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ADAPTIVE ROBOTIC DEBURRING

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Abstract. The paper describes the development of an active end effector force control system for robotic deburring. The purpose of the control is to maintain a constant cutting force by making position adjustments normal to the part edge. Autoregressive moving-average (ARMA) models which relate the position command for the end effector to the resulting change in the cutting force were developed for the deburring process. A non-adaptive PID controller is designed and tested using real time control experiments. The results indicate a rise time of about 150 ms to a step change in the reference force. A force variation from the reference level of about 1 N peak-to-peak, which produced a chamfer variation of 0.12 mm peak-to-peak, was achieved. The robot speed used in these experiments was 25 mm/s.

The application of parameter adaptive control is examined as a solution to the problem of deburring complex contours at higher robot speeds, and to improve the robustness of the control. Simulation results are presented for an adaptive version of the Smith predictor and a form of model reference adaptive control. The results suggest that the use of adaptive control could provide significant improvements in the speed of response and robustness to sudden changes in plant dynamics, over the non-adaptive controller.

Keywords. Adaptive control; discrete time systems; computer control; force control; machining; robots.

INTRODUCTION

Deburring of manufactured parts is a costly and often overlooked part of manufacturing. In the United States an estimated $3.9 billion a year is spent on deburring, with total finishing operations representing up to 25 % of all manufacturing costs (Tortolano, 1985).

Deburring is commonly performed at the final stage of the manufacturing process where parts have their highest added value, and therefore quality control is an absolute necessity. The problems of varying operator skill; high job turnover rate; and a noisy and dangerous work environment have prompted the development of automated robot based deburring systems (Bopp, 1983).

The burrs are removed by chamfering the part edge with the cutting tool guided by the robot arm. By controlling the cutting force the desired chamfer size can be maintained to produce higher quality parts, more consistently.

Passive systems, where a passive compliance device is added to the robot's end effector to control the force, have been shown to be limited in dealing with the problems of varying robot arm dynamics, robot positioning errors, and part fixturing errors (Gott, 1985).

These limitations have spurred the development of active force control systems. Their aim is to maintain a constant cutting force by making position adjustments normal to the part edge.

In terms of hardware their are two main methods for implementing active force control. With "through the arm" control the adjustments are done through the robot arm's position control system. The performance of this method is limited by the typically poor accuracy and slow response of the arm's control system. Until robot controllers are improved these problems can be solved using a completely external or "around the arm" type adjustment system. With this approach the robot is first commanded to follow a nominal path around the part; once contact is made an independent active end effector senses the force, computes the adjustment, and moves to correct the path. Only the small end effector and not the entire robot arm is controlled, allowing higher bandwidth and accuracy to be achieved. No communication with the robot controller is required, making the method nearly independent of the host robot type.

Active end effector based systems have been applied to reduce deflections of the robot's structure by Paul, Gettys and Thomas (1982); Zalucky and Hardt (1982); and Tlusty and Wegerif (1986). For the deburring problem Hollowell and Guile (1987) have implemented two active end effectors with an ASEA Irb-6 robot with promising results, while a system by Kazerooni and Guo (1987) is under development. The common element to these applications is that simple, non-adaptive, control strategies were used.

Developed initially for force control in assembly, the designs were based on simplified static models of arm and environmental stiffness and simple control laws resulted (Whitney, 1987). The first was stiffness control with: