euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016

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Development of an intelligent automated polishing system

E. Kalt[1], Dr R.P. Monfared[1], Prof. M.R. Jackson[1]

[1]*EPSRC Centre for Innovative Manufacturing in Intelligent Automation, Loughborough University*

e.kalt@lboro.ac.uk

Abstract

In high-value manufacturing sectors, many manufacturing processes are still performed manually, such as polishing operations for small metallic parts. Increasing volume, the need for consistency in quality, and health and safety issues are some of the reasons for industry to search urgently for alternative solutions for manual polishing processes. This article reports the development of an intelligent automated polishing system to achieve consistent surface quality and removal of superficial defects from high-value components, such as those used in aerospace industry. The article reports an innovative method to capture manual polishing processes by skilled operators. The captured polishing parameters are then used to develop and control a robotic polishing system that can adopt various polishing patterns. A brief summary of existing fully and semi-automated polishing systems and their inadequacy for industrial applications are discussed. The need for building automation system based on manual operations are explained and a systematic data capturing process for a specific aerospace-based component is defined. The development of the process capturing device is explained, the data analysis and interpretations are discussed and the migration from manual operation to an automated polishing system is reported. Further detailed information is given in relation with combining data from various sensors and building of an automated system based on learning from manual operations. The research results are also briefly discussed and conclusions are drawn regarding applicability of automated systems for highly skilled manual operations.

Type the keywords here Automated Polishing, Robotic grinding, manual operation, data capture through mechatronic devices

1. Introduction

In the manufacturing industry, mechanical polishing plays a vital role in the development of a product's surface quality and final geometry. Despite the current growth of automated technologies in industry and in research, mechanical polishing is still mainly carried out manually. Manual polishing typically involves a highly skilled and trained worker in an un-healthy environment due to exposure to dusts, vibrations, and noises. For example, lengthy manual polishing processes could lead to musculoskeletal diseases (MSD) such as vibration white finger, or other severe injuries [1].

These processes are usually performed at the final stage of the manufacturing process of a component or product and could represent up to a third of production time in some industries [2]. Therefore, industry is strongly motivated to implement automation in polishing processes to improve the working environment and to drive cost down, whilst keeping the same level of quality or better [2-5].

Many industries already benefit from the advancement of multi-axis machining to produce parts to precise tolerances and specifications [4-5]. Industrial robots have also been widely used to perform well-defined, repetitive tasks in carefully controlled environments, but fully autonomous operation of the robot may not be cost effective for polishing [6]. However, none of the existing technologies are offering flexibility and the autonomous provided by skilled operators. For instance, one of the main challenges in automated polishing is to maintain a constant contact force between the tool and the workpiece in relation with the geometrical profile of the part. If the force is too high or uneven the part can be over polished [2].

Investigating the existing research and industrial efforts in automated polishing, it is understood that a key element missing in developing automated polishing is the understanding and capturing of manual operations, and building the automated system accordingly.

Mechanical polishing includes a wide range of technologies and processes, such as abrasive blasting, mass finishing, chemical mechanical polishing, and ultrasonic polishing. Review of the literature has shown three main technologies: robotic arm [2-3], commercial and designed computer numerical control (CNC) [5, 7], and mass finishing [4, 8] are all currently used in industry or are in development [9].

The main focus of these works are driven by cost, removing humans from unsafe/unhealthy processes, and interest in specific components (e.g. mold die or turbine blade). It was also noted that the study or capture of manual operations, in order to build an automated system, was neglected. In this research, the development of an intelligent automated system is based on the study of manual operation is investigated. Section 2 describes the development of a fixture to capture forces and motions of human operators during manual polishing operations. In Section 3, the capture and analysis of data with the fixture is reported. Finally, in Section 4, the development of the automated system based on the results in Section 2 is discussed.

2. Capture of Forces & Motions

The polishing approach proposed in this article is initially based on capturing and understanding the manual polishing operation. By understanding how manual operators adjust the process parameters to improve the surface quality and remove defects, the manual processes are interpreted to develop an automated robotic polishing system which is controlled flexibly and adapt to the surface profile intelligently. To achieve this, it was necessary to monitor the motion, the force, and the speed of the operators during the polishing processes. The other variables derived from captured parameters include time, acceleration, and the polishing patterns. A fixture was designed to enable capturing the forces, motions, and speed of a skilled human operator through a set of sensors (multi-axial force and torque sensor, inertial measurement unit, and 3D motion capture system), as illustrated in Figure 1.

3. Capturing Manual Polishing Operation

To identify different patterns and polishing techniques used by skilled workers in manual operations, several experiments were designed. The first set of experiments aimed at polishing the surface using different polishing patterns and techniques (e.g. various forces and movements). This is particularly useful to understand data output from the sensors and match them to the approach used by the operators. In the second set of experiments, the operators were tasked with removing machining marks and defects on the surface respectively.

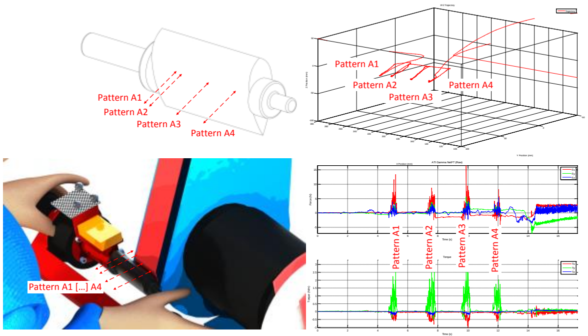

Figure 1. Example of data captured with the fixture during manual polishing operation

The data captured by the fixture (as seen in Figure 1) provide a good understanding of how the operation is carried out and has been reproduced for further experiments.

The data shows that the operators mainly followed the profile of the part and applied a constant force (avg. 10 N) with variable feedrate (i.e. variation in pace).

Operators also used different movements depending on the type and feature of the surface. For example to polish trailing edges at the top and bottom of the workpiece, the operators moved horizontally from one side to the other side while applying a lower force and trying to keep the part perpendicular to the abrasive tool.

The operators techniques are interpreted to force and motion parameters only. And then, replicated in the automation system using a multi-axial force and torque sensor and a stream of point-to-point coordinate data to follow the desired surface profile. The frequency of sending coordination data will also change to provide variable feedrate required for defects.

4. Development of an Intelligent Automated System

The captured parameters and the polishing approach was replicated with a robotic arm. Initially, the automated system followed a pre-programmed trajectory that follows the profile of the surface. However, by developing the realtime streaming of motion data, the need for CAD model to define the robot trajectory was eliminated. This is to match the way that a skilled operator compensates the position and orientation of the part for optimum polishing.

In the proposed automated approach, the resultant contact force is kept constant while polishing the surface of the part. However, by controlling the force and the speed of polishing, the system is able to reconfigure the polishing parameters, for instance, to remove defect from surface. The experiments proved that better results on the surface texture are achievable when the speed changes (hence decreasing material removal rate - MMR) while keeping a constant force.

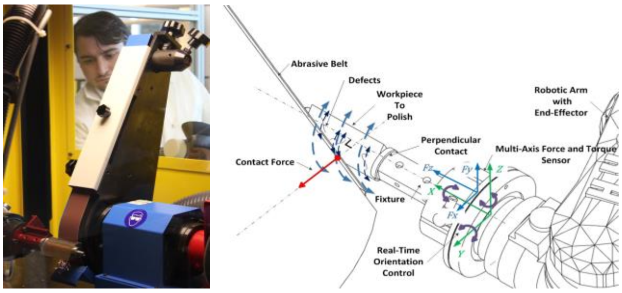

Figure 2. Manual polishing approached replicated on a robotic arm.

The current developed automated system (see Figure 2) uses a 6DoF KUKA KR16 robotic arm and a multi-axial force and torque sensor. The realtime motion feedback control to the robot is generated based on developed polishing application tool that uses the feedback from the multi-axial force and torque sensor, the cutting parameters, and generates incremental positioning data based on a set of developed algorithms, originally learned from manual operations. For example, the robot position is changed based on the force feedback using a incremental value (defined by user) until the polishing force is achieved (also defined by user). Using this method, it was proved that the developed automated polishing system is independent from the geometry of parts and can flexibly reconfigure the cutting parameters, similar to the way human operators do, based on force, feedrate, motion patterns, and the position of the defects on parts. This clearly distinguishes the proposed system from the traditional force-controlled robotic operations.

5. Conclusion & Further Work

The parameters captured with the fixture provide useful information on how the polishing operation is carried out manually. The next step of this research project was to use the same approach with a robotic system. We understood that the operators followed the profile of the workpiece, so as to not to alter the geometrical and dimensional tolerances while applying a constant force perpendicular contact to the abrasive tool, and changes speed depending on the type of defects.

The experiments conducted on the robotic arm demonstrate that the robotic system can follow the same approach as the operator. The system could follow the profile of the part. However, force and torque control was required to polish the surface evenly. In addition, the system could be used for different geometry as the position is controlled by the force and torque output (no need for CAD data).

Further work of this research includes torque and speed control, and a vision system to detect and locate defects.

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