ABSTRACT
Dimensional precision of manufactured parts is nowadays of paramount importance in many applications including shipbuilding, automotive and aerospace industries. The design of a new part is many times carried out using reverse engineering techniques that is accomplished by the measurement of a prototype, the Computer Aided Design (CAD) modeling and the manufacturing of dies or parts. There are some types of surfaces as freeform ones that may present details that may demand two or more measuring instruments to be measured, as laser scanner (non-contact device) and a conventional Coordinate Measuring Machine (CMM, contact probe device). Data fusion technique is then required to build the CAD model and represent the complete surface with improved accuracy in relation to the single instrument measurement. The most used CAD modeling technique applies NURBS (Non-Uniform Rational B-Splines) fitting and the parameters like the number of control points and knots and the degree of the curve affects the accuracy of the modeled surface. This paper addresses the problem of merging data from two different types of CMMs and discusses the sources of uncertainty involved in agreement with the recommendations of the ISO GUM.

Keywords: freeform surfaces, uncertainty, inspection

INTRODUCTION
Data fusion can be defined as the process of combining results from multiple information sources (sensors) so that each used resource provides the information necessary for the metrological study is as clear and real the measurement obtained, especially in the implementation of CAD models. This means that the measurement results obtained can be determined close to the real model [1].

Recently, there have appeared some efforts in literature showing case studies about this subject. Zhao et al. (2009) developed a multi-sensor integration system to measure with a laser scanner, a touch probe and a chromatic confocal sensor adapted on a CMM. The authors described two subsystems required, data acquisition and geometry processing. Data acquisition was based on physical integration of the sensors and optimization of the measuring strategy. The geometry processing was carried out fitting polyhedral surfaces to data points. The application was inserted in the Product Lifecycle Management (PLM) context [2].
Weckenmann et al. (2009) applied data fusion to obtain accurate and more reliable information about parts based on several or multiples measurements with more than two sensors. The authors showed applications as the fusion of images, tactile and optical coordinate metrology, computed tomography and as scanning probe microscopes. The main operations involved in data fusion are pre-processing, registration, optimization and data fusion. Registration involves the alignment and transformation of data to a common coordinate system.

The fusion process involves fitting data to models and estimation, inference, fuzzy or neural networks may be used [1]. In the case of freeform surfaces, the nominal geometry is generally defined by the CAD model [3]. When dealing with freeform surfaces, parametric surface representations are generally used and Non-Uniform Rational B-Splines (NURBS) is often used to fit measurement data.

When expressing the measurement result of a physical quantity, the quality of this result is indicated by a quantitative evaluation of the errors. This evaluation is required to verify the suitability of the part when comparing to the reference values given in specifications and standards and it is accomplished by uncertainty determination that follows the recommendations of the ISO GUM [4]. The combined standard and expanded measurement uncertainty are determined taking into account all sources of uncertainty [4].
The combined uncertainty is determining starting from the knowledge of all contributing sources that are categorized as type A or type B standard uncertainties. A mathematical model representing the measurement quantity is established to relate all contributing error sources. The method defined by ISO GUM [4] requires the application of propagation of uncertainties to the expression. This method has some complication when the mathematical model in non-linear or complex and application of Monte Carlo simulation is recommended [5].

**EXPERIMENTAL STUDY AND RESULTS**

An application was carried out to evaluate the process of data fusion beginning with the measurement of a freeform surface. Thus, a small runner (Fig. 1) was measured with two Coordinate Measuring Machines (CMMs), an Articulated Arm CMM (Romer Arm 100) and a Cantilever CMM (Mitutoyo QM-353). Twenty-one lines were scratched over runner surface and ten points were determined in each line with both CMMs. Data points were stored in IGES format and the CAD models were fitted using the software Rhinoceros. The data points and fitted curves are presented in figure 2, where points in green and red corresponds to the Cantilever and Articulated Arm CMM, respectively.

![FIGURE 1. Runner used to perform measurements.](image)

![FIGURE 2. Data from measurement with Cantilever CMM (red) and AACMM (green).](image)

An analysis of the deviations between data points and fitted surface was performed and the results are presented in Table 1. It was observed an increase in standard deviation with fused data (III), above the expected from single standard deviations (I and II).

<table>
<thead>
<tr>
<th>Number of points</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.038</td>
<td>0.126</td>
<td>0.608</td>
</tr>
<tr>
<td>Median</td>
<td>0.016</td>
<td>0.066</td>
<td>0.537</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.061</td>
<td>0.141</td>
<td>0.402</td>
</tr>
</tbody>
</table>

As a first approximation, the combined standard uncertainty of data points was determined as a function of the CMM used (u\(_{\text{CMM}}\)) and the standard deviation of data points in respect to fitted surface (u\(_{\text{fit}}\)), according to the equation 1.

$$u_c = \sqrt{\frac{1}{u_{\text{fit}}^2} + u_{\text{CMM}}^2}$$

The results are presented in Table 2.

<table>
<thead>
<tr>
<th>combined uncertainty (mm)</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.003</td>
<td>0.010</td>
<td>0.033</td>
<td></td>
</tr>
</tbody>
</table>

**REFERENCES**


