



HAL
open science

Virtual Image Correlation Approach for Updating an Analysis-Suitable CAD Model of a Manufactured Lattice Structure

Dorian Bichet, Robin Bouclier, Jean-Charles Passieux, Jean-Noël Périé

► To cite this version:

Dorian Bichet, Robin Bouclier, Jean-Charles Passieux, Jean-Noël Périé. Virtual Image Correlation Approach for Updating an Analysis-Suitable CAD Model of a Manufactured Lattice Structure. 14th Conference on Industrial Computed Tomography (iCT 2025), Feb 2025, Antwerp, Belgium. ⟨hal-04940240⟩

HAL Id: hal-04940240

<https://hal.science/hal-04940240v1>

Submitted on 11 Feb 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

Virtual Image Correlation Approach for Updating an Analysis-Suitable CAD Model of a Manufactured Lattice Structure

Dorian Bichet^{1,2}, Robin Bouclier^{1,2}, Jean-Charles Passieux², Jean-Noël Perié²

¹Institut de Mathématiques de Toulouse, Toulouse, France, e-mail: dbichet@insa-toulouse.fr, bouclier@insa-toulouse.fr

²Institut Clément Ader, Toulouse, France, e-mail: passieux@insa-toulouse.fr, jean-noel.perie@iut-tlse3.fr

Abstract

Manufactured lattice structures often deviate from their original CAD designs, significantly affecting their mechanical response. Using image-based methods within a B-spline framework, this study presents a technique for adjusting CAD models to account for manufacturing defects.

Keywords: Active Contours, Virtual Image Correlation, Multipatch B-spline, Lattice structure

1 Introduction

Additive Manufacturing (AM) processes open the door to the creation of increasingly complex structures. Lattices are cellular architected structures known for their ability to achieve high specific characteristics. When manufactured, they exhibit geometric defects that are perfectly revealed by X-ray tomography and have a significant impact on actual mechanical performance [1]. It is therefore particularly tempting to develop image-based models. Classically, a Marching Cubes algorithm is then used to extract a triangular surface mesh of the lattice structure from the CT reconstructed image. This mesh usually contains a very large number of nodes. From this mesh, a volume mesh can be created and used to compute the mechanical response of the structure. Nevertheless, the computational cost of such finite element-based methods is considerable. Besides, because the mesh is in a different format than the initial *as-designed* CAD model, characterizing the geometrical transformation is challenging. This work focuses on constructing an explicit analysis suitable CAD description of a real *as-manufactured* lattice part. This process uses a theoretical *as-designed* analysis suitable CAD geometry and an implicit description of the *as-manufactured* part as the CT scan. The analysis suitable CAD descriptions are considered to be multipatch B-splines [2]. This choice is motivated by the complexity of lattices structure as well as the widespread use of b-splines in CAD software. The proposed method conforms to the Active Contours framework [3], where the gray-level metric is inspired by the Virtual Image Correlation method [4, 5]. The regularization is divided into two parts : inside a B-spline patch, a membrane elasticity constraint [6] is weakly prescribed, while another method is used to impose a high regularity multipatch continuity between patches.

2 Method

The method exposed here deforms a multipatch B-spline surface, initially representing the skin of the *as-designed* lattice, to match the *as-manufactured* geometry. Thanks to the tensor product formulation of the B-splines, extracting the skin of a shape and creating a volume from a skin is not complex in most cases.

2.1 Geometry

B-splines are a family of curves, surfaces, or volumes that can describe complex smooth geometries with only a few degrees of freedom (DOFs). This reduces the complexity of the algorithms and can filter out some high frequency defects or artifacts. The DOFs of these geometries, called control points, can be moved in 3D space to deform the shape without affecting its regularity. However, B-spline surfaces are a smooth mapping from a rectangular parametric space to 3D space. This means that a B-spline surface can only be topologically identical to a square. This limitation can be overcome, in a manner similar to finite element meshes, by creating connectivity between multiple B-spline surfaces, called patches. In summary, the geometry of the lattice structure is represented by a multipatch B-spline surface, which itself is controlled by the displacement of its control points \mathbf{U} .

2.1.1 Problem

The aforementioned displacement is calculated through the minimization of a sum of cost functions, which are also referred to as energies in the active contours framework:

$$\min_{\mathbf{U}} (E_{image}(\mathbf{U}) + \alpha E_{intra}(\mathbf{U}) + \beta E_{inter}(\mathbf{U})) \quad (1)$$

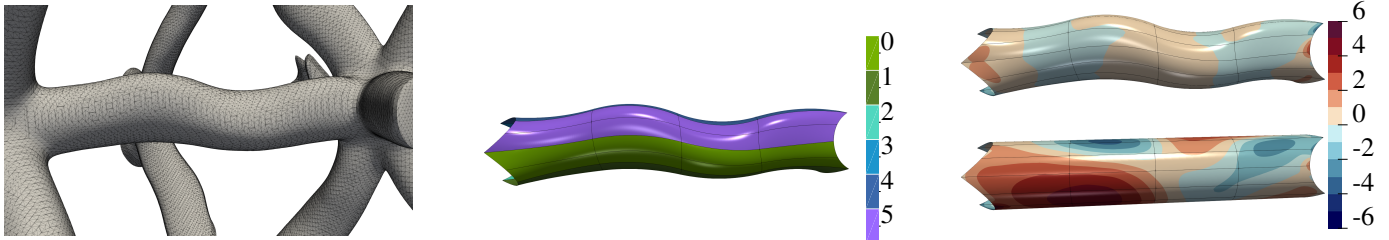
- E_{image} : This energy attracts the surface to the desired location within the image. Given the substantial volume of data present in a CT scan, performing calculations on the entire scan would be prohibitively expensive. Therefore, the Virtual Image Correlation framework is employed.
- E_{intra} : The intra-patch regularization energy. The intrinsic regularization of B-splines makes Virtual Image Correlation work well with relatively coarse meshes. However, as the spline mesh is refined, tangential deformations that preserve

the geometry degrade the conditioning of the problem. Additional regularizations as bi-laplacian and gradient-based ones, commonly used in the literature, appear to degrade the results by also penalizing out-of-plane displacements. As a remedy, a regularization term is proposed based on the membrane strain energy. This energy increases when the surface is subjected to tangential strains, such as in-plane shear and stretching, regularizing in-plane deformations while leaving out-of-plane modes unaffected.

- E_{inter} : The inter-patch regularization. It is a penalization term that ensures higher regularity (C^1) between the patches.

3 Results

A nylon lattice with defects was made using the SLS process. Each strut is about 13 mm long and 4 mm in diameter, but has waviness and cross-section deviations. A CT system was used to create $267 \times 327 \times 327$ voxel binned images of the lattice. A multipatch B-spline geometry is utilized to model struts. As illustrated in Fig.1b, it comprises six patches, each representing one-sixth of a tube containing 2×4 B-spline elements. With degree 2 basis functions, the mesh contains 144 nodes, reduced to 108 after eliminating duplicate nodes at patch edges, resulting in a sparse problem with 324 degrees of freedom. This is a significant improvement over the Marching Cubes mesh presented in Fig.1a. Virtual Image Correlation, spanning 10 voxels above and below the B-spline surface, explores the image with approximately 8 integration points per voxel. A modified Gauss-Newton algorithm was used to solve the virtual image correlation problem. Fig.1b demonstrates the ability of the method to detect complex defects. A distance field estimator to the actual surface in the *as-manufactured* 3D CT is presented in Fig.1c. This estimator shows how the method can reduce the distance from about six voxels to less than one.



(a) Triangular mesh of the *as-manufactured* obtained by Marching Cubes from the 3D CT.

(b) The multipatch B-spline strut mesh at the final iteration, colored by patch.

(c) Distance in voxels of the final (top) and initial (bottom) meshes to the *as-manufactured*.

Figure 1: Multipatch surface fitting on a strut in a real lattice, based on the proposed virtual image correlation approach.

4 Discussion and Conclusion

Thanks to the regularization techniques introduced, the proposed virtual image correlation method makes it possible to fit a surface with an estimated resolution around the pixel on real CT images of lattices. The explicit representation of as-fabricated geometry, combined with the introduction of a morphing field, will facilitate the quantitative assessment of geometric defects and enable the development of more efficient numerical simulations [7].

Acknowledgements

This research was supported by the "French Agence nationale de la recherche" under grant ANR-22-CE46-0007 (AVATAR).

References

- [1] L. Liu, P. Kamm, F. García-Moreno, J. Banhart, D. Pasini, Elastic and failure response of imperfect three-dimensional metallic lattices: the role of geometric defects induced by Selective Laser Melting, *Journal of the Mechanics and Physics of Solids* 107 (2017) 160–184.
- [2] L. Piegl, W. Tiller, *The NURBS Book*, Monographs in visual communication, Springer, 1995.
- [3] M. Kass, A. Witkin, D. Terzopoulos, Snakes: Active contour models, *International Journal of Computer Vision* 1 (4) (1988) 321–331.
- [4] M. L. François, B. Semin, H. Auradou, Identification of the Shape of Curvilinear Beams and Fibers, *Applied Mechanics and Materials* 24-25 (2010) 359–364.
- [5] J.-C. Passieux, R. Bouclier, O. Weeger, Image-based isogeometric twins of lattices with virtual image correlation for varying cross-section beams, *International Journal for Numerical Methods in Engineering* Publisher: Wiley (2023).
- [6] J. Kiendl, K. U. Bletzinger, J. Linhard, R. Wüchner, Isogeometric shell analysis with Kirchhoff–Love elements, *Computer Methods in Applied Mechanics and Engineering* 198 (49) (2009) 3902–3914.
- [7] R. Bouclier, T. Hirschler, *IGA: Non-conforming Coupling and Shape Optimization of Complex Multipatch Structures*, 1st Edition, Wiley, 2022.