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Process Control for Robotic Surface Finishing

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Abstract—**Process control methods are developed that leverage compliant robot control, CAD model data extracts, self-acquired surface geometry measurements, and strategy based programming to finish grind cast turbine blades. The processes achieve high finishes, accommodate varying work needs, and require only a brief teaching session to program for new parts.**

I. Introduction

Effectively automating smoothing and shaping newly formed and remanufactured turbine engine blades has eluded robot developers for many years. Task characteristics that prove challenging include:

1. Part forming processes leave varying amounts of material to be removed.
2. Geometric envelope tolerances are relatively broad, while local surface finish requirements are high.
3. Manufacturer's product portfolios are dynamic and include hundreds of configurations of complex, free-form curved parts made from difficult to machine materials.

Conventional robot control methods using trajectory repetition cannot be applied because geometric tolerances and varying work requirements make each part's needed tool path unique. Even if individual paths could be determined in advance, tracking inaccuracy produces unacceptable surface finishes. Auxiliary tool compliance devices achieve desired finishes, but cannot shape to a specified contour. Moreover, path-based robot programming is typically a time consuming, trial-and-error affair, sometimes assisted by auxiliary tools that carry their own complexities. Because of the inability of current systems to work simply, reliably and efficiently, human workers perform a significant amount of turbine blade finishing, despite it being difficult, dirty, and prone to causing injury. The cost of poor quality is high, and human involvement in an exacting production process requires multiple inspection and re-work steps.

In the work presented here, Western Robotics leverages compliant robot control, tool contact measurements, and CAD model data to quickly configure and control a robot to grind an imprecisely located part with variable finishing requirements.

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II. Robot Task Teaching

The work was performed on a ParaDex closed-chain manipulator chosen for its force control performance. The turbine blade's CAD model is used as a reference, with the robot's compliance used to acquire and accommodate workpiece-specific geometry. For instance, the turbine engine airfoil blade we experimented with has pin bumps left over from casting that are on the critical, airfoil section of the blade. Putting the robot into a relaxed mode allows the user to guide the robot to the bumps, teaching the robot their locations. These points are stored with the CAD model for later reference.

III. Part Registration

Using touch eliminates the need for custom, precision-made part fixtures, and allows for rapid setups and single-piece production runs. The part need only be clamped in a general position in the robot's workspace. The operator gives the robot a single reference point, and it feels for additional points. The robot approaches the part with a soft touch and quickly halts on contact. Combining these points with geometry from the part's CAD model allows the robot to identify the position and orientation of the part. It can now apply information from the CAD model to locate taught features and other part attributes.

IV. Fine Surface Geometry Acquisition

Although the robot has a good idea on the location of the bumps from the annotated CAD model, it uses the grinding tool as a probe to touch off on the part and get more precise information for grinding. It feels the surface to precisely locate the bump's position and acquire the position of the surrounding "good" surface.

V. Strategy-Based Task Execution

The robot works by applying preprogrammed material removal strategies. These strategies consist of parametric force settings, motion paths, and success metrics. With self-acquired surface data and a desired surface contour extracted from the CAD model, the "strategy" automatically generates the sequence of motions and actions appropriate to grind the bump. The size of each bump varies, but the robot's ability to feel the shape of the surface while it works allows it to measure its progress, modify its actions, and determine when the job is done.

Pin bump removal is a common requirement for many of

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the cast turbine blades, and with the grinding strategy, a non-technical person can program the robot to do a new part in minutes. All that is required is to specify the locations of the bumps on the CAD model, a process that can be done by the previously described lead-through method, or by off-line markups in the CAD system.

VI. CONCLUSION

Using touch technology, Western Robotics has created a grinding system that is programmed in minutes rather than days, does not require precision-made part fixtures, and accommodates part variation. It enables small batch, automated production of tasks that currently are performed by hand. The results can be extended to virtually any part formed by casting, forging, machining, or molding that requires additional material removal to arrive at a final net shape and finish.

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