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On the Use of Force Control with Compliant Sensing for Robot Safety

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Extended Abstract

With new applications ranging from automated rehabilitation [1] to cooperative human-robot manufacturing [2], robots are increasingly being called upon to interact with people in unstructured environments. Physical human-robot interaction (pHRI) poses inherent risks and requires measures to ensure user safety. Previous approaches to robot safety employed collision detection and reaction using lightweight robots with compliant actuation; however, such approaches limit the performance of the robot [3]. The collision detection and reaction with compliant tactile sensors and zero force control offers the potential to ensure safety without affecting robot performance or requiring robot redesign.

In implementing force control with compliant sensors, the direct feedback of sensor deformation into a position controller has been employed in industrial settings and shown to improve transient response over standard force control [4]. The current work seeks to investigate the use of zero force control with deformation feedback in the application of robot safety. Deformation feedback for zero force control with compliant sensors does not require an accurate model of the sensor compliance, allowing foam or other materials with nonlinear behaviour to be incorporated in the sensor, such as the sensor in [5].

To gain insight into the behaviour of a deformation feedback force controller for use in robot safety, a single degree of freedom, linear robot with a PD controller is analysed. The compliant sensor is modelled as a mass spring damper, allowing the effect of friction on the stability and performance of the controller to be analysed. The stability of the controller is analysed for both the case of interacting with a passive environment and the isolated system. Without contact with the environment, the controller is found to be stable for all positive controller gains. In analysing the stability of the isolated system, it is found that initial deformation of the sensor will result in steady state motion of the robot. Steady state motion of the robot can result in secondary collisions with the environment and so the motion must be minimized. When interacting with a passive environment, stability can be guaranteed by ensuring the robot is passive with respect to the interaction with the environment. For the given system, conditions on the controller gains are derived to ensure passivity of the system and stability during interaction. The stability conditions take the form of restrictions on the maximum proportional gain as a function of the derivative gain and the dynamic properties of the compliant sensor.

To analyse the performance of the controller, the perceived impedance of the system with respect to the environment is developed. The effect of controller gains and sensor properties on the perceived impedance is analysed. It is shown that the mass of the external compliant sensor determines the high frequency impedance of the control law, while the derivative and proportional gains determine the low frequency behaviour. The results indicate that to decrease the impedance and contact forces, the controller gains should be maximized within the constraints of the system while the mass of the compliant sensor must be minimized. Preliminary simulation results confirmed the previous theoretical analysis.

References

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