Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnline CONFERENCE PAPER ARCHIVE

IFAC-PapersOnLine 49-21 (2016) 301–308

Robust Surface Abnormality Detection for a Robotic Inspection System

Sara Sharifzadeh, Istvan Biro, Niels Lohse, Peter Kinnell

EPSRC Centre for Innovative Manufacturing in Intelligent Automation
Wolfson School of Mechanical, Electrical and Manufacturing Engineering
Loughborough University

UK, (Tel: +44 (0)1509 227146, E-mail: P.Kinnell@lboro.ac.uk)

Abstract: The detection of surface abnormalities on large complex parts represents a significant automation challenge. This is particularly true when surfaces are large (multiple square metres) but abnormalities are small (less than one mm square), and the surfaces of interest are not simple flat planes. One possible solution is to use a robot-mounted laser line scanner, which can acquire fast surface measurements from large complex geometries. The problem with this approach is that the collected data may vary in quality, and this makes it difficult to achieve accurate and reliable inspection. In this paper a strategy for abnormality detection on highly curved Aluminum surfaces, using surface data obtained by a robot-mounted laser scanner, is presented. Using the laser scanner, data is collected from surfaces containing abnormalities, in the form of surface dents or bumps, of approximately one millimeter in diameter. To examine the effect of scan conditions on abnormality detection, two different curved test surfaces are used, and in addition the lateral spacing of laser scans was also varied. These variables were considered because they influence the distribution of points, in the point cloud (PC), that represent an abnormality. The proposed analysis consists of three main steps. First, a pre-processing step consisting of a fine smoothing procedure followed by a global noise analysis is carried out. Second, an abnormality classifier is trained based on a set of predefined surface abnormalities. Third, the trained classifier is used on suspicious areas of the surface in a general unsupervised thresholding step. This step saves computational time as it avoids analyzing every surface data point. Experimental results show that, the proposed technique can successfully find all present abnormalities for both training and test sets with minor false positives and no false negatives.

Keywords: Automatic abnormality detection, Point Cloud analysis, Feature extraction, Feature classification, Adaptive smoothing, surface inspection.

1. INTRODUCTION

In many manufacturing applications, surface inspection is a critical part of the manufacturing process. For components that are large and highly sculptured, reliably searching for small surface abnormalities represents a difficult, time consuming and costly task. The complexity of the task often means this type of inspection is performed only by human experts; however, due to limitations in accuracy, consistency, speed and reliability there is a strong motivation to automate these inspection tasks. One possible solution is to use a robot-mounted laser line scanner. Laser line scanners are fast contactless sensors that can be used for the measurement and inspection of surfaces. The low weight and compact size of laser line scanners allow them to be integrated with industrial robots to form a flexible inspection system.

A significant quantity research has been conducted on the use of laser scanners for automatic inspection in manufacturing applications. One group of strategies for surface abnormality detection are based on the use of an existing ideal CAD (computer aided design) model. (Newman & Jain, 1995) proposed an automatic visual inspection system for abnormality detection using range images and computer-aided design (CAD) models. An alternative approach is presented by (Lilienblum, Albrecht, Calow, & Michaelis, 2000) about the automatic detection of small dents in car bodies by training an artificial neural network (ANN) using measurements of several master work pieces; (Hong-Seok & Mani, 2014; Prieto et al., 2000; Prieto, Redarce, Lepage, & Boulanger, 2002) are other examples of this approach. Other techniques that are independent of a CAD model include (Schall Oliver, Belyaev Alexander, 2005), where a noise removal method was proposed to detect simple deformations in a point cloud (PC) that resembles outliers in a smooth surface. However, the parameter selection for this method is not intuitive, and it is not appropriate when the deformations do not resemble outliers. In (H. Woo, E. Kang, Semyung Wang, 2002), a technique for PC segmentation based on

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.572

octree structures and recursive subdivision of the volume of a 3D mesh was introduced. The subdivision was performed based on thresholding the standard deviation of surface normal. A problem with this approach is that the threshold must be selected appropriately, to exclude the expected surface form and roughness (including measurement noise), but include the surface features that must be detected. Similarly, (Yogeswaran & Payeur, 2012) combined enhanced octree-based feature extraction with segmentation and classification. Deviation in surface normal was also used as point weights in (Pauly, Keiser, & Gross, 2003). At different scales, different local neighbourhood sizes were used to compute point weights, and the corresponding weights to strong persistent surface features exceeded a threshold across multiple scales. This method is appropriate if the structure of the features allows quantification based on scale-dependant variation and the choice of an appropriate threshold is not an issue.

In this paper, the problem of abnormality detection, when using a robot mounted 2D laser scanner is considered. This application provides challenging PCs that contain variable noise and scan resolution due to object surface curvature and the relative position of the scanner from the object. To investigate this problem, two common scenarios are considered; high resolution and high line space variability (H-H) and low resolution but low line space variability (L-L). The scan line spacing in the PC of the two cases is firstly different due to the robot controlled scan steps, but also, the object curvature and the robot position causes geometrically dependent changes in line spacing. Due to these issues, the measured set of points that represents a given surface abnormality is not always consistent. In this paper a robust defect detection strategy, that is able to cope with inconsistent point spacing, is presented. The proposed method consists of a pre-processing step, a feature extraction and training step and finally a test step. The main contribution of this work is addressing the variable quality of data collected within a single PC. This is done by detecting and excluding the local regions of the PC with excessively high levels of noise, but noting the locations for follow-up scans or inspections. Then, where possible, adaptive filtering of local patches before feature extraction is used to reduce the number of false positives from lower quality data. Once suitable data is identified a defined set of structural and statistical features capable to deal with typical line spacing variations are proposed.

The paper is organized as follows; Section 2 describes the equipment setup used for this work. Section 3 is about PC analysis techniques. The experimental results are presented in section 4 and finally there is a discussion and conclusion in sections 5 and 6 respectively.

2. DATA AQUISITION

2.1 Laser Scanner

A custom made laser scanner consisting of a Flexpoint MVnano, 450nm, 1mW, 30° fan angle, focusable laser and a Basler acA1600-20gm GigE camera was used. Choosing a triangulation angle of 35° and a stand-off distance of 110mm, the scanner resolution is calculated to be 84µm/pixel (X direction, along the laser line) and 146µm/pixel (Z direction, depth – this can be substantially improved by fitting across the imaged laser line width, achieving sub-pixel resolution, as done by Halcon at the time of PC extraction – see Data sets in section 2.2). This laser scanner was mounted on a Fanuc LR Mate 200 iC industrial robot arm, driven by a R-30/A Mate controller (Fig. 1). Moving the scanner with the robot arm over an object allowed us to scan the object, with a resolution in Y direction defined only by the robot motion. The robot path was chosen such that the laser scanner should always be normal and at the same stand-off distance to the currently investigated part of the target object. This allowed us to scan large objects, having substantial curvature and height variation, without losing laser scanner data due to exceeding the working distance (field of depth) of the scanner or due to signal loss occurring at high angles (attributed to light scattering and back-reflection). However, this path was generated from the assumed (estimated) target geometry, obtained either via few sample points (interpolated) or via estimated surface modelling (mathematical function). As a consequence, the scanning path may not always accurately follow the object surface, resulting in sub-optimal data quality, especially for highly irregular surfaces. Additionally, the scan was performed with fixed step size in the Y direction (dY), resulting in potentially varying scan line spacing L_i on a curved object (see Fig.2, constant dY, varying L_i).

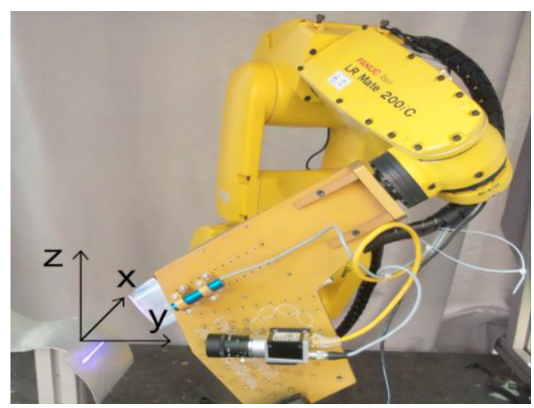

Fig. 1. The laser scanner setup mounted on a robot arm

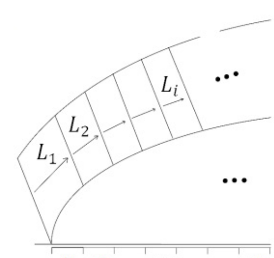

Fig. 2. The inconsistent line spacing due to robot path following.

2.2 Data Sets

Two pieces of aluminium were used for test surfaces; one was formed into a curved shape and was scanned with lower resolution resulting from a robot step size of 0.5 mm (L-L), and the second has slightly higher curvature and was scanned