$\mathscr{H}_\infty$-based Absolute Stable 4-channel Teleoperation Control

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1 Abstract

This text shows how through the use of $\mathscr{H}_\infty$ theory one can design absolute stable four-channel teleoperation controllers that require no acceleration information, are robust against sensor noise and at the same time show good performance.

2 Introduction

Bilateral teleoperation controller synthesis boils down to making a good trade-off between performance and robustness. Compared to two and three-channel control schemes, four-channel controllers, employing force and displacement information at both master and slave side have more tuning flexibility and allow for a better trade-off. But, parameter-tuning of four-channel controllers is rather involved. Which partially explains the popularity of the simpler two or tree-channel schemes. Lawrence derived the controller parameters for a four-channel controller that realises perfect transparency[1]. With such ‘ideal’ controller the system is *lossless* which means that it is marginally passive. For this controller to work a few assumptions must be met. Apart from perfect system knowledge, also perfect measurements of position, velocity, acceleration and forces at master and slave are required. In practice acceleration measurements are usually not available. Also velocity measurements mostly obtained through differentiation of a quantisized position signal can be poor representations of the true velocity. Also force measurements are typically noisy. In practice a controller following Lawrence can become active, causing instable behaviour under certain contact situations.

3 Robust Controller Synthesis

The authors employ $\mathscr{H}_\infty$ theory to compute four-channel controllers that do not rely on above assumptions and where the parameter tuning follows naturally from the $\mathscr{H}_\infty$ approach. The framework described e.g. in[2] shows how to incorporate passivity conditions right into the controller synthesis only requiring that operator and environment are behaving passive, thus that the infinity-norms of their scattering representations $\|S_{op}\| \leq 1$ and $\|S_e\| \leq 1$.

Measurement vector: No acceleration measurements are used. The vector $\mathbf{y}$ of measurement variables is $[x_m\ x_s\ \dot{x}_m\ \dot{x}_s\ f_m\ f_s]^T$ and contains position and velocity of master and slave as well as the exchanged forces f_m and f_s measured at the interface with the operator and the remote environment. Note that velocity is obtained through differentiation of the quantisized position data.

Input vector: The exogeneous forces f_{op} and f_e exerted by operator and environment form along with the noise on these measurements and noise representative for the velocity error due to differentiation of a quantisized position signal, the input vector of the generalized plant. Thus $\mathbf{w_{in}} = [f_{op}\ f_e\ df_{op}\ df_e\ d\dot{x}_m\ d\dot{x}_s]^T$. Through solution of a set of LMI's with additional rank conditions, this extended version of the framework described in [2], can be solved to obtain an absolute stable controller that realises robust performance against the augmented uncertainty block diag$([S_{op}, S_e, \Delta_{perf}])$. The blockmatrix Δ_{perf} makes sure that the transfer function from $\mathbf{w}_{in}$ to $\mathbf{z}$ is minimised. Where the **Control objectives** are position and force tracking under minimial controller effort: $\mathbf{z} = [x_m - \phi x_s\ \ f_m - \varepsilon f_s\ \ u_m\ \ u_s]^T$ for position and force scales ϕ and ε.

4 Experimental Results

Fig.1 shows experimental results of a robust controller designed for a 1-d.o.f. teleoperation setup. A rigid wall located at -16mm is contacted several times. Good position and force tracking is realised during contact and in free space.

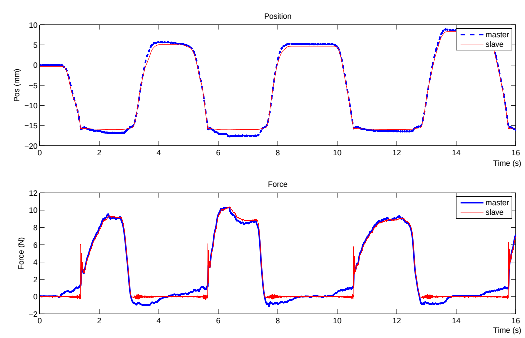

Figure 1: Position and force tracking of a robust controller

5 Conclusion

The framework described in [2] to derive robust absolute stable 4-channel teleoperation controller is extended here to take into account noise on force and velocity measurements. Experimental results on a 1-d.o.f. setup showing good performance are given. Future work will be directed to incorporate model uncertainty into the same framework.

References

[1] D. Lawrence, “Designing teleoperator architectures for transparency,” in *Proc. IEEE Int. Conf. on Robotics and Automation*, Nice, May 1992, pp. 1406–1411.

[2] E. Vander Poorten, D. Reynaerts, H. Van Brussel, T. Kanno, and Y. Yokokohji, “Robust 4-channel teleoperation controller design,” in *Benelux Meeting on Systems and Control*, Spa, 16-18 March 2009, pp. 36–36, No. MoA03–4.