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Image based quality control of free-form profiles in automatic cutting processes

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Abstract

In manufacturing, Machine Vision Systems are increasingly being used for their ability to collect information pertaining to the quality of a product in real time. When physical profiles are collected from images captured by Machine Vision Systems, the number and locations of the observed points can change from one item to another. The research is focused on non-parametric control charts for statistical monitoring of free-form profiles with different number and locations of observed points. The proposed method consists in extracting the shape of the monitored profile from images and in comparing it to a baseline model taken as reference. A new discrepancy metric, which consists in computing the deviation area of the monitored profile from the baseline model, is proposed. Two control charting procedures, based on univariate and a multivariate statistics are illustrated and validated through computer simulations. The automatic cutting process in leather part manufacturing (e.g. furniture, automotive interior, apparel) is the reference context.

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1. Introduction

Machine Vision Systems (MVSs) are increasingly being used in manufacturing since they can capture information pertaining the quality of the manufactured parts in real time. A typical MVS usually consists of image capturing devices (e.g. camera or vision sensors) to provide images, and computer systems to process/analyse the acquired images. When physical profile of a manufactured part is collected from images, the number and the locations of the observed points can change from one item to another. The integration of statistical process control (SPC) principles with imaging systems provides an opportunity for real time detection of out-of-control process conditions and for improving current MVS inspection implementation.

In the SPC literature, different methods for profile monitoring have been proposed to understand and to check over time the stability of the relationship between a response and one or more argument variables. Noorossana et al. [1] provide an overview of the SPC literature involving profiles. In this field, the quality of free-form profiles is an emerging area of research.

Profile monitoring methods can be divided into parametric and non-parametric approaches. In the parametric approaches the response and argument variables are assumed to satisfy a known model and the charting statistics are then developed based on the estimated model parameters from the data [2–6]. In the non-parametric methods a baseline profile is taken as reference and charting statistics are based on metrics that reflect the discrepancies of the observed profiles from the baseline one. The baseline profile may be a theoretical profile (e.g. the ideal profile) or may be estimated through non-parametric fitting methods [7–11].

Most studies in the literature assumed that the locations of the observed points on each profile, i.e. the values of argument variables for profile monitoring, are fixed for all the observed profiles. In some applications, e.g. MVS-based application, this assumption may be not valid and makes the profile monitoring problem more difficult [12–14].

The objective of this paper is to propose a new approach for statistical monitoring of free-form profiles acquired by a

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MVS. In particular, two non-parametric approaches, a univariate approach and a multivariate one, for statistical monitoring of free-form profiles with different argument variables are proposed. Our approaches are based on images provided by a MVS, consequently they may be suitable for cases where the measured points are not specified or may not be chosen before process monitoring. The focus is on the 'shape' property of profiles and our approaches are suited also for profiles not easily specified by a functional relationship between a response variable and one or more argument variables (e.g. the relationship between *y* and *x* in the model $y = f(x)$). In order to compute the form error between produced profiles and baseline model, a new discrepancy metric based on the deviation area between them is proposed.

A specific industrial context concerning monitoring of the leather cutting process in leather sofa production is taken as reference. In this context, a non-rigid material, i.e. the leather hide, is cut into parts, which may assume shapes different from the baseline. Traditionally, visual inspection and quality control of cut parts were performed by trained workers. Since human workers are incapable of inspecting multiple parts simultaneously, susceptible to fatigue, MVS have been found more efficient for inspection and quality control of cut parts. In this context, an efficient method for automatically monitoring the profile of the cut parts is needed.

Section 2 presents the proposed non-parametric monitoring approaches for free-form profiles acquired by a MVS. Section 3 reports the performance evaluation and discussion of the results obtained through simulated test cases. Conclusions and final remarks are discussed in Section 4.

2. The profile monitoring method

The profile monitoring method is based on three main steps:

- Step 1 - *Image analysis and processing*: a bitmap image of the real profile is acquired by the MVS. The bitmap image is transformed by a computer system through a combined vectorization/contour extraction procedure. For each produced part, the output of this step is a vector graphic in which a geometrical primitive, namely, a two-dimensional polygonal curve, describes the part shape. Each polygonal curve is composed by a set of *n* vertices $v_1, \ldots, v_n$ in clockwise order and defined by the line segments connecting $v_i, \ldots, v_{i+1}$ for $i = 1, \ldots, n$. Each polygonal curve may be closed, that is vertices v_i and v_n may be also connected by a line segment. The number and locations of vertices on each polygonal curve may vary from a profile to profile. Given a closed polygonal curve (hereinafter simply referred to as profile), the polygon associated to it is the set of two dimensional points in the plane inside such a curve, i.e. the set of points to the right as one walks clockwise around the curve. Let ∂D and D represent respectively the profile and the polygon associated to it, with reference to the baseline model. Similarly, let ∂P_j and P_j represent respectively the profile and the polygon associated to it, with reference to the produced part of index j.
- Step 2 - *Registration*: a registration procedure is implemented to properly align it to the baseline polygonal curve. In fact, a registration step is needed in order to correctly match the actual profile to the baseline one, since each produced part may be randomly positioned on the cutting table, i.e. the image-plane, while the camera of the MVS is fixed above the cutting table. In many cutting processes, as the reference one, the baseline polygonal curve is known as it corresponds to the ideal profile for cutting. For such a profile, a model in a standard CAD (Computer Aided Design) file format is considered available from the designing process of that part. A simple way to register two curves involves the use of a Procrustes-based method [15]. In this work, a Generalized Procrustes Analysis [15,16] method was implemented in order to align the profile ∂P_j to the baseline model ∂D. To this aim, *l* landmarks were taken as equally spaced points in clockwise order along the two polygonal curves.
- Step 3 - *Matching computation and control chart:* after registration, a specific procedure is carried out in order to quantify the discrepancies between ∂D and ∂P_j and to monitor it through control charting. In detail, we proposed two approaches, the first considers the entire profile and is based on a univariate control chart; the second divides each profiles in different segments and is based on a multivariate control chart. The proposed matching computation procedures are non-parametric and are based on computing the deviation area between the polygon P_j associated to the real profile ∂P_j and the polygon D associated to the baseline model D. Details of the two proposed approaches are detailed in the following subsections.

2.1. Univariate approach

Let *T* be the profile tolerance region required (for example, in the reference case study *T* is known and provided by the assembling process). *T* corresponds to the δ-annulus of the profile ∂D, i.e. the closed region defined by all points in the plane at distance δ from ∂D. In general, the value of δ is not constant but it changes along the baseline model. An example of tolerance region T with not-constant δ-annulus is graphically depicted by the striped region in Fig. 1(a). Given D and P_j, let $(D \,\Delta\, P_j)$ represent the *symmetric difference* between D and P_j. Mathematically, this symmetric difference is equal to $(D \,\Delta\, P_j) = (D \cup P_j) \setminus (D \cap P_j)$ i.e. the union of D and P_j, minus their intersection. The region $(D \,\Delta\, P_j)$ is depicted by dark grey region in Fig. 1(b). In order to implement profile monitoring, a univariate control chart is used. The monitored statistic for the j-th produced profile P_j is given by: