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A customer oriented methodology for reverse engineering software selection in the computer aided inspection scenario

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ABSTRACT

Industrial metrology of mechanical components has been facing a gradual revolution recently through the application of contactless 3D scanners in computer aided inspection. Following the industrial trend and request, new modules for quality control activities on scan data have been integrated in reverse engineering software packages.

The aim of this work is to propose a structured methodology for the screening and comparison of reverse engineering programs that are suitable for inspection activities. Specific features that distinguish this kind of software are described and detailed. Six different commercial software are tested using invariant scan data from a reference part that was specifically designed for inspection purposes.

The selected packages are then compared by means of a multicriteria fuzzy AHP analysis that considers quantitative and qualitative criteria. The criteria were grouped into three categories related with the user, the vendor and the technical requirements. Two different scenarios are considered for the choice of the software that best suits to computer aided inspection activities.

1. Introduction

Inspection is a fundamental activity of modern manufacturing because complex specifications have to be met to assure the quality of products [1]. The term computer aided inspection (CAI) commonly refers to automated inspection among other computer aided applications (CAx) that are extensively used in manufacturing industries. Up to some years ago the computer aided inspection of mechanical parts involved the use of metrology software coupled with a coordinate measuring machine (CMM).

Even if the resolution of 3D scanners is not yet comparable to that of CMMs, nowadays contactless 3D digitizing devices can provide fast measurements with high point density (hundreds of thousands or millions of points per second) for those parts whose tolerances are larger by few thousandths of a millimeter. Therefore they are preferred to pointwise measuring machines when complex free-form shapes or large parts have to be inspected [2].

Programming a CMM for measurements of a physical part can be slow and tedious if compared with the use of latest portable optical 3D scanners. The traditional measuring method is time consuming, and it often requires customized fixtures to support complex parts during measurements [3–7].

On any part of a non-rigid material, sheet metal or plastics, contact measurements are hopelessly impractical. In addition to this, when using an optical scanner there is no physical size limitation for the part being inspected, because the scanning device can be moved around the part. If needed, a component can be digitized twice, as an individual part and as a part of an assembly, to analyze the deformations caused by assembling.

Another advantage is off-line inspection from saved scan data. If some new features have to be evaluated for any reason on an inspected part after some time, there is no need to repeat the measurement of the piece. After loading the point cloud of the scanned part, adding some evaluations on its geometries inside the inspection software is rather fast and easy. The inspection of the same features by a CMM would require fixing the part on the machine once again, aligning it and then measuring it online.

Recent improvements in the performances of 3D optical scanners have extended the application field of reverse engineering (RE) techniques to quality control. Traditional metrology software were born to manage pointwise measurements carried out by CMMs together with the computation of dimensional deviation and form tolerances for simple classic geometries (i.e., planes, cylinders, spheres, cones, etc.). On the contrary reverse engineering software

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were born to generate a virtual 3D model (i.e., CAD model) from the scan data of a physical object.

As soon as the metrological characteristics of 3D optical scanner became interesting for inspection applications of a large number of mechanical components, RE software were equipped with specific modules for CAI activities. These modules were developed to allow the full use of optical scanners for inspection purposes. They deal with significantly more information about the part than what is provided by traditional pointwise measurements. They are based on complex mathematics and genetic algorithms to manage massive amounts of data collected by contactless scanners allowing for the inspection of sculptured freeform surfaces and complex geometries. Reverse engineering software can handle the dense data from 3D scanners and critical scattered points from CMM.

There are plenty of RE software packages for sale on the market. They are similar, but each one has its own characteristics and advantages. The innovative aspect of our research is the proposal of a structured methodology to screen and compare several inspection software with respect to quality control suitability. The proposed methodology is applied to six commercial RE software packages that were selected for their worldwide diffusion.

In the first step of this study, the features required by a generic CAI software for contactless inspection are identified and divided into two groups: the basic features and the advanced ones. The basic features are those that a CAI software should contain as an essential requirement. Other features that can be available, but are not imperative, where addressed as advanced features. The six selected RE software were then analyzed for detecting the presence of the basic features and the advanced ones, as described at the end of the second section.

In the second step, a set of features are selected and the features were tested for each software during the inspection of a reference part that was specifically designed for benchmarking activities [8]. The tests are carried out on fixed and invariable scan data, so that the performance of the tests is dependent on the software only, thus allowing for a rigorous comparison. The test is presented in the third section.

Finally the results of the previous two steps are included in a multicriteria comparison of the selected RE software packages. The multicriteria comparison is based on the fuzzy AHP (analytic hierarchy process) method, which was often used in the literature for comparing software packages [9–18]. Quantitative and qualitative criteria are selected and divided in three categories with respect to the user, the vendor and the technical requirements. This study considers two different scenarios that are characterised by two contrasting requirements of small and medium industries, the cost and the performance of the inspection software, respectively. The fourth section is dedicated to the AHP analysis, which leads to the ranking of the compared software packages.

2. Features of a RE software for CAI activities

The CAI process from scan data involves the comparison of one point cloud with the theoretical CAD model or STL (solid to layer) model or a reference point cloud. The inspection process is outlined in Fig. 1. Dimensional measurements can be done directly from scan data on the 3D model or on 2D cross sections. Geometric tolerances can be also evaluated after the definition of reference features to which the tolerances are related.

Before the comparative analysis, the compared objects have to be aligned one to another. After the alignment, the scan data and the reference model can be compared for deviations. The results of the comparative analysis are often displayed as colored 3D maps or colored vectors in the case of 2D cross sections. At the end of the analysis, the CAI process provides automated reporting by graphical documents and tables.

The features that characterize a CAI software are classified in the following. They are divided into categories according to the functionalities related to the main steps of the inspection process that are shown in Fig. 1.

2.1. Alignment or registration

The alignment of an inspected 3D model to the reference one is carried out by computing the 3D rigid transformation to be applied to the first model to bring it into a common coordinate frame with the other. The alignment operation is also called registration and aims at matching the two models. The computation results in finding a roto-translation matrix to be applied to the first model in order to minimize its distance to the other. The selected point cloud is rotated and translated so that the mean square distance between its points and the ones of the reference point cloud is minimized or kept within a specified tolerance. The iterative closest point (ICP) algorithm and its variations are the most used ones for the minimization [19–51].

RE commercial software packages are able to perform registering operations by manual, semi-automatic or automatic procedures. In the manual operation, the human operator has to select at least three couples of homologous points on the two models and the ICP algorithm is applied to the selected couples only. The point couples constitute a system of reference points, that is renowned as RPS (Reference Point System). If the alignment operation is semi-automatic, the operator has to select at least three couples of homologous points for a rough registering operation, then the software refines the computation considering all the points of the two models. In the case of the automatic procedure, the software computes the transformation automatically without requiring any human interaction.

In quality control of mechanical components, the requirements in terms of features' location and tolerances are set by the designer with respect to a unique fixed reference system, that has to be

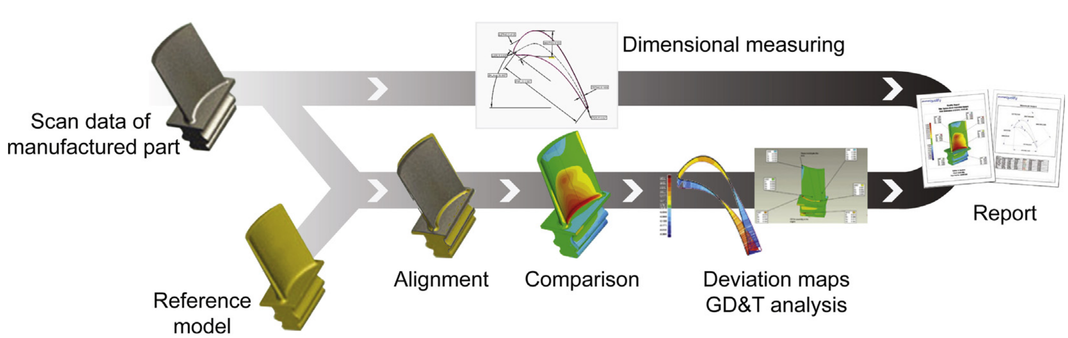

Fig. 1. Outline of the CAI process from scan data.