CHAPTER VI

Conclusion & Future Work

6.1 Conclusion

Initially this research began with the focus on identifying alternative brakes / clutches for use in PTER. Past research has recognized some of the existing actuator's deficiencies and attention was given to how alternatives may improve PTER's performance. After surveying industrial available units and concluding that none of the alternatives suited the project's needs, focus shifted to improvements of the existing Dynacorp clutches and brakes.

Careful examination of the original clutches & brakes was performed to better understand the performance variation between each unit and to better understand their adverse dynamics; primarily a nonlinear torque mapping and a pure time delay with an approximate first order dynamic response. As a result one prototype of an improved electromagnetic clutch with torque sensing capabilities for feedback control was designed, built, and tested. Considerations were given to available magnetic force, endurance strength, and repeatable performance. Efforts were made to make the design as modular as possible, allowing future modifications without having to start over.

Calibration, assembly, and control issues for the new clutch were addressed. Testing results validated the structural model developed for the spoke design, while benefits of proportional control for rejecting non-modeled friction properties and system disturbances was demonstrated; but due to insufficient controller frequency maximum stable gain was restricted and only limited disturbance rejection could be achieved. Simulations showed expected benefits of increased controller frequency and possible differential control (digital PD) with the existing power supply. By controlling the electromagnet with current instead of voltage, eliminating the clutch's first order response, power supply dynamics were found to be a dominant factor. Unfortunately, increasing the power supply's speed further increases the necessity for a quick digital controller and limits maximum achievable stable gains. Several options may exist, such as tuning a RLC circuit or implementation of analog control. In addition, it was found that friction properties varied over time, signifying a need for real-time parameter adjustment or intelligent integral control. Though, if analog control were implemented the feed-forward term would be eliminated and modeling error would not become an issue. Likewise, if an extremely fast controller can be realized, large gains can be used to reject any modeling errors in the feed-forward term.

6.2 Future Work

6.2.1 Further Clutch Work

The natural next step is implementation of a faster digital controller (higher sampling frequency). This may be achieved through use of Matlab, Real Time Workshop, and a dSpace board; all currently available in the IMDL laboratory. Alternatively analog control, with proper circuit logic for programmable saturation limits and unipolar torque feedback, might prove simpler in the long run. Ideally the clutch and its controller should be thought of as one unit that transfers a reference signal into a desired slip torque. By implementing analog control, computer resources would no longer have to be allocated for servo control of the four units; leaving more resources for the higher level control that process haptic algorithms and determines which combination of clutches to apply. Other improvements may include modifications to the spoke design or analysis of potential friction materials, such as Delrin. Converting the power supply to fast mode and alternative power supplies should be investigated. A power supply with increased bipolar voltage capabilities would improve dynamic performance as long as the controller (digital) is fast enough. Regardless, a power supply that exhibits a response closer to first order would be more beneficial then underdamped second order. As it stands, at least two of the existing power supply units are deficient (too low of current limits) and should be replaced. It may be desirable to pursue the more comprehensive clutch dynamic model, accounting for torque transmission through the compliant spokes. Some work is necessary to improve simulation stability and parameter estimation. Identification of values for damping and actual inertia will require some experiments. Alternative friction models and materials may be investigated with the simulation.

After an acceptable combination of power supply, clutch, and controller is developed three more units must be built to replace the remaining actuators. Careful attention must be given to actual friction material thickness (above the magnet) for minimizing performance variations between each unit. Again, if alternative friction material is used, this thickness would be carefully machined to within a tolerance.

6.2.2 Other Improvements to PTER

Currently the force sensor located on PTER's handle has the strain gauges mounted in the wrong location. They are mounted at an inflection point, requiring large signal gains; making noise and thermal affects significant factors. In past experience it was found that the force signal drifted, requiring constant adjustment and resulting in imprecise measurements. Relocating these strain gauges should alleviate the problem.

PTER uses angular potentiometers to measure position and relies on numerical differentiation for velocity. Tachometers that directly measure angular velocity may improve performance through a cleaner velocity signal. By measuring velocity directly, position would not have to be differentiated which tends to add noise to the system. Alternative position sensors, such as encoders or resolvers, may be attractive. Regardless, the mounts for the existing potentiometers must be replaced.

In the past PTER's control algorithms were processed on a 486-50 MHz with DOS. Since the development of PTER several alternative control software such as Wincon, Hyperkernal, and Real-Time Linux have been developed. Many of these software packages already have methods for Internet communication and user interface. A new software package should be chosen that facilitates real-time control, that is capable of working with a graphical user interface, and internet communication. Software selection in not a trivial matter and must be given careful attention.

Once the software and aforementioned hardware is updated, PTER should be in fit condition and ready for testing of past algorithms and new algorithms developed with simulations. Future activities should include reconstruction of HURBIRT and bilateral tele-operation with PTER. Ideally communication for such a task should utilize communication over the Internet.

A final avenue that may be worth pursuing, depending on the final performance of PTER, is replacement of the inverse coupling transmission with a continuous variable transmission (CVT) and coupling clutch. By using individual brakes on links one & two and a coupling CVT, PTER can be limited to almost any 1 degree of freedom device. The brakes can be used to slow down a link while the CVT can couple the links with any relative velocity constraint. Before such an option is pursued, the existing configuration with hardware / software upgrades should be exhaustively tested.