Inspection of 3D Deformable Parts Using Radial Basis Functions

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ABSTRACT

In industry, one of the most common schemes to perform automated inspection tasks consists of matching a design represented by a 3D CAD model with 3D data measured by geometric sensors such as laser scanner or industrial CT. To carry out this comparison it is necessary to first align or register both the CAD model and the part 3D measurements. Usually, the part to be inspected can be considered to be rigid where a simple rigid body transformation is enough to achieve alignment with the CAD model. However, modern manufactured parts are becoming more and more flexible due to new materials such as composites. Traditional inspection system requires in this case that the part have to be fixed in place using clamps. This process is time-consuming and difficult to automate. What is necessary is an inspection system capable of applying to the CAD model a general transformation that includes the deformation of a part. In this work, we propose the use of radial basis functions (RBFs) to apply a non-rigid transformation to the model to represent deformation. The new approach is evaluated on several models and compared to Finite Elements Model.

Keywords: radial basis functions, deformable models, surface inspection

1. INTRODUCTION

Given the demand for high-quality parts in industry, inspection has become a key factor for the success of companies dedicated to the production of parts in different industrial sectors, like in the aeronautical and the automotive industries, among others[1]. In many industries, there are currently automated systems capable of performing the inspection of industrial parts with high accuracy, efficiency, and with great flexibility to adapt to different types of manufacturing processes. But in many cases the automation of these inspection systems is not working so well. Although there are very precise measurement devices such as coordinate measuring machines, many of these systems are neither very efficient nor versatile, and they are usually designed for specific manufacturing processes[2,3]. In most cases, the inspection time required by such systems is significantly higher than the rest of manufacturing processes, making it impossible to be used in an online process. In addition, in most inspection systems it is assumed that the objects under inspection have a specific geometric CAD model is rigid. There are, however, many types of industrial parts which, due to its structure and composition, have a remarkable flexibility making it impossible to inspect until they are completely assembled. Currently, in order to perform the inspection of such parts, it is necessary to fix them in a mechanical support call a ”jig”, as if they were actually assembled. Following this time consuming process, traditional inspection can then be used to perform tolerance verification[4].

Surprisingly, the literature on inspection of deformable parts is not very large[5]. Most inspection systems do the tolerance analysis by comparing the CAD model against the data obtained from the 3D sensor measurements of the actual part, which is considered a rigid object[6-8]. Zhang et al.[9] proposed a method for the reconstruction and inspection of deformable sheet metal parts. In this system, photogrammetric techniques based on sequences of intensity images is used to measure in 3D each part surface. Both, initial reconstruction and inspection use a CAD model to represent the part at nominal position and at its deformed state. Kim[10] presented a system to examine defects in deformable cylindrical plugs. This system uses intensity images and a pyramidal array of mirrors to get four points of view and avoid occlusion problems. The purpose of this system is to calculate the deformations and the misalignments in an assembly to determine

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the appropriate compensation for parts coupling. Weckenmann et al.[4] proposed a 3D visual inspection for non-rigid laminated parts. This system uses laser triangulation for the acquisition of surface data. The system then generates a triangulated, smoothed, and optimized model of the part surface, and then makes virtual compensation of deformation using a finite element method. From this virtual deformation the part is then inspected for tolerance evaluation. That paper is the closest work to the one presented here.

Although the finite element method (FEM) gives us an accurate approach to real deformation provided the material properties and a detailed geometrical model of the piece, it is computationally expensive[11]. On the other hand RBFs are well known as interpolation functions used to approach surface deformation starting from a reduced set of points whose displacements are known beforehand[12]. For inspection purposes, the set of assembly constraints of the part constitutes the control points of the RBF system. Motivated by the advantages of the RBF interpolation, like smoothness and meshless, we propose a novel approach to the problem of inspection of deformable parts that regards the use of a RBF system to get a better alignment between the data and the CAD models. We evaluate this approach on deformed pieces and compare the results to FEM .

This paper is organized as follows. The next section presents the mathematical formulation. Section 3 describes the proposed approach. Section 4 shows and discusses the results of the experiments, and the last section presents our conclusions and future work.

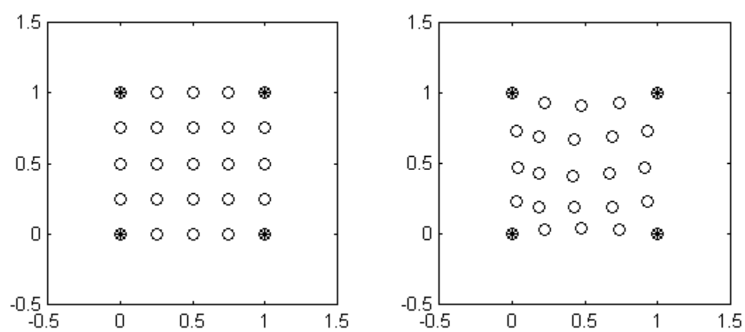
2. BACKGROUND

The RBFs are functions of the form

$$F(p) = \sum_i C_i R(|p-p_i|) , \tag{1}$$

where the base functions $R(|\bullet|)$ are functions whose values depend only on the distance to reference points p_i, called centers or control points, and C_i are constants weights of a basis functions[13]. Usually, the norm $|\bullet|$ is taken as the Euclidean distance.

The transformation given by Equation 1 is not practical for our case because it produces a distortion of the models, even in the event that the control points do not change their position. Figure 1 shows this effect on a two-dimensional grid.



(a) Square grid with fixed corners

(b) Deformed grid

Figure 1. 2D grid deformation by using Equation 1.

A more general expression that reduces this effect is the one which considers an additional term, which corresponds to a rigid transformation[14], namely

$$F(p) = \sum_i C_i R(|p-p_i|) + Mp + t , \tag{2}$$

where M is the rotation matrix and t is the translation vector. However, since this work only considers the deformation of the model, the previous expression is reduced to

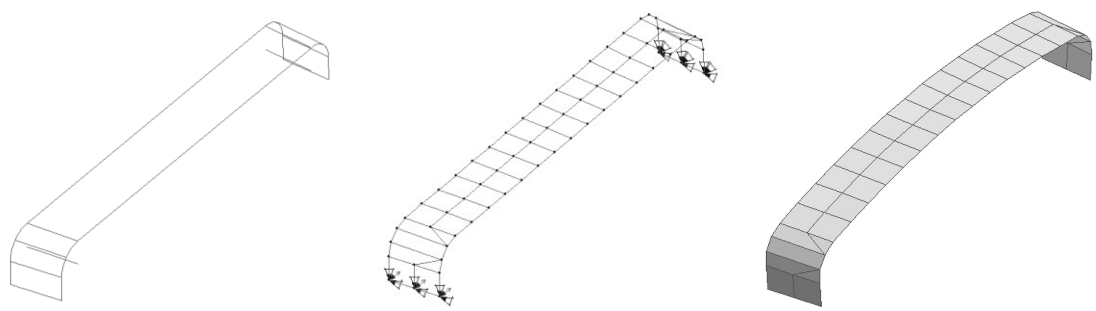
$$F(p) = \sum_i C_i R(|p-p_i|) + p , \tag{3}$$

In this paper, we use the multi-quadrics basis functions $R(x) = (x^2 + \beta)^{1/2}$ to represent deformation. The parameter β controls the smoothness of the interpolation[15], which is calculated for each point from the distance to the nearest neighbor, as suggested by Eck[16]. Other RBFs were tested in a previous paper[17]. Specifically, inverse multi-quadrics, Gaussian and also multi-quadrics were used, and the deformation obtained with the RBF system was compared to that one obtained by FEM. As a result, it was found that none of them is better than the others for all the tested models.

3. DEFORMED SURFACE MATCHING

In order to compare the alignment of the models with and without the RBF transformation, we do the following:

First, the CAD model is created and tessellated. Then, the constraints are applied and the displacements of the mesh nodes are calculated by FEM. This result is taken as the deformed data model. Figure 2 shows an example of a CAD, the mesh with the constraints applied and the resulting deformation.



(a) CAD model (b) Mesh and constraints (c) Deformed model

Figure 2. A CAD model and a FEM deformation.

Second, constraint nodes are used as the set of input control points for the RBF system. Since the positions of the constraint nodes are known, as much for the CAD as for the deformed model, these points are used to compute the RBF coefficients, C_i in the Equation 3.

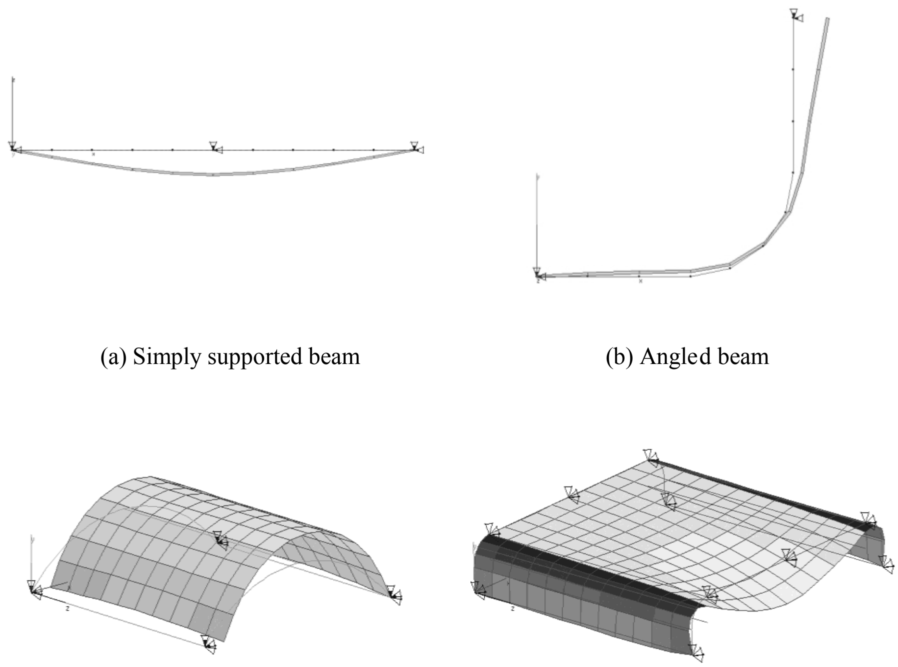
Third, once the RBF coefficients are obtained, Equation 3 is applied on all the points of the un-deformed mesh. This last step constitutes the non-rigid transformation used to improve the alignment of the CAD model with the deformed data.

Finally, the deviations are calculated for the rigid transformation approach and for the compensation using RBF transformation.

4. RESULTS

Four models were considered: a simply supported beam, an angled beam, a circular section, and a square section. In all cases, bending forces were applied to the surface at the hanker points. The CAD models, the meshes, the constraint points, and the deformations are illustrated at Figure 3.

The characteristics of the models for FEM calculations were the following: Young modulus of elasticity = 25000 Kgf/cm^2; Poisson ratio = 0.35; beam section = 0.1cm × 0.1cm; thickness of the shell elements = 0.1cm.



(a) Simply supported beam (b) Angled beam

(c) Circular section (d) Square section

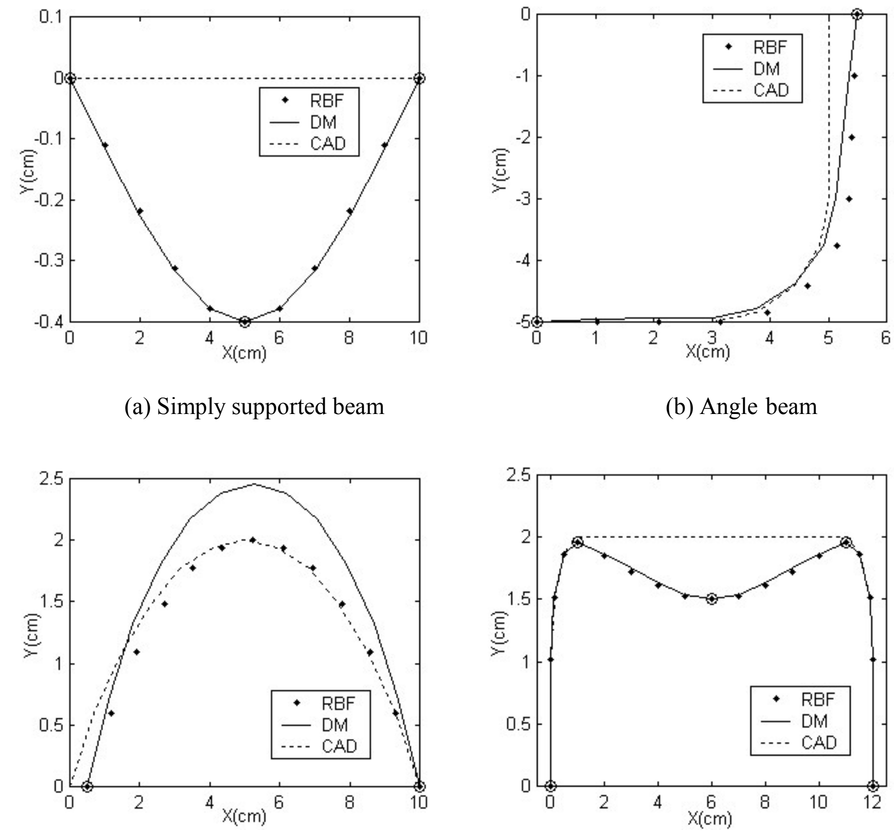
Figure 3. Testing Models

4.1 Discussion

Figures 2(a) and 2(b) show curves representing: the rigid CAD, the deformed model (DM), and the deformation obtained by using the RBF transformation. Figure 2(c) and 2(d) show similar curves for sections of the cover and the lid models, respectively.

Tables 1 to 4 summarize the results of the maximum and the average deviations in both cases: rigid alignment and RBF transformation for each model. Also, it is indicated the number of nodes of the CAD mesh and the number of control points (CP) for RBF calculations. From these results it is possible to observe that in the four cases the RBF transformation improves the alignment between the CAD model and the deformed model, especially for the simply supported beam, if the average and maximum deviations are the most important values for the inspection task. However, the deviations of the alignment are increased for some points of the models.

In these experiments, the meshes used were coarse, but the same deformations can be obtained for more refined meshes with the same control points. Mostly, the number of points involved in the calculation of RBF coefficients is a small set points in comparison to the set of all points of the mesh.



(a) Simply supported beam

(b) Angle beam

(c) Circular section

(d) Square section

Figure 4. Comparison between rigid and non-rigid alignments.

Table 1. Numerical results for the beam model

Alignment	Maximum deviation (cm)	Average deviation (cm)
Rigid CAD (11 nodes)	0.4000	0.2255
RBF transformation (3 CP)	0.0083	0.0040

Table 2. Numerical results for the angle beam model

Alignment	Maximum deviation (cm)	Average deviation (cm)
Rigid CAD (11 nodes)	0.5000	0.1427
RBF transformation (2 CP)	0.2410	0.1323

Table 3. Numerical results for the circular model

Alignment	Maximum deviation (cm)	Average deviation (cm)
Rigid CAD (143 nodes)	0.5227	0.3921
RBF transformation (4 CP)	0.4592	0.2933

Table 4. Numerical results for the square model

Alignment	Maximum deviation (cm)	Average deviation (cm)
Rigid CAD (247 nodes)	0.5000	0.0601
RBF transformation (10 CP)	0.1635	0.0512

5. CONCLUSION AND FUTURE WORK

In this work, we consider the use of RBFs to improve the alignment of virtual models involved in the inspection processes of deformable pieces. As input control points to the RBF system we use only the points whose final position is known, that is, the clamping points of the piece. Mainly because of this, the computational load of calculation of deformation was reduced greatly in comparison with the FEM approach. Although the RBF transformation increases deviations in some points with regard to the rigid alignment, average and maximum deviations are reduced. Now we are developing a method to add more input control points to the RBF system, and to introduce physical constraints to get a better fitting of the real deformed surface. Also, we are preparing experimental data from real pieces and deformations to test the performance of the system.

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