Chapter 6

Conclusions and Recommendations

This chapter presents the conclusions resulting from this study. A number of recommendations are presented for further design and research into the problem of developing a high-bandwidth torque sensor and torque loop.

6.1 Conclusions

Through identification of different system components, an LQ controller was created and tested to achieve improved performance on the ARTISAN wrist joint torque loop. Because of design limitations, the performance characteristics were constrained by the motor and amplifier system. The resulting time domain characteristics are shown in Table 6-1.

Characteristic	Parameter	Value
Bandwidth	w_{BW}	216.7Hz
Rise Time	t_r	1.703 ms
Overshoot	M_p	8.3 %

Table 6-1: Final Time Domain Characteristics

6.2 Recommendations for Future Work

Since the purpose of this work was to develop a high-bandwidth torque sensor for use in a high-performance torque loop, the following recommendations are suggested regarding design changes dependent on the future design direction of the ARTISAN manipulator.

6.2.1 Modifications to Existing Closed Loop System

The following recommendations are made for future research on the current sensor configuration.

6.2.1.1 New excitation source

The current source, the Analog Devices AD2S99, has a lookup table flaw that adds a disturbance that cannot be eliminated. As shown in Figure 6-1, the sinusoid generated by the AD2S99 has a small flaw in the last quadrant of the cycle. In an operation that relies on small variations between amplitudes such as the AC Ratio Bridge, which subtracts two signals, the excitation flaw becomes a disturbance that the AD2S93 erroneously attempts to track.

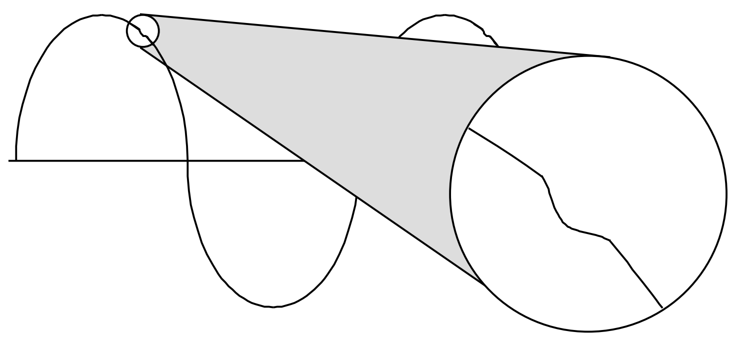

Figure 6-1: Magnification of AD2S99 Output Flaw

Because of the signal flaw, the AD2S93's gain and bandwidth are limited. A new excitation source that provides a cleaner signal without harmonics or disturbances will improve the tracking ability of the AD2S93.

6.2.1.2 Properly tuned LVDTs

Because of the phase effects that occur when the LVDT is excited by a frequency it was not tuned for, future LVDTs should be tuned at the manufacturer to the excitation frequency used for the converter. In the current design, this would mean that the frequency of the excitation source (10.2 KHz) would be tested and optimized at the factory. This change would improve LVDT performance by reducing phase shift and amplitude variation.

6.2.1.3 Modify or replace the current amplifier

Due to the motor and amplifier poles, the LQ design of the torque controller resulted in a sub-optimal performance. The motor and amplifier zero also provided a constraint on the speed of the state estimator by pinning one of the state estimator poles at the motor/amplifier's zero location. Hence, the ratio between the state estimator poles and the closed loop poles was limited. Modification of the current amplifier's PI compensator through the component values (C_{17} and R_{150}) would improve performance of the state estimator that directly impacts the closed-loop torque loop. Care should be taken in this modification to ensure that controller effort (voltage limits) into the pulse-width modulator is monitored to meet the design specifications for the current amplifier.

6.2.1.4 DSP Controller

To reduce chip real estate, a Digital Signal Processor (DSP) could be designed to take the place of the many interface components that exist on the sensor electronics board. This design change would improve performance and enhance communication between the sensor electronics board and the torque control computer.

6.2.2 Future Sensor and Control Recommendations

As technology advances, a number of potential solutions can be implemented that can address the need for an improved, high-bandwidth torque loop.

6.2.2.1 DSP representation of the AD2S93 functionality

Given a DSP with two fast analog-to-digital converters and a single digital-to-analog converter, the functional aspect of the AD2S93 can be simulated and improved without the problems discussed in Appendix C. With a full digital implementation, the bandwidth of the sensor electronics can be improved past the performance of the AD2S93 limit.

6.2.2.2 Develop frequency-based messaging scheme

The use of an amplitude-modulated scheme to transmit position information has the potential for decreased signal-to-noise ratios - especially in a system that would require the message signal to travel through the manipulator to get to the converter electronics. Using a system that converts position into frequency by tuning a resonant circuit on board the mechanical sensor could provide great noise immunity and improved resolution above and beyond the performance of a typical synchronous demodulator scheme. A circuit similar to the one depicted in Figure 6-2 could provide this benefit.

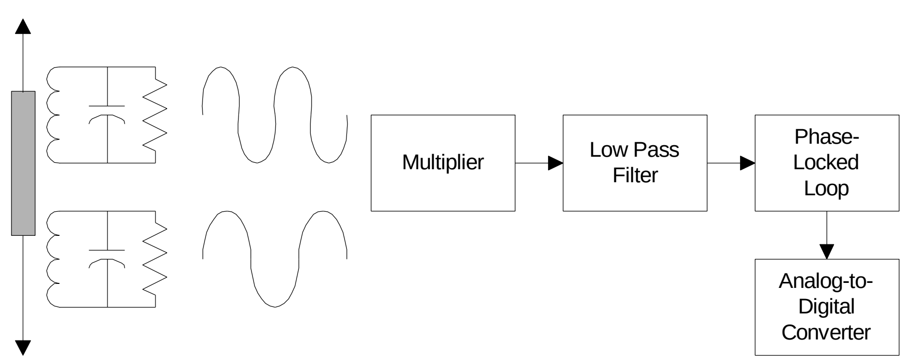

Figure 6-2: Potential Frequency Based Scheme