freely. There-

[1]The peak force depends highly on the robot posture. The given value holds for a worst case, i.e. against gravity in a horizontal stretched posture.

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fore, this interface can be used in combination with data gloves, e.g., the CyberGlove® [6] and tactile finger feedback devices [7]. Since the clamp is magnetically coupled to the robot flange, the user is detached from the robot if the applied forces or torques exceed the maximum coupling force of the clutch. In that case, a dead-man mechanism causes both robots to stop immediately.

B. Vibrotactile Feedback

Additional feedback can be provided to human arms using tactile devices, such as the wireless DLR VibroTac [8]. This device worn on the forearm is composed of an array of vibration motors, and can increase further immersion into remote or virtual environments.

C. Intuitive System Interaction with Pedals

The HMI comprises pedals for both feet. Different functionalities can be mapped to the pedals, such as emergency stop, manipulation of a remote system, or interaction in a virtual environment.

III. Workspace Analysis

The workspace of the haptic system can be determined through reachability maps. Each point of such a map specifies a local reachability index that quantifies the reachable three dimensional orientations at that position. A recent workspace analysis [4] based on reachability maps determines the ideal location of the robots, at which the the correspondence of the human and robot workspaces is optimal. The resulting configuration enables unscaled movements in the usual human working area.

IV. Safety Issues

A bio-mechanical evaluation for the LWR with crash tests for human-robot interaction applications was conducted in [9]. Beyond that, several control strategies for reacting on non-voluntary collisions have been compared recently [10].

The DLR bimanual haptic device itself is equipped with several additional safety features. A collision avoidance module prevents collisions between the two robots, as well as with the table. A robot viewer illustrates the goal configurations of the robots and the forces and torques applied on the hand interfaces and the robot structure. A dead-man loop including the foot pedals and the magnetic clutch rounds the safety architecture off.

V. Control Issues

Specific control modules enhance the usability of the presented haptic device. The robots' redundant kinematics is utilized so that the robots' elbows can react compliantly to external forces. If no force is applied, the elbow position is optimized in such a way that the distance of the elbow to the user is maximized and robot singularities are avoided.

In impedance control mode, the robots are operated with gravity compensation. Since such compensation does not affect the robots' dynamic behavior, feedforward compensation [11] is used, which scales down the perceived translational inertia to 33%, and the rotational inertia to 25% of their original values.

VI. Applications

Our bimanual haptic device allows users to experience high immersion for several applications, such as virtual assembly simulation, telemanipulating robots, transfer of skills, and rehabilitation. The video exemplarily shows two of these applications: (1) virtual assembly simulations in which stiff collisions and smooth sliding are possible; and (2) telepresence simulations in which the DLR humanoid robot Justin [12], [13] is manipulated performing complex tasks in remote environments.

VII. Conclusions

The presented bimanual haptic device arranges the LWRs – similarly to exoskeletons – around the user. The resulting system offers large workspace for human arms. Together with the presented control and safety measures, the DLR haptic device is suitable for versatile haptic applications.

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