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Detection of workpiece shape deviations for tool path adaptation in robotic deburring systems

Alexander Kuss[a,*], Manuel Drust[a], Alexander Verl[b]

[a]*Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Nobelstrasse 12, 70569 Stuttgart, Germany*
[b]*Institute for Control Engineering of Machine Tools and Manufacturing Units ISW, University of Stuttgart, Seidenstrasse 36, 70174 Stuttgart, Germany*

* Corresponding author. Tel.: +49-711-970-1297; fax: +49-711-970-1008. *E-mail address:* alexander.kuss@ipa.fraunhofer.de

Abstract

Robotic systems have the potential to automate deburring processes along edges of arbitrarily shaped workpieces. The desired robot movement can be realized by proper trajectory planning using the computer-aided design (CAD) model of the manufactured workpiece. A fundamental problem is that geometric shape deviations between the nominal CAD model and the manufactured parts might be beyond acceptable limits for correct execution of the deburring process. This paper proposes a novel, easy to implement and practical approach to detect shape deviations of workpieces for automatic adaptation of robotic deburring processes. The approach only uses dimensional tolerance specifications of the manufactured part provided by the product design to derive possible variations of the workpiece geometry model. A matching process is performed between point clouds for each of the considered variants and a measured point cloud from the manufactured workpiece using an Iterative Closest Point (ICP) approach. Resulting point distances are used for evaluation of shape similarity between the compared point clouds. Finally, the most similar geometry model is identified for subsequent trajectory planning and workpiece localization. Experimental validation is performed by an industrial robot equipped with a stereo camera for shape sensing and a milling tool for subsequent execution of a deburring process. The results demonstrate the effectiveness and practicality of the proposed approach in industrial applications and an increased deburring quality.

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Keywords: Deburring; Industrial Robot System; Shape Deviation; CAD Model

1. Introduction

Robotic deburring systems based on machining processes have been investigated for several years to overcome quality and ergonomic problems of a manual process execution. Especially for large and complex workpieces, robots represent a flexible and cost-effective solution for an automated deburring process [1]. However, positioning or shape errors of the deburring workpiece can cause an incorrect process execution resulting in insufficient deburring quality and high forces on the robot end effector.

To overcome these drawbacks, extensive research has been done on active control of the contact forces between deburring tool and workpiece to adapt the tool path [2], [3], [4]. Here, the deburring quality however depends on the dynamic behaviour of the complete robot cell and on shape deviations along the deburring contour, like e.g. varying burr size. Other approaches try to generate the tool path without prior knowledge about the workpiece geometry model by using teaching methods [5], [6], [7], computer vision [8], [9], [10] or combined methods [11]. The deburring contour is reconstructed from the real workpiece geometry so that there is no influence of position and shape errors on the deburring quality. However, for complex workpiece geometries, teaching is a time-consuming procedure and surface or contour reconstruction needs complex computations.

Other research focuses on a precise object localization to adapt the robot tool-path [1], [12]. In this case, the workpiece is only roughly positioned within the robot workspace and can be registered using sensor data and its nominal CAD-model. The most popular approach for solving the registration problem is the Iterative Closest Point (ICP) algorithm introduced by Besl and McKay [13]. It iteratively minimizes the sum of squared distances between points in a dataset and the closest points in a model to compute the rigid transformation for the alignment of the two datasets. The perfomance of the ICP algorithm for non-deformed datasets is analysed in [14]. Many variants of the ICP approach exist, e.g. Segal et al., who propose a generalization of the ICP algorithm that also takes into account the locally planar surface structure of both datasets to increase robustness in the case of measurement noise and outliers [15]. However, inaccuracies of upstream manufacturing processes, like e.g. milling or drilling, can result in geomet-

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ric shape deviations between nominal CAD model and sensor data of the manufactured part resulting in inaccuracies of the registration process. Considering high-precision deburring of contours, these deviations are not negligible and should be included in the registration procedure.

The precise registration of deformed parts based on ICP methods is widely discussed in the field of Computer Aided Inspection (CAI). A method for extending the ICP algorithm to align a point cloud with a CAD model based on the original surface model and instantaneous kinematics is proposed in [16]. An efficient ICP algorithm to register point clouds with a surface mesh model and a data structure to combine nearest nodes and topological neighbour facets is proposed in [17]. A modified ICP algorithm for automated shape inspection based on region-based triangulation for capturing of part deviations is discussed in [18]. However, these approaches only focus on the analysis of shape deviations for quality evaluation but do not create an updated product model representing the actual workpiece shape.

Registering of deformable objects can be achieved by extended shape deformation models with differential-geometric constraints [19], [20], [21], [22], with projection functions [23], [24] or by integration of the physical behaviour with finite element methods (FEM) [25], [26]. The drawback of these methods however lies in the complexity of these models and the problems that arise in industrial applications in terms of fast and robust integration.

In this paper, a novel, easy to implement and practical approach is proposed to detect shape deviations of workpieces for automatic adaptation of robotic deburring processes. The approach only uses dimensional tolerance specifications of the manufactured part provided by the product design and a matching process based on the generalized ICP algorithm by [15]. This contribution is structured as follows: Chapter 2 describes the approach for detection of workpiece shape deviations to adapt the tool path in robotic deburring processes. In Chapter 3 implementation details are presented and possible influences on a correct detection of shape deviations are analyzed. In Chapter 4 the developed approach is validated by a virtual test case and by experiments on a real robotic deburring process. Finally conclusions are presented in Chapter 5.

2. Approach

The proposed approach focuses on the detection of shape deviations between nominal CAD model and 3D sensor data of a manufactured part to adapt the trajectory planning of the tool path along a workpiece edge contour. Fig. 1 shows the setup of a robotic deburring system equipped with deburring tool and 3D sensor and the influence of workpiece shape deviations on the deburring contour and the object localization process.

The concept of our approach is shown in Fig. 2. In a first step, a set of reference CAD models is generated representing variations of the nominal product geometry. To derive these samples from the nominal CAD model additional information about manufacturing tolerances is used. This information is typically provided by the technical drawings of a product. It describes the acceptable deviations between the nominal product design and the workpiece geometry after a manufacturing process to guarantee the correct product function. These tolerances

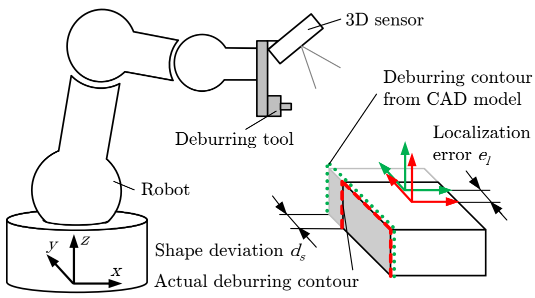

Fig. 1. Influence of workpiece shape deviations on deburring contour and object localization.

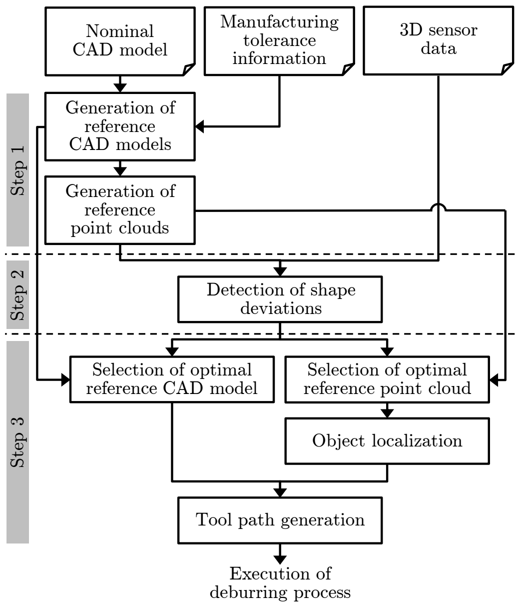

Fig. 2. Concept for detection of shape deviations for tool path adaptation in robotic deburring.

however might be beyond acceptable limits for the correct execution of an automated deburring process using a CAD-based trajectory planning. In the presented approach, we use information about dimensional tolerances to generate possible variations of the workpiece geometry model like shown in Fig. 3. For a given nominal dimension w, the upper and lower tolerance values t_u and t_l can be used to generate different dimension variations w_i and hence different geometry models:

$$w_i = w + t_l + \frac{t_u - t_l}{n-1} \cdot (i-1) \tag{1}$$

with $i = 1, ..., n$ and $n \geq 2$. The generation of reference CAD models can be performed manually or automatically if the tolerance information is added to the CAD model during the design phase. From the reference CAD models, a set of related reference point clouds is derived. Before each specific deburring task, it has to be identified which tolerances have a possible influence on the geometry of the deburring contour. As the calculation time for the deviation detection increases for the number of reference models, the quantity of reference models should be