Precise and Adaptable Motion Control of a Compliant Manipulator provided with Variable Clutch Actuation systems

N. Kashiri, M. Laffranchi, N. G. Tsagarakis, and D. G. Caldwell

The high stiffness of transmission systems and high reflected inertia of traditional drive systems used typically in robots make their output mechanical impedance considerably high, thereby these robots do not have enough flexibility to safely interact with humans and appropriately adapt to interaction required by the task. Incorporating passive elasticity to these drive systems helps to reduce their output impedance and improve the robustness of robots when entering in contact with unknown environments. However, despite the clear advantages of these compliant actuators, the considered flexibility in the actuator can introduce vibrations and oscillations in the system and limit the tracking performance achieved by the control system. As a result, the suppression of underdamped oscillatory modes is achieved in these systems by means of active control; however this might be too arduous to perform due to the complexity of the system's dynamic, especially if the robot presents transmission elasticity in several of its drives. A solution to this problem has been proposed which consists in embedding variable damping mechanisms in driving systems [1]. Hence, a number of variable damping actuators has been recently designed and proposed to improve the performance of compliant joints and to facilitate the control of them [1-3]. The variable damping actuator used in this work [1] is based on a clutch mechanism working in parallel to the transmission compliance. By exploiting this mechanism, aside from modulating the damping of the system via changing the piezo forces, the clutch can be employed in making the transmission stiff in the case high precision motion is needed. In this work, the normal clutch force is modulated to make the complaint joints rigid when no external force/torque is exerted, and to enable the joints' flexibility as soon as an interaction with environment is commenced to benefit from the effects brought by the compliance. To achieve this, the amount of normal clutch force should lock the system in a way such that the lowest amount of resistant force/torque can then unlock the system and make the system compliant. To realize this, the critical amount of piezo force needed for locking the joints should be found. The mechanical model of the joint is shown in Fig. 1.

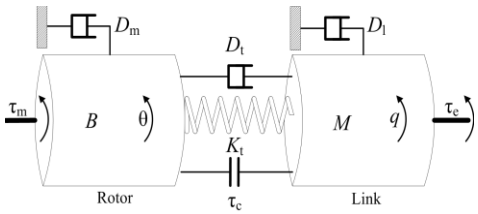

Figure 1. Mechanical model of the VPDA jonit

*This work is supported by the European Commission project SAPHARI FP7-ICT-287513. The authors are with the Advanced Robotics Department, Istituto Italiano di Tecnologia (IIT), Genova, Italy (e-mail: navvab.kashiri, matteo.laffranchi, nikos.tsagarakis, darwin.caldwell @iit.it).

The friction torque applied by the clutch of the VPDA mechanism, τ_c, is computed considering two possible operation conditions: locked mode, resulting in a one D.O.F. stiff system, and unlocked mode, when the coulomb friction can be computed using the conventional relation of coulomb friction, i.e. $\mu F_n sign(\dot{q}-\dot{\theta})$. Considering the case of the locked system with no external forces/torques applied, the amount of normal clutch force is regulated to keep the friction torque just below maximum static friction torque and hold the system in locked mode as far as no interaction happens. By applying this clutch force, the system can track a desired path precisely, and the system slips as soon as an interaction occurs. When the contact is detected, the clutch is disengaged to benefit from the flexibility of the system during interaction. Also, a simple external force controller based on approximate deflection of Cartesian stiffness of the robot has been designed to prevent the external force from exceeding the threshold. Fig. 2 illustrates the simulation results for a two link manipulator using the proposed strategy assuming a wall at x = 0 and considering 20N threshold for the external force.

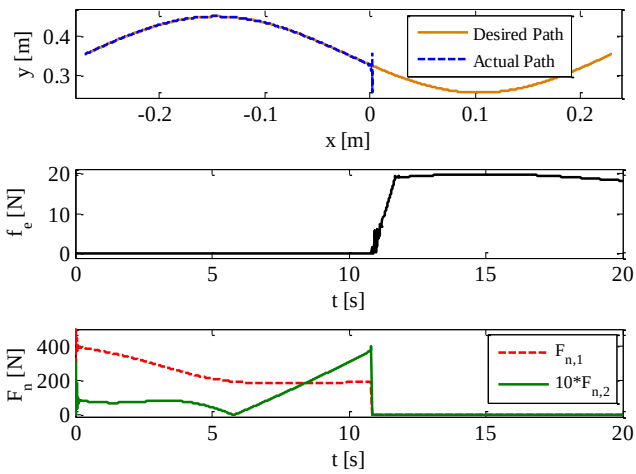

Figure 2. Simulation results for a two link manipulator

References

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