Chapter 1

Introduction

In today’s modern, automated environment, manufacturing engineers are developing new applications for automation, including:

- Chip placement and wire stringing by manipulators
- Autonomous operation of a manipulator within a dynamic workspace
- Robotic sanding and milling of materials requiring precise force application
- Grinding welds made by robotic arc welders
- Precision path following for laser cutting

Current manufacturing operations rely on simple, position-based manipulators operating in a paradigm of joint angles and end effector locations. However, when precision manufacturing tasks are required, expensive fixturing devices and vision systems are implemented to allow for the shortcomings of the conventional manipulator. In order to overcome the manipulator's dynamic limitations, designers are often forced to forgo the manipulator full performance potential. In addition, longer setup times and maintenance periods often need to be incorporated into the workflow to properly tune the robotic work cell to meet its performance requirements.

1.1 ARTISAN manipulator

A preferable solution to fixturing devices and vision systems is a manipulator with better performance characteristics. Such a manipulator would improve on conventional manipulators by incorporating design constraints that benefit from force and position control schemes. The ARTISAN manipulator, whose wrist joint is shown in Figure 1-1, has been designed as the next generation of robotic manipulators at the Stanford Computer Science Robotics Laboratory.

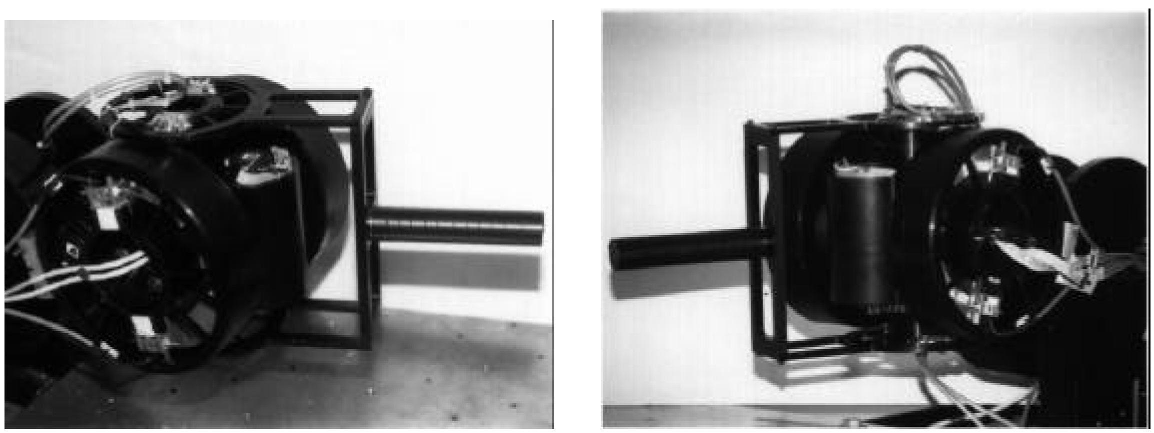

Figure 1-1: Wrist Joint of ARTISAN manipulator

The unique design characteristics of ARTISAN include:

- **Uniform inertial characteristics**

  The mass matrix of the manipulator as seen from the end effector is uniform in all three directions

- **Redundant degrees of freedom**

  Due to the eleven degrees of freedom, ARTISAN can be broken into a macro and mini manipulator allowing for high dynamic performance within its operating space

- **High bandwidth joint torque control**

  By incorporating joint torque sensors for precise control of link torques, improved force and dynamic performance are attained

The combination of these three design aspects provides ARTISAN with force and dynamic performance characteristics previously unattainable by conventional manipulators. By incorporating a high-performance joint torque control loop, motion control strategies that implement gravity compensation, inertial decoupling, centrifugal compensation and Coriolis compensation are greatly enhanced. In addition, active force control strategies used in high-speed assembly can be improved without additional hardware or fixturing.

1.2 Prior Research

There have been several efforts to develop precision joint torque control using joint torque sensing. Based on experiments with a single joint [Wu80], the first two joints of a Stanford Arm were redesigned [Luh83] to accommodate torque sensors. Joint torque sensory feedback was also implemented in a direct-drive manipulator [Asada84] and in a PUMA manipulator [Pfeffer86]. These prior experiments demonstrated that joint friction effects can be substantially reduced by torque control. However, wide joint actuation bandwidth is difficult to achieve without actually reducing the friction and non-linearities in the actuator-transmission system.

Incorporating the understanding gained by these experiments, a mechanism must be designed to minimize the effects of friction and non-linearities from the beginning. Only then can accurate joint-torque control be achieved using a closed loop torque servo, with reliable torque sensors, at each joint of the robot. The design of the ARTISAN manipulator has taken this lesson into account and has developed a manipulator that minimizes these effects.

1.3 Objective of Thesis

Once these design concerns have been taken into account, the next step in the creation of the precision joint-torque loop is the development of a high-performance torque sensor that fits within the constraints of the manipulator.

This research discusses the issues involved in developing such a torque sensor within the constraints of the mechanical system. The goal of this thesis is to design and implement a high-bandwidth torque sensor and simulate its performance within a joint-torque control loop for the wrist joint of the ARTISAN manipulator.

1.4 Organization of Thesis

This thesis is divided into six chapters and four appendices. Chapter 2 describes the joint control loop in the context of the ARTISAN manipulator, including a focus on the system equations for the motor and current amplifier. Chapter 3 further describes the design of the joint torque sensor, including the mechanical design and the transducer and converter selection. Chapter 4 discusses the overall joint control loop requirements in terms of the multiple-loop environment. Chapter 5 discusses the experimental results from the identification of the converter parameters and the simulation of the ARTISAN joint torque loop showing improved tracking performance through the use of the joint torque sensor. Chapter 6 concludes the thesis with a summary of the results and potential directions for improvement.

The Appendices cover various details of the experimental research included in this thesis. Appendix A is a brief discussion on the operation of LVDTs. Appendix B is the formulation of equations for determining components for the AD2S93 using the Analog Devices methodology. Appendix C is the formulation of the ARTISAN solution for the AD2S93 through detailed analysis of the AD2S93 sub-components. Appendix D is a compilation of the system values for various components of the experimental setup used in the research.