Tele-Impedance: An Approach for Skill Based Body-Machine Interface

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This work presents the novel concept of Tele-Impedance as a method for controlling/teleoperating a robotic arm while performing tasks which require significant dynamics variation. As an alternative method to bilateral force-reflecting teleoperation control approach, which uses a position/velocity command combined with force feedback from the robot side, Tele-Impedance enriches the command sent to the slave robot by combining the position reference with a stiffness (or full impedance) reference estimated from the arm of the human operator while prioritizing the position accuracy through a closed-loop and robust position control algorithm. Position control prioritization is due intolerability of the price paid for position inaccuracies compared to deviations from reference elastic profiles due to impedance modeling uncertainties.

Estimation of endpoint stiffness in real-time and in vicinity of specific arm configuration is done by means of extraction of EMG features which correlate with endpoint impedance regulations and are independent from endpoint force fluctuations. The idea is inspired by the exclusive capability of central nervous system (CNS) which incorporates inverse dynamic models (for the joint torque modifications) and impedance control, independently, while interacting with environments with uncertainties and stochastic disturbances. Based on the orthogonality of the two subsystems described above, muscular activities can be then decomposed and mapped into two subspaces. First mapping corresponds to the force fluctuations and the second will be defined as the kernel of the former which correlates with impedance regulations without causing any effect on generated joint/endpoint forces. Therefore, the nullspace-muscular activities are extracted based on identified EMG to endpoint force mapping. Consequently, nullspace-EMG to endpoint stiffness mapping is identified based on direct measurements of human endpoint stiffness in different cocontraction levels. Stochastic perturbations are applied to the hand of the subject in the specific posture which is identical to the arm configuration that the tasks will be performed. Position deviation from equilibrium position and resulting endpoint force values are used for the estimation of visco-elastic profile.

In this work, the efficiency of the Tele-Impedance algorithm is evaluated by two complementary tasks. First task concerns with the classic peg-in-hole robotic problem and evaluates the efficiency of the proposed algorithm concentrating on transparency issues. In first set of evaluative experiments, the slave robot (KUKA, DLR) performs the task by tracking both the reference position profile (which corresponds to the end-point position of the arm of the human operator as measured from an optical position tracking system) and the end-point stiffness profile (estimated from the muscular activity of the operator's arm) in real-time. Second task is chosen to incorporate subjects impedance regulation skills in slave robot while performing tasks with significant dynamics variation and is concerned with throwing ball reception experiments. On the master side, the subject is performing the ball catching task while on the remote side, the robotic arm is performing simultaneously the same task while copying the kinematics and elastic profile modifications of the human's end point in real-time. In both set of experiments, The performance of the proposed algorithm is compared to different constant profiles of the robot's endpoint according to defined performance indexes.

We believe that the human-inspired modulation of the endpoint impedance during execution of tasks with significant dynamics variation inquiries can finally permit robots or assistive devices to reach high interaction performances, and also possibility of demonstrating a versatile and stable behavior even when interacting with environments with dynamic uncertainties.

Corresponding youtube movies:

http://www.youtube.com/watch?v=-Fn2dObnFpw

http://www.youtube.com/watch?v=KPO6IO7Tr-Q

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