The CAPIO Active Upper Body Exoskeleton

Extended abstract for a poster contribution to the workshop 'RoboAssist 2014 – Wearable Robotics for motion Assistance and rehabilitation' at the 'IEEE International Conference on Robotics and Automation' (ICRA)

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Introduction. In this extended abstract, a concept for a poster is explained which will present an *exoskeleton* for the human upper body. This device was developed at the Robotics Innovation Center (RIC), DFKI Bremen, in scope of a project called CAPIO, and is intended to be used for teleoperation of robotic systems. Several novelties of the exoskeleton in the areas of *kinematic design*, *actuation*, and *manifacturing* are presented in the first paragraph 'Design'. Subsequently, in the paragraph 'Workflow', the procedure of obtaining the *kinematic* and the *dynamic* model from the *computer aided design* is reflected. Finally, the approaches of *controlling* the exoskeleton are described in the paragraph 'Control'.

Design. An active exoskeleton is a human-machine-interface which records the movements of its human operator and transfers force back to the human body. For example, it can be used to facilitate realistic interaction between the operator and a remotely controlled robotic system or a simulated environment. The active Capio exoskeleton is a device which covers the complete human back, both arms, and hands. It was developed with a focus on a lightweight construction, a large covering of the human workspace, a safe and comfortable operation, a simple dressing and undressing procedure and a rich force feedback experience.

Multiple contact points at the hip, the shoulder, the upper arms and the lower arms are used for transferring forces to the human operator. Kinematically, the exoskeleton offers eight active degree of freedom (DOF) at each arm and four active DOF at the back. In addition, four passive DOF and five adjustment DOF are available. To reduce the overall weight, high tensile aluminium and carbon-fiber-reinforced polymer (CFRP) parts were used. To realize a simple dressing and undressing procedure for the system, which covers back and both arms with precise movement capabililties, the Capio system features a so-called open joint concept: this concept describes an approach where the motion axes of the human and of the exoskleton do not coincide, but only intersect at rotation points of spherical joints. In essence, the alignment of exoskeleton and human as two concentric spherical mechanisms enables to exoskeleton to follow the human motions. For the synthesis of the developed device, the human anatomy and its motions were studied by using motion tracking systems and simulations.

All actuators of the Capio upper body exoskeleton were equipped with serial-elastic elements. These elements are realized with different springs and enable a natural and safe wear comfort and motion experience. Further more, the elastic elements are used to obtain force and torque measurements for controlling objectives. All used actuators and their actuation loops are specialized in-house developments. In particular, for the powerful joints at the shoulders and the elbows, highly integrated devices, combining a brushless DC motor, a gear system, a spring element, and a magnetic position sensor in a compact housing and realizing a high power weight ratio, were realized in a modular design. In the back structure, specific, light-weight spindle drives were applied to actuate the system.

Workflow. For operating the Capio upper body exoskeleton, it is necessary to work with consise models reflecting the kinematic and dynamic properties of the complex system. For obtaining these models, a software called CAD-2-SIM [1] was used which was developed within the project. This software is based on the Sheth-Uicker convention [2] and enables to extract the necessary information (link–joint incidences, geometric information about the system's zero-posture, its dynamic data, and a graphic representation) directly from the original data used during computer-aided design process. By using this software, the manual effort for editing software models, can be reduced drastically. In particular, the outputs of the software CAD-2-SIM include mechanism specifications for the simulation platform OPENRAVE [3], the OROCOS KDL library (`http://www.orocos.org/kdl`), and the libarary for rigid body dynamics (RBDL) (`http://rbdl.bitbucket.org`).

Control. The control architecture for the Capio upper body exoskeleton was implemented in modular multistage architecture. On the low level, real-time torque controllers were implemented to drive the exoskeleton joints. These controllers were realized based on the flatness approach to compensate for non-linear dynamical effects like friction [5]. As mentioned above, each controller integrates the torque information by the measurement of the displacement of the serial elasticity which is combined with the actuator.

On the middle level, the precise coordinated function of all joints was ensured by the computation of the (inverse) dynamic model of the device with the recursive Newton-Euler method [4]. For this purpose, the open source Rigid Body Dynamics Library was used. In particular, the libary enables to compensate for the gravity such that the resulting forces of wearing the exoskeleton are applied only at the back of the human operator. Additionally, contact forces can be simulated easily be using the RBDL.

On the high level, the human operator can be guided by the system by using the inverse kinematics of the exoskeleton.

References

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