High Performance Adaptive Control of Multi-Axis Positioning Systems

Problem:

In manufacturing processes, it is important to achieve the desired contour as accurately as possible. Better control of the desired contour will allow either more dimensionally accurate parts to be produced or higher feed rates with the same dimensional accuracy.

An adaptive controller has been designed to improve the accuracy of the contouring error in the milling process by a factor of five. However, as in most processes, there can be disturbances or sensor noise that degrade the desired performance. It is therefore desirable to design disturbance and noise rejection into the controller.

Research Objectives:

- To design a control scheme to include frequency domain requirements into adaptive control.
- To determine which frequencies are associated with disturbances and sensor noise in milling processes so that their effect on the system can be reduced.
- To incorporate actuator constraints into the design of the controller.
- To prove stability of the control scheme.
- To implement the design on the Mazak milling machine to demonstrate the controller's capability.

Approach:

The control structure to be used is shown in Figure 1 which is the same adaptive control structure utilized by Rober and Shin. In order to simultaneously meet both time and frequency domain specifications, the R and S controllers are have been extended to include both fixed and variable components. The fixed components are then used to design for the frequency domain specifications. The R_{fixed} controller is used primarily for noise rejection while the S_{fixed} controller is used primarily for disturbance rejection. The variable components are used to achieve the desired closed loop performance as specified by the polynomial C_r. The higher order C_r dynamics may be used to further enhance the performance of the system.

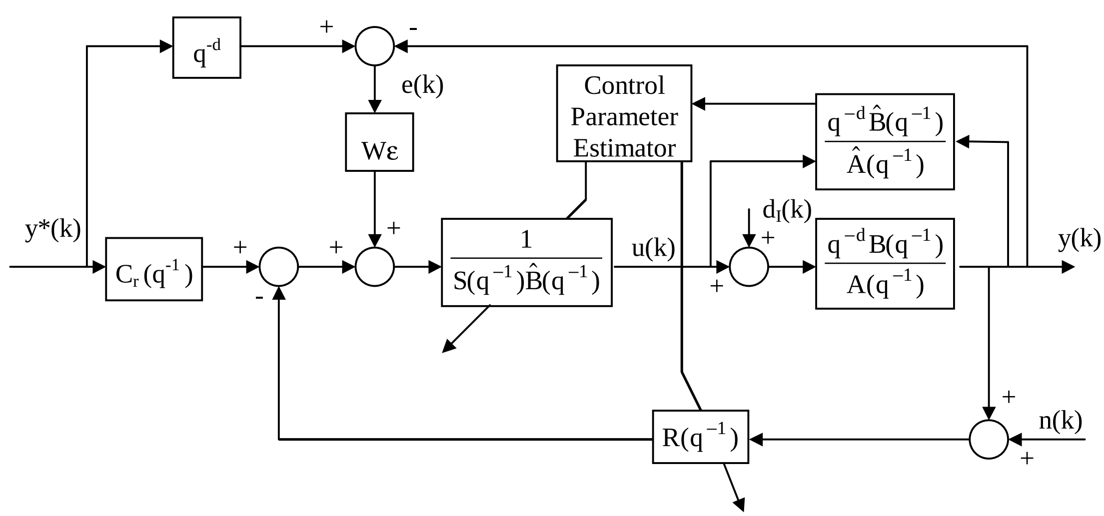

Figure 1: Block Diagram of Adaptive Control Structure

Accomplishments:

The fixed components of the S and R controllers can be used to shape the frequency domain sensitivity responses for disturbance and noise rejection. The example presented here is for the instance when it is desired to reject a low frequency disturbance. As is shown in Figure 2, the original system is only attenuating disturbances in the higher frequency region. The fixed S controller is used to modify the frequency response to that shown in Figure 3 without changing the overall closed loop response. However, as shown in Figures 4 and 5, the cost of this improvement was that the system can no longer reject noise, especially in the high frequency region. Since it is desirable to also reject high frequency noise, the fixed portion of R is used to modify the frequency response to that shown in Figure 6. Some of the disturbance rejection is lost especially at high frequencies as shown in Figure 7, but there is still good disturbance rejection at the lower frequencies. Experiments were run on the Mazak milling machine with a disturbance at a frequency of 0.16 hertz added to simulate a low frequency disturbance. For the desired path shown in Figure 8, the contouring errors for the on-line test are shown in Figure 9. It can be seen that a significant improvement in contouring error has been achieved with the improved controller when compared to the original system.

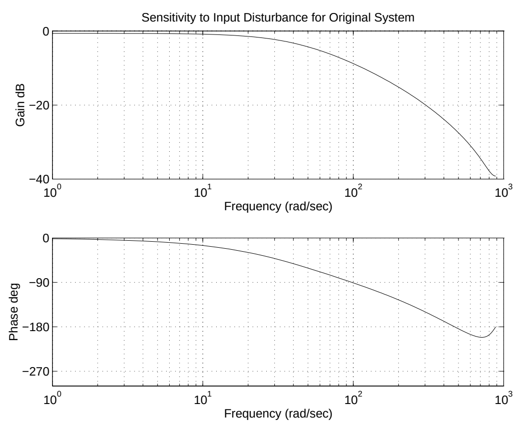

Figure 2: Sensitivity Plot of Disturbance for Original System

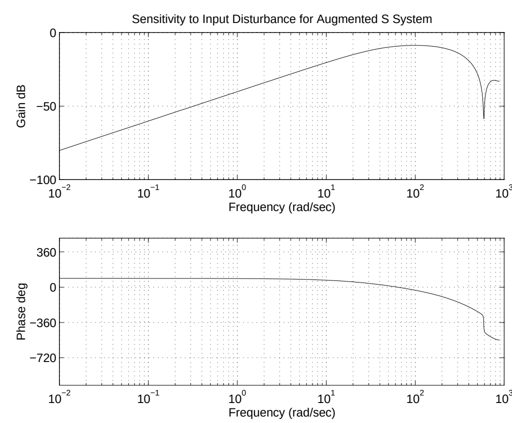

Figure 3: Sensitivity Plot of Disturbance for S_{fixed} Addition to Controller

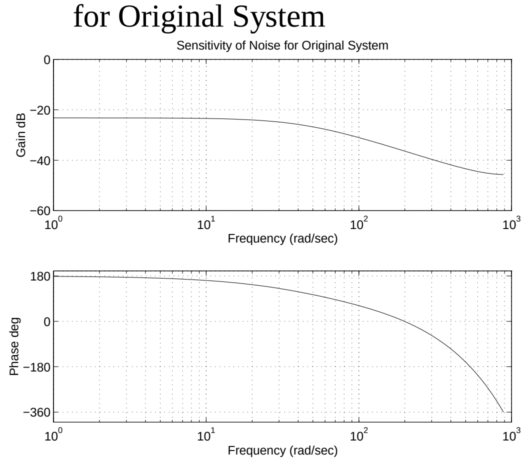

Figure 4: Sensitivity Plot of Noise for Original System

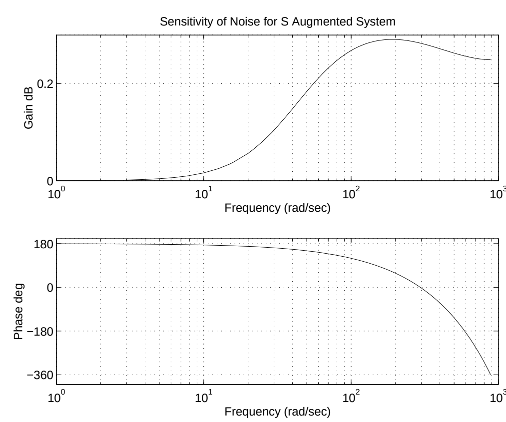

Figure 5: Sensitivity Plot of Noise for S_{fixed} Addition to Controller

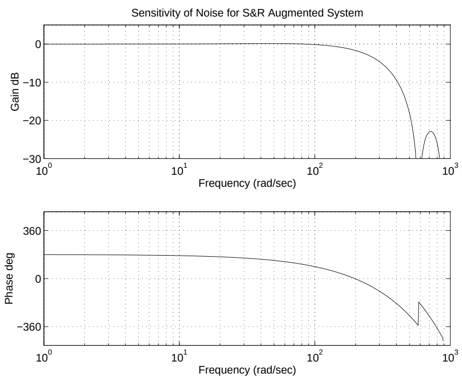

Figure 6: Sensitivity Plot of Noise for S_{fixed} and R_{fixed} Addition to Controller

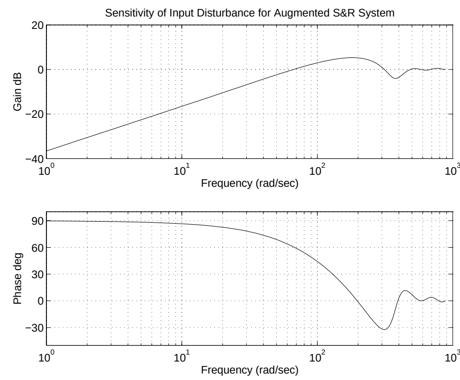

Figure 7: Sensitivity Plot of Disturbance for S_{fixed} and R_{fixed} Addition to Controller

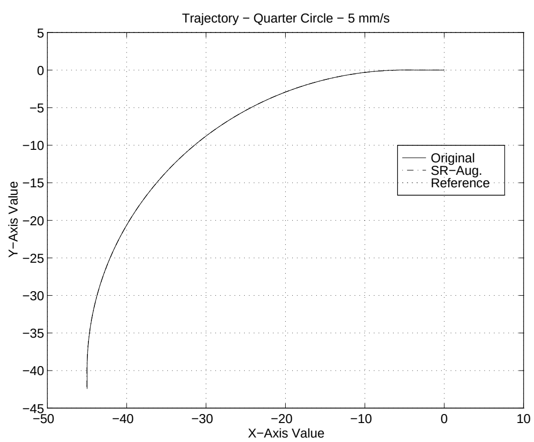

Figure 8: Trajectory for Arc

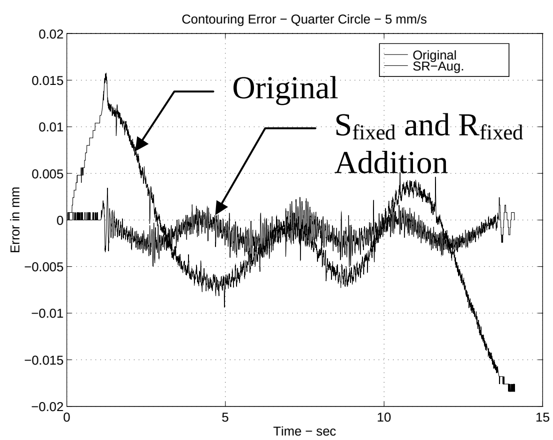

Figure 9: Contouring Error