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● *Paper*

ACTIVE END EFFECTOR CONTROL OF A LOW PRECISION ROBOT IN DEBURRING

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An active end effector is developed to improve precision in robotic deburring. The design objectives are obtained from a dynamic analysis of the combined system of robot arm, end effector, and deburring process dynamics. The unit allows robot-independent positioning, over a range of ±15 mm in two orthogonal directions with an accuracy of better than 0.01 mm and a bandwidth of 20 Hz. A combination of d.c. servo motors with linear ball screws achieves both high precision and a large mechanical advantage. A high quality chamfer is obtained by performing position adjustments normal to the part edge for constant cutting force. An extended discrete PID controller based on an ARMAX plant model is designed and simulated off-line prior to real-time implementation. In real-time force control tests, the active end effector system is shown to improve the precision of a PUMA-560 robot by an order of magnitude over the open-loop case.

1. INTRODUCTION

Burrs are formed by the plastic flow of material during machining and must be removed for part fit in assembly, product safety, and effectiveness of further finishing operations.[1] At present the majority of burrs are removed by manually chamfering the part edges, and significant improvements in both production rate and product quality can be achieved by automating deburring using robots.[2] While the large workspace and high mobility of robots make them highly suited to deburring, these attributes also result in a structure with both low stiffness and low positioning accuracy relative to conventional machine tools.[3] Since the tolerances required for deburring are tight, this presents difficulties unless additional sensor feedback is used to improve the robot's precision. In deburring, the force is proportional to the chamfer depth, allowing a high quality chamfer to be produced through force control.

The limited performance of passive systems, where the force is controlled by adding a passive compliance device between the arm and cutting tool, has spurred the development of active force control systems. The force is controlled by performing position corrections normal to the part edge. (In some systems the tangential speed is controlled.) In terms of hardware, the corrections can be performed either through the arm's position control system or by a completely external, active end effector system. These configurations are shown in Fig. 1. While through-the-arm systems require minimal external hardware, their performance is limited by the poor accuracy and slow response of most robot position control systems. With the external system, the robot traces a nominal path around the part while the position adjustments are performed by the end effector. Only the small end effector (and not the entire arm) is controlled, allowing higher bandwidth and accuracy to be achieved.[4,5] One or two motion axis designs are the most common. Both force measurement and corrective motions can be performed in the same direction, requiring no coordinate conversion. Since no communication with the robot controller is needed, the system is nearly independent of the host robot type.

This paper describes the development of a high performance active end effector for improving robot precision in deburring. Following a review of earlier designs, the design objectives are obtained from a dynamic analysis of the combined robot arm, end effector, and deburring process dynamics. The unit is then built and tested. The force control system, based on a discrete time plant model, is developed off-line through computer simulation. The end effector based deburring system is then tested in real-time.

2. ACTIVE END EFFECTOR DESIGN REVIEW

In active end effector systems, an end effector which allows independent position adjustment is attached between the robot's wrist and the cutting tool. This is distinct from the use of an X–Y table to move the part while the tool is held by the robot. This method was applied to deburring by Kramer *et al.*[5] with a GE P-50 robot, and by Kazerooni[6,7] with the tool rigidly mounted; it has the advantage that X–Y tables are