DOWNLOAD PDF FORCE REFLECTING HAND CONTROLLER FOR MANIPULATOR TELEOPERATION

Chapter 1 : USA - Force reflection with compliance control - Google Patents

A force reflecting hand controller based upon a six degree of freedom fully parallel mechanism, often termed a Stewart Platform, has been designed, constructed, and tested as an integrated system.

In the position-error-based class, the position error between the commanded and the actual position of a compliantly controlled robot is used to provide force reflection. In the low-pass-filtered force reflection class, the low-pass-filtered output of the compliance control is used to provide force reflection. The increase in force reflection gain can be more than fold as compared to a conventional high-bandwidth pure force reflection system, when high compliance values are used for the compliance control. It is thus hard to expect safe and reliable telemanipulation with this system. Two major techniques that alleviate this excessive contact force problem are force reflection and shared compliance control. Recent experiments demonstrated that shared compliance control is essential in time-delayed telemanipulation [Kim, et al. The results also indicated that the task performance with SCC was superior to that with FR in terms of task completion time, cumulative contact force, and total contact duration. The relatively poor performance with FR was mainly due to a poor force reflection gain. With this low gain, the operator could feel only 1 lb when the manipulator hand senses a 10 lb contact force. The problem of poor force reflection is not specific to this testbed system, but rather inherent to the conventional FR control scheme being used for dissimilar master-slave systems where the slave system usually has much higher stiffness than the effective stiffness of the human hand holding the force reflecting hand controller. In a typical force-reflecting telemanipulation system consisting of dissimilar master-slave arms, the position of a slave arm remote manipulator is controlled by the human operator command, HO, through a master arm force-reflecting hand controller 10 as shown in FIG. This forms a closed-loop system and raises a stability issue. This poor force reflection problem will now be discussed. As a first-cut rough approximation, a linear decoupled system model in Cartesian axes is assumed. R s is the robot servo system transfer function in Cartesian space [W. R s could be second-order, fourth-order, or higher depending upon the Cartesian axis and the arm configuration. In this example, the double-pole corner frequencies are at about 3 and 6 Hz, behaving as a fourth-order system. The transfer function can be obtained by measuring the magnitude ratio of the hand controller deflection to the applied force input for different frequencies. The bandwidth of H s is about 1 Hz for a loose grasp and 3 Hz for a firm grasp. In order to have a stable teleoperation system with a constant force reflection gain Gfr, the open-loop DC gain Q O should not be much greater than 1, since a higher-loop gain causes instability due to the higher-order dynamics of H s R s. A good direction to increase the force-reflection gain is to make the robot more compliant by employing compliant control. An approximate mechanical equivalent of the above implementation consists of a spring connected in parallel with a damper. It can be shown that the compliance control force feedback gain Gcc is approximately the new compliance value of the compliant robot control system of FIG. The results are two novel schemes of force reflecting control: In the position-error-based scheme, the position error between the commanded and the actual position of a compliantly controlled robot is utilized to provide force reflection. In the low-pass-filtered force reflection scheme, the low-pass-filtered output of the compliance control is utilized. The magnitude ratio of the hand-controller deflection to the applied force is plotted as a function of frequency. This scheme does not increase the force reflection gain noticeably. Newly developed schemes first three operation modes demonstrate the best task performances. This combination results in a system having two feedback loops; the inner compliance control loop residing in the robot side of the telemanipulation system and the outer force reflection loop with the operator in the loop. Experimental testings, however, revealed that this combination increases the maximum force reflection gain only slightly. This can be understood by noting that the compliant control has a low-pass filter 12 whose bandwidth is lower than the manipulator bandwidth. As the frequency increases above the low-pass filter bandwidth, the effect of the inner compliant control loop diminishes resulting in the original model of FIG. Compliance control is essential to achieve high force reflection gain. A variation of the position-error-based force reflection has eventually led to an alternate scheme that also enabled the system to have high force reflection. This results in another new scheme of force reflecting control. In this alternate scheme of FIG. Note that simple combining of pure force reflection and compliance control FIG. The above two newly developed schemes of FIGS. In both schemes, high force reflection is achieved only with a limited bandwidth that is the same bandwidth imposed by the low-pass filter of the compliance control compensator. An interesting feature observed in the position-error-based force reflection is that the operator feels artificial force when the operator moves the hand controller faster than the actual robot motion. Compliance measurements robot hand deflection vs. The plots show that the new compliance value of the robot hand is approximately equal to the compliance compensator feedback gain Gcc. The measured compliance data also show excellent linearity in the robot work volume. In the SCC implementation, a low-pass filter is used to add damping to stabilize the system. A larger compliance means a higher compliance feedback gain Gcc , which requires a lower bandwidth of the low-pass filter with a more sluggish compliant response. The maximum bandwidths of the low-pass filter for given desired. Compliance values were measured and plotted in FIG. The maximum bandwidth of the low-pass filter is about 3. In the above measurements, compliance compensators were added only along translational axes not about rotational axes. When both were enabled, the maximum bandwidth values were reduced further approximately to a half. The force reflection behaviors of the position-error-based force reflection scheme of FIG. Note that the force reflection gain in this scheme is given by Gpe Gcc. This limited drive force is probably a good feature since excessive force in the hand controller causes rapid operator fatigue. For a given compliance value, both the bandwidth and the force reflection gain are limited. It is interesting to observe the an abrupt oscillation occurs as soon as the force reflection gain exceeds a certain maximum value. These data indicate that the maximum bandwidth is inversely proportional to the compliance value, while the maximum force reflection gain is proportional to the compliance value. The maximum bandwidths are limited by the stability boundary of the compliance control feedback loop as described earlier FIG. The maximum force reflection gains are somewhat higher than expected from Equation 2 , and a more careful stability analysis is in progress. The maximum force reflection gain is inversely proportional to the position scale factor Gps, which can be easily conjectured from Equation 2. It can be observed in FIG. Peg-in-Hole Experiments wt Different Operating Modes Peg-in-hole tasks were performed with eight different operating modes to evaluate the position-error-based force reflection in comparison with other operating modes. The peg-in-hole task module has 9 holes arranged in a square matrix. In our experiments, only one hole with 10 mil clearance and no chamfer was used. The peg was 4. The peg-in-hole task consisted of the following steps: In our advanced teleoperation setup, the hand controller of the master side was installed in the control station room separate from the PUMA arm of the slave side. Three television camera views of the task board and robots were provided in the control station: The focus and zoom settings were fixed throughout the experiments. The eight operating modes tested are: The stiffness values inverse of the compliance values used for SCC were 6. The low-pass filter bandwidths were 0. For simplicity, the same compliance and bandwidth values were used for all three Cartesian position axes and also for all three orientation axes, and no serious attempt was made to find the optimal parameter values. In the experiments, test operators performed the peg-in-hole task three times each with the 8 operating modes in random order 24 tasks in total. Three test operators participated in the experiments. All operators first trained themselves until they could complete the peg-in-hole task comfortably for all operating modes. Then, each operator performed one complete set of the experiment of 24 peg-in-hole tasks as a practice run. Thereafter, actual experiment was performed for experimental data collection. Performance with position control modes 1 through 7 is superior to that with rate control. Due to limited bandwidth, operators felt force reflection sluggishness during the peg-in-hole task execution. Low-pass-filtered FR alone without SCC was marginally operational, requiring the operator to maintain a very firm grasp during the peg-in-hole task performance, and thus was not included in our experiment. Again the newly developed position-error-based force reflection combined with compliance control resulted in the best task performance among all control modes tested. Conclusion Two novel schemes of force reflecting control have been presented, namely position-error-based force reflection and low-pass-filtered force reflection, both combined with shared compliance control, for dissimilar master-slave arms. These new schemes enabled high force reflection gains, up to about 2 for the unity position scaling, which were not possible with a conventional scheme when the slave arm with a limited dynamics bandwidth is much stiffer than the master arm. The experimental results with a peg-in-hole task indicate that the newly developed force reflecting control schemes combined with compliance control resulted in best task performances. Claims 4 I claim: A system as defined in claim 1 wherein said means for producing said force reflection signal produces a signal proportional to the difference between said actual robot position signal and said commanded position signal, HC, transmitted with gain, Gps, by said hand controller. A system as defined in claim 1 wherein said means for producing said force reflection signal produces a signal proportional to the difference between said servo control input signal from said signal mixer and said commanded position signal transmitted to said mixer by said hand controller. A system as defined in claim 1 wherein said force reflection signal comprises said contact force signal, which is itself a function of said commanded position signal, filtered by said low-pass filter without said position signal, filtered by said low-pass filter without said gain, Gps.