Automatic Mirror Polishing of Rough, Freeform AM Surfaces using a Toolpath Generation Framework

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Abstract.
Despite the emerging adoption of robots in the manufacturing industry, the mirror polishing processes still dependent on skilled labour. As a labour-intensive process, mirror polishing requires extensive number of man-hours to obtain high-quality surface finishing. Traditional automation techniques that rely on robot programming is an extremely tedious and time-consuming process. To automate the mirror polishing process and to eliminate the bottlenecks associated with traditional robot programming, we propose a simple yet robust mirror-polishing framework. In our framework, a simple graphical interface processes the 3D point cloud and generate the toolpath using the user selection. Subsequently, the generated toolpath executes in the real robot automatically through ROS. As our graphical interface is very intuitive and easy to use, it does not require skilled labour. Using the trials in Stainless steel (MS1) work pieces. Through preliminary validation, our framework obtained high-quality mirror surface finishing with desired geometric profile and roughness value of Ra 0.5 μm with a distribution of 0.1 μm (1σ).

Keywords: Robot toolpath generation, Robotic polishing, Mirror polishing

1 Introduction

As the final stage of the manufacturing pipeline, polishing is an extremely important process that improves the final quality, aesthetics and extends the lifespan of the component [1] . Due to its complexity, the mirror polishing process is predominantly carried out by highly skilled labour [2], which leads to long manufacturing cycle time, variabilities in output, need for reworks, etc. Hence, there is a great demand for automating the mirror polishing process and obtaining high-quality finishing. While the repeatable and low skilled tasks are easier to automate, specialized tasks such as robotic polishing require skilled labour for programming the robot, which is a bottleneck in the adoption of robots. This difficulty compounds in a high mix - low volume production setup that is becoming more common especially in the Small-Medium Enterprises (SME). Simplifying robot programming is an open research problem and is an active area of research [3]–[6]. In this paper, we present a simple polishing framework that can obtain high-quality surface finishing through an intuitive graphical user interface (GUI). The GUI that we developed can obtain the point cloud from the 3D scanner or CAD model, and automatically carry out semantic segmentation to cluster the part into different surfaces. The operator can select various surfaces in the GUI and generate the desired toolpath in real-time. Finally, the user can generate the robotic toolpath using the GUI and execute the robotic motion. The main contribution of this paper is our intuitive framework that can accomplish high-quality mirror polishing. The paper is organized as follows: in Section 2, we describe the methodologies of the framework, followed by the hardware setup and the trials are described in the Section 3. In the Section 4, we present our results and discussion points based on the results obtained.

2 Methodology

The proposed framework comprises data acquisition using Artec Eva 3D scanner, pre-processing, surface identification and toolpath generation, and finally, robotic execution as shown in Fig.1.a. The point cloud data of the component geometry, along with the work environment was first acquired using the 3D scanner. The data is pre-processed to remove noises and background information and the coordinate system of each point is transformed to align with the robot's tool coordinate point (TCP) by using 3D feature detectors. Once the pre-processing completes, the point cloud is segmented to identify the different surfaces in the 3D environment using the PCL library. Users can subsequently select the required surfaces and toolpath surface patterns such as Zigzag, Spiral, etc. intuitively by interfacing with the GUI as shown in Fig.1.b.

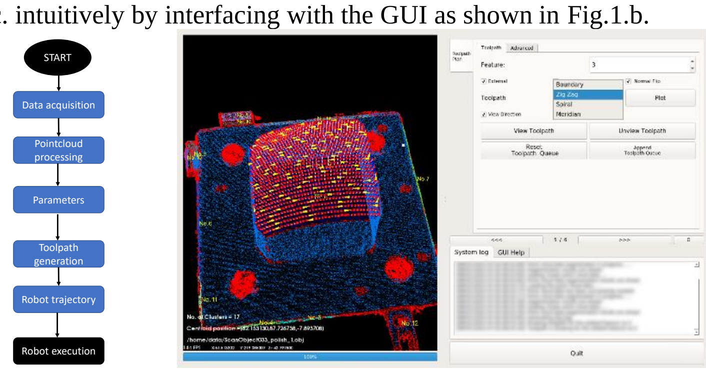

Fig. 1. a. System process flow b. Toolpath Generation GUI

Once the desired toolpath is generated, it is projected onto the 3D Cartesian system with normal directions on the component surface. Using the motion planner in ROS, the software computes for a via robot motion for the desired toolpath accounting for collision and pose viability. In addition, the operator can select multiple process parameters such as force, spindle speed, tool path recommender, feed rate, and the end-of-arm tools in the GUI. Thus, through the GUI, even unskilled labour can able to accomplish the entire toolpath generation pipeline from pre-processing to the robot execution without any knowledge of robots or programming.

3 Experimental setup and trials

The hardware setup consists of ABB 1200 robot, fixtures for fastening the work-coupons, ATI Delta F/T sensor, NSK Nakanishi spindle as shown in the Fig.2.a The ABB 1200 is a Six degree of freedom (DoF) industrial robot and is selected for the polishing trials due to its high accuracy. We have utilized an ATI Delta IP65 Multi-Axis Force/Torque Sensor system that measures all six components of force (Fx, Fy and Fz) and torques (Tx, Ty and Tz).

Fig. 2. a. Hardware setup b. Printed wavy and dome component

Trials on curved stainless steel (MS1) coupons were carried out to validate the capability of the framework. The coupons dimensions are 50 x 50 mm, printed on EOS powder bed machine, and cut using EDM wire cutting. The average initial roughness value is Ra 18 µm with 6.5 µm variance (1 σ) for the dome design, and 23 um with 7.9 um variance (1 σ) for the wavy design (see Fig.2.b). Mirror polish can only be obtained in multiple iterations by the using abrasives with gradual increase of the grit size. In total, we conducted a set of trials by varying the KPVs such as Force, Spindle speed and Feed rate with the variation as shown in the Table 1 below.

4 Results and Discussions

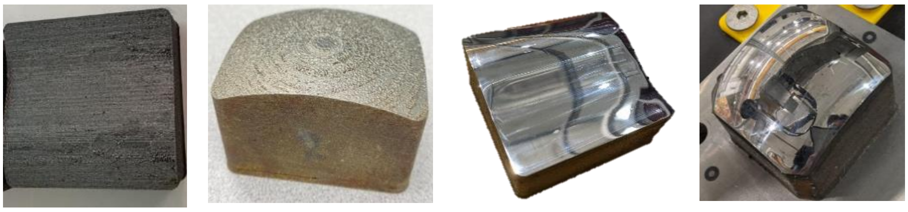

Fig.3. Input components and output of the mirror polishing

Visual qualitative analysis indicates a promising result with the wavy, and dome design. The images in Fig.3. shows the polishing result before (left) and after (right). This is a promising indication that polishing with our toolpath generation is able to achieve a mirror finish. Preliminary surface roughness analysis conducted with white light interferometry done on the dome component shows that the roughness has decreased from 18.68 µm, with 6.56 µm standard deviation throughout 6 different points on the surface, to 0.56 µm with 0.14 µm distribution throughout the entire surface. The preliminary result shows that the polishing process on raw additive manufacturing surface, with our automated toolpath generation shows a great promise.

5 Conclusion:

In this paper, we presented a novel toolpath generation framework for mirror polishing to mitigate the robot programming. The proposed framework is extremely suitable for SMEs that has low volume high mix product catalogue and cannot afford the time, cost associated with manual programming. Our preliminary trials on stainless steel coupons, indicates that the methodology is able to bring down the surface roughness of the dome coupon from 18.68 um with 6.5 um variance (1 σ) throughout, to a mirror finish, 0.56 μm with 0.14 um distribution (1 σ) throughout the surface.

Table 1. Details of the trials

Abrasive	Feedrate (mm/s)	Force (N)	Spindle Speed (rpm)	Iterations (#)
Grit 60	2	3	5000	4-14
Grit 150	2	5	5000	4
Mesh 200	2	10	6000	8
Mesh 1200	2	5	8000	4
Mesh 8000	2	5	8000	8-12

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