PGD-Vademecum for based distance optimization and control methods in LCM processes.

N.Montes[1*], L.Hilario[1], F.Chinesta[2], A.Falco[1], J.L.Duval[3]

[1] *Department of Mathematics, Physics and technological sciences, University CEU Cardenal Herrera, C/San Bartolome 55, CP 46115, Alfara del Patriarca (Valencia).*
[2] *Arts et Metries ParisTech. 151 Boulevard de l'Hôpital, 75013 Paris.*
[3] *ESI Group, 100-102 Avenue de Suffren, 75015 Paris.*
*Corresponding author (*nicolas.montes@uchceu.es*)

Keywords: *Optimization, control, PGD-Vademecum, Poison equation, geodesic distance.*

Introduction

Distance between two point Euclidean distance in a mould geometry is a common technique used in LCM processes in the design and manufacturing phases.

In the design phase, this distance is used to compute the optimal vent and gate location for RTM, see [1], and for resin infusion processes, see [2],[3],[4]. Moreover, the it is also used in the design process as a process performance index where the optimal flow front for each time instant is defined as vent oriented, that is, if the distance between each flow front point and the vent is the same, see [5].

In the manufacturing phase, this distance is commonly used as an on-line control strategy. For instance, in [6], the optimal vent point is selected between a predefined set of vent points using a vent oriented flow criteria. In [7], a square mould with an outlet located in the square centre and one inlet in each corner is proposed for the on-line control. The shortest flow front distance for each mould size to the outlet is used to control the flow rate of the inlets.

The main drawback using distance is the computational costs. When the mould geometry is restricted to 2D moulds without holes or obstacles, Euclidean distance could be used but, when the mould has holes or obstacles and/or the mould is 2.5D, a geodesic distance is required. LCM researchers tend to avoid the geodesic distance computation, as it is not a cost-effective solution in comparison to FEM simulation. However, real world geometries are, in most of the cases, 2.5D with holes and obstacles.

The exact and fast computation of Geodesic distance is a current topic for research. For instance, in [8], the geodesic distances of Michelangelo's David, composed by 400 K FE, would be computed in 75.13 s, using a 1.6 GHz Pentium M. Recently, in [9], a new approach to compute geodesic distance is proposed. This method uses the heat flow equation to compute it. In [9], the geodesic distances for a lion with 353K FE, would be computed in 5.49 s, on a 2.4 GHz Intel Core 2 Duo. Also in [9] compares heat method with fast marching method. As a result, heat method is twice fast.

PGD for Geodesic distance computation

The use of the heat flow equation to compute geodesic distances, allow us to introduce PGD (Proper Generalized Decomposition) framework. In the PGD framework, the resulting model is solved once in life in order to obtain a set that includes all the solutions for every possible value of the parameters, that is, a sort of computational vademecum, [10]. Consider the solution of the Poisson equation

$$\Delta u(x,y) = f(x,y) \tag{1}$$

In the case proposed here, we need to assume that a constant source term f in the equation *(1)* is in really a non-uniform source term $f(\Omega_{\underline{X}}, \Omega_{\underline{S}}, \Omega_{\underline{T}})$ where $\Omega_{\underline{X}} = \Omega_x \times \Omega_y$, $\Omega_{\underline{S}} = \Omega_r \times \Omega_s$, $\Omega_{\underline{T}} = \Omega_r \times \Omega_t$. In this definition, the inlet point S and the outlet point T are defined a Gaussian model with variance and mean $\underline{S} = (r,s)$, $\underline{T} = (r,t)$, where r is the variance and *s*,*t* are the median value located in an specified point $\underline{X} = (x,y)$ in each separated space $\Omega_{\underline{S}}, \Omega_{\underline{T}}$. The PGD-Vademecum to construct is;

$$u(\underline{X},\underline{S},\underline{T}) = \sum_{i=1}^{N} R_i(\underline{X}) \cdot W_i(\underline{S}) \cdot K_i(\underline{T}) \tag{2}$$

where $R_i(\underline{X}), W_i(\underline{S}), K_i(\underline{T})$ are the matrices for each separated space and N is the number of PGD terms. Each PGD component is computed by a fixed-point iteration technique as;

$$u^{n,p}(\underline{X},\underline{S},\underline{T}) = u^{n-1}(\underline{X},\underline{S},\underline{T}) + R_n^p(\underline{X}) \cdot W_n^p(\underline{S}) \cdot K_n^p(\underline{T}) \tag{3}$$

For instance, if we compute the PGD-Vademecum for a square mould with an obstacle in the middle and 50x50 nodes, the residual error that approximates the Poison equation for all inlet and outlet combination is depicted in Figure 1.

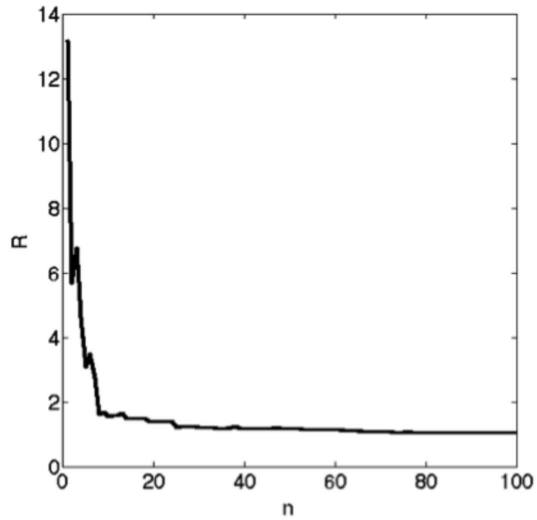

Figure 1: *Residual error.*

Conclusions

The present paper shows, for the first time how to compute geodesics in real-time. It could be used in LCM processes for optimization and control in 2.5D moulds and 2D moulds with obstacles.

References

[1] Jiang, S., Zang, Ch., Ben, W. Optimum arrangement of gate and vent locations for RTM process design using a mesh distance-based approach. In: *Composites part A: Applied science and manufacturing*,33: 471–481, 2002

[2] N. Montes, F.Sánchez, U.Pineda Efficient resin distribution channel for the design of resin infusion processes using geometric methods, In: *Advanced science letters*, *19(3)* pages 760-765, 2013

[3] F.Sanchez, L.Domenech, V.Garcia, N.Montes, E.Cueto, F.Chinesta, P.Fideu Fast and reliable gate arrangement pre-design of resin infusion processes, In: *Composites part A: Applied science and Manufacturing*, 77, pages 285-292, 201

[4] Kessels JFA, Jonker AS, Akkerman R. Optimising the flow pipe arrangement for resin infusion under flexible tooling. In: *Composites Part A* 38:2076–85, 2007.

[5] Jiang S, Zhang C, Wang B. A process performance index and its application to optimization of the RTM process. In: *Polym Compos*;22(5):690–701 2001.

[6] N.Montes, F.Sánchez, J.A.Garcia, A.Falco, J.Tornero, F.Chinesta. Application of artificial vision in flow redirection during filling of Liquid Composite Molding process. In: *AIP conference proceedings* 907(1), pp 902-907. 2007.

[7] Modi D, Correia N, Johnson M, Long A, Rudd C, Robitaille F. Active control of the vacuum infusion process. In: *Composites Part A* 2007;38:1271–87.

[8] Surazhsky V, Surazhsky T, Kirsanov D, Gortler SJ, Hoppe H. Fast exact and approximate geodesics on meshes. In: *Proceedings of ACM, SIGGRAPH*, vol. 4(3); July 2005. p. 553–60

[9] Crane, K. Weischedel, C, Wardetzky, M. Geodesics in heat: A new approach to computing distance based on heat flow. In: ACM Transactions on Graphics, Vol 32 (3), pp 1-10, 2013.

[10] F.Chinesta, K.Roland, L.Adrien. The proper generalized decomposition for advanced numerical simulations. In: *SpringerBriefs in Applied Sciences and Technology*, 2014.

[11] N.Montés, F.Chinesta, A.Falco, M.C.Mora, L.Hilario, N.Rosillo, J.L.Duval. Applications for Proper Generalized Decomposition method in motion planning robotics systems. In: *4th International workshop on reduced basis POD and PGD Model Reduction Techniques.* 2017