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Dual-Sensor Based Robotic Deburring

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New results quantifying the performance of a vision and force sensor based robotic deburring system at high feedrates and on stainless steel parts are presented. The performance with stainless steel is similar to that achieved with mild steel due to adaptation of the process model. Increasing the feedrate from 25 mm/s to 50 mm/s did not greatly affect deburring performance and could be used to reduce cycle time. The dual-sensor approach is shown to be 14 times more reliable than a single sensor solution. The overall accuracy of the system is ±30 μm for straight edged parts, and ±60 μm for 2-d edged parts with geometry similar to those tested.

1 Introduction

In previous work (Bone and Elbestawi, 1994) a vision and force sensor equipped active end effector has been applied to automated robotic edge deburring. The objective was to accurately and reliably measure and control the chamfer depth. Generalized predictive control (GPC) and a new form of adaptive GPC incorporating learning (AGPCL) were implemented. The system was tested on mild steel parts (AISI 1018) at a feedrate of 25 mm/s.

Tests have subsequently been performed with the system at a feedrate of 50 mm/s (whereas typically with automated deburring the feedrate is 10–20 mm/s) and on harder to deburr, stainless steel (AISI 304), parts. The reliability of the dual-sensor approach in comparison to a single sensor solution has also been quantified. Finally, manual microscope measurements were done to verify the overall accuracy of the system. In this brief paper, these new results are presented and analyzed.

2 Deburring Experiments

2.1 Experimental Setup. The hardware setup consists of the active end effector mounted to a Unimation PUMA-762 industrial robot, and controlled by a 33 MHz Intel 80486-based microcomputer. The sampling rate is 105 Hz.

The deburring was performed on machined parts that had edge burrs with an average height of 0.2 mm. Straight (1-d) edged, and 2-d edged parts with the edge geometry shown in Fig. 1(a) were used. The vision sensor was used to automatically inspect the deburred edge. These measurements were obtained by retracing the deburring path with the tool retracted from the edge.

2.2 Results and Discussion

2.2.1 Deburring Results. The results of the deburring tests are summarized in Table 1. The chamfer depth setpoint is d_{ref}, and σ is the standard deviation of the chamfer depth measurement, d. The position error is the peak-to-peak variation of the robot's path relative to the part's edge. This was measured by the vision sensor during a noncontact pass. The average model gain equals the D.C. gain of the estimated process model averaged over the deburring test.

From tests 1 and 2 it can be seen that AGPCL reduced σ by 47 percent in comparison to GPC. With the stainless steel part (test 3) the deburring performance, with $\sigma = 9$ μm, was not greatly affected by the greater hardness of the material due to adaptation of the process model. This was reflected by a reduction in the gain from 0.75 (for test 2) to 0.52.

The tool path for tests 4 and 5 is shown in Fig. 1(a). The tool proceeded from points A to I. Rather than trying to rotate the end effector instantaneously, at the sharp corners (points C and G) the cut was exited and reentered. These brief jogging motions (C-D-C and G-H-G) had little effect on the total cycle time. The vision sensor measures the tool's position relative to the part prior to contact (during segments AB, DC and HG) allowing the transient at cut entry to be minimized. The tool position/depth measurement for test 5 is shown in Fig. 1(b). Based on tests 4 and 5, the 50 mm/s feedrate only slightly worsens the deburring performance ($\sigma = 20$ μm vs. 17 μm), and could be used to reduce the cycle time. Acceleration limits of the robot prevented testing at higher feedrates. The substantial increase of σ in comparison to tests 2 and 3 was due to the larger position error encountered during the 2-d tests.

2.2.2 Inspection Results and Overall Accuracy. Frequency distributions of the depth measurements obtained from an automated inspection pass and from manual microscope measurements of the test 4 part are compared in Fig. 2. The pass was performed at 25 mm/s with a 52 Hz sampling rate. With the manual approach the rate was approximately $\frac{1}{30}$ Hz. A Nikon Measurescope microscope with an accuracy of 1 μm was used. For the microscope measurements $\bar{d} = 0.387$ mm, and $\sigma = 15$ μm; and for the inspection system $\bar{d} = 0.39$ mm, and $\sigma = 19$ μm. The $\bar{d}$ values agree within the accuracy[3] of ±24 μm determined for the inspection measurement (Bone and Elbestawi, 1994).

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[3] All accuracy values given in this paper were obtained using the method specified by the National Machine Tool Builders' Association (1972).

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