Numerical technique for the space discretization of resin infusion mould sensing with artificial vision

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ABSTRACT: On-line control strategies are used to ensure full reliability of Resin Infusion processes. The top half of the mould is transparent or translucent, allowing the use of artificial vision as a sensor for mould filling processes. It has been recently introduced for Liquid Composite Molding processes [1], [2], [3]. In this sense, the CCD sensor can be considered as a matrix of nodes that produces a space discretización. It implies that it is possible to relate the regions defined by the finite elements used in the process numerical simulations and the image. Therefore, it is possible to define a single camera vision sensor as a space discretizer and to relate it directly with on-line Finite Element discretization. Also is possible to relate an off-line mesh with camera vision sensor. In both cases, a direct relationship between the FEM or proxy simulations and the real process evolution can be defined. The mould complexity for real 2.5D resin infusion process can be easily solved including multiple cameras and calibrated them with Stereovision techniques [4]. As a result, a 2.5D mould mesh is obtained where the camera vision acts as Finite Element mesher and process sensor simultaneously.

Key words: Resin Infusion, FEM, Proxy simulator, Numerical Simulation, Artificial Vision

1 INTRODUCTION

Resin infusion process depicted in Fig.1, is one of the common techniques used in the industry for large composite parts production. This technique uses vacuum pressure to drive the resin into a laminate. Preform is laid dry into the mould and the vacuum is applied before the resin is introduced. Once a complete vacuum is achieved, resin is sucked into the laminate via placed tubing. This negative pressure allows the top half of the mould to be made of a flexible material, thus reducing costs permitting manufacturing parts of practically any size. In Liquid Composite Moulding processes, the resin impregnation of the fiber is described using the flow through porous media theory.
Analytical treatment of the flowing evolution is difficult except for a few simple geometries. Therefore, numerical methodologies for flow simulation were developed in past decades for RTM and extended to other processes more recently. The most common form for the flow numerical simulation is to use a discretization approach with finite elements.

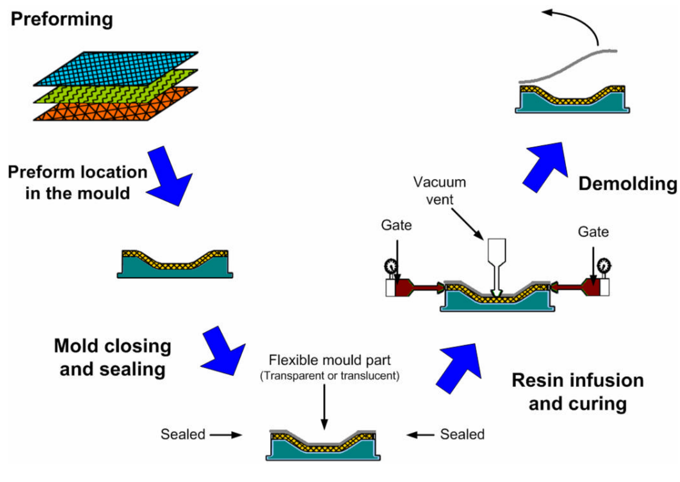

Fig.1. Resin Infusion Process stages

An important concern in the mold filling simulation is the numerical treatment of the moving boundary defined by the flow front of the liquid resin, Fig.2. The flow kinematics can be computed by means of a conforming finite element Galerkin technique applied to the variational formulation extended to the whole domain, imposing null pressure at the nodes not connected with at least a completely filled element. The domain occupied by the fluid where the governing equations have to be integrated changes continuously, so it has to be defined at each time step during the simulation. The fluid domain evolution is accomplished by the resolution of the hyperbolic transport equation that governs the fluid presence function updating.

Most of the flow simulation methods use Darcy's law and need information about the material modelling. A major aspect to model is the perform permeability that characterizes the resistance offered by the porous medium to fluid flow. Therefore, for accurate description and design of the infusion process, characterization of the textile permeability is essential. Many research efforts are focused to an exact characterisation of permeability. However, this goal is complex due to its dependence on a multitude of parameters such as preform architecture, fibre volume fraction, etc. In addition, in the resin infusion process, compaction of the preform affects thickness, fibre volume fraction and permeability. In summary, the pressure driven infusion process is highly complicated since the mould and process design are not intuitive and may be variable due manufacturing conditions.

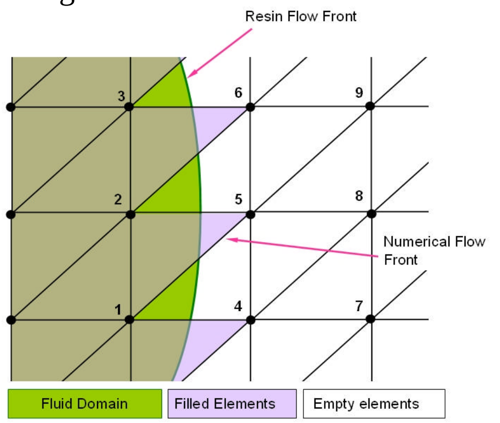

Fig.2. Finite Element numerical treatment for the resin flow front simulation.

A prediction of the mold flow pattern, pressure distribution, temperature and curing profile of the resin using simulation techniques allow one to optimize the process and, hence, to improve the final properties of the manufactured part.

Off-line control strategies or passive control systems are another possibility to develop an efficient resin infusion process. In this case, a database of possible flow scenarios is generated from numerical flow simulations. However, passive control systems cannot ensure complete success and full reliability due to various aspects of the process such as edge effect, wrinkling of the vacuum bag, local preform heterogeneities, exact assignment of various material properties, etc. In order to overcome the off-line control problems, recent research works developed advanced on-line control systems. This systems can be divided into two categories, depending upon of the simulation used to obtain a corrective action are performed prior to the start resin infusion or in real-time, during the resin infusion.

The use of real-time simulations in on-line control systems implies that must be fast enough to match mould filling times. In this sense, in many on-line control systems, proxy simulators instead of numerical simulation are used to predict flow progression.

As can be seen in Fig.3, a typical closed-loop control system is basically compound of the controller and the process in a feedback structure. Actuators and sensors are also required in order to accommodate signal as well as to force and to measure system variables respectively. The desired output of a process is also called the reference for the control system. In resin infusion processes the top half of the mould can be made of a flexible material. It implies that the top half can be transparent or translucent. This allows the use of artificial vision as sensor of the process in order to control it.

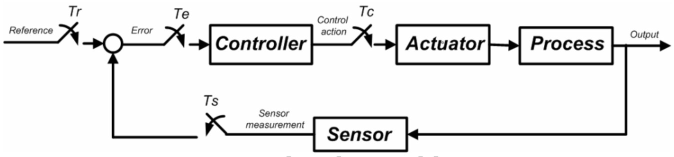

Fig.3.Closed control-loop

1.1 *Objective and outline*

The goal of our research is to obtain a computational framework that allows an efficient closed control loop for resin infusion process based on artificial vision. In this paper, we propose a camera as a sensor of a resin infusion process. Cameras permit to define the pixels as nodes, generating a proper discrete space. The previous pixel association allows defining the sensed Finite Elements to be used in simulations. Moreover, the use of multiple cameras joined with artificial vision techniques allows monitoring real 2.5D resin infusion process as a FEM simulation does.

2 SENSING LCM FLEXIBLE TOP HALF OF THE MOULD USING ARTIFICIAL VISION.

Artificial vision is a sensor that samples the light scene. It is typically used in the industry for quality inspection. The use of this device as a sensor for mould filling processes is actually a research field for resin infusion processes. In this works, the camera is defined as a grid of customary sensors used in RTM where the pixels acts as a punctual sensors. These studies do not exploit the amount of properties that the artificial vision has. In this sense, the CCD sensor can be considered as a matrix of nodes that produces a space discretization. It implies that it is possible to relate the finite elements and the image pixels using the resulting mesh in the proxy or on-line FEM simulations. Also is possible to relate an off-line mesh with camera sensor. In both cases, a direct relationship between the FEM or proxy simulations and the real process is defined. The mould complexity for 2.5D resin infusion process can be easily solved including multiple cameras and calibrated them with stereovision techniques. As a result, a 2.5D mould mesh is obtained where the camera acts as finite element sensor.

2.1 Numerical technique proposal for the space discretization sensing using artificial vision.

Considering the CCD sensor as a rectangular matrix of nodes, the relationship between the neighborhood photodiodes-pixels-nodes establishes the typical definition of the Finite Elements; see Fig.4.

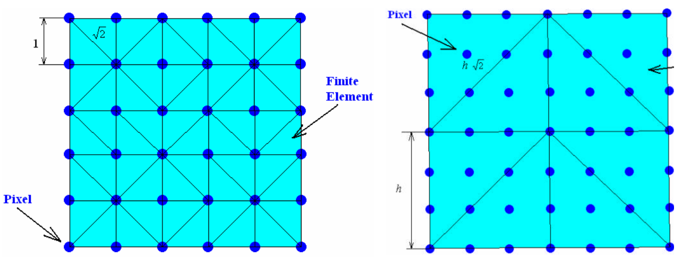

Fig.4.Finite Elements without (left) and with (right) grouping pixels into finite Elements.

The CCD sensor permits to construct whatever meshes distribution using the pixels as nodes, Fig.4. (left), or grouping them in Finite Elements using some pixels as nodes, Fig.4. (right). The translation between both processes is quite simple. Given a CCD with *P*,*Q* pixels, Fig.5 (left), and knowing the typical definition of Finite Elements in a mesh, Fig.5. (right), just only need to relate the number of each pixel with each Finite Element. In this sense, the simplest appropriate mesh possible is to obtain a uniform node distribution in a symmetrical mesh. Therefore, the pixels of the CCD sensor can be related to define the Finite Elements as can be seen in Fig.6.

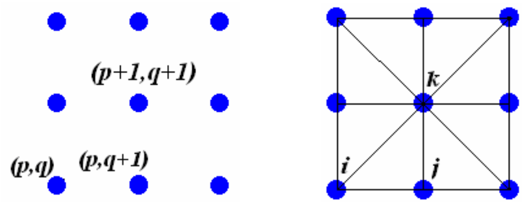

Fig.5. CCD to Finite Elements Discretization

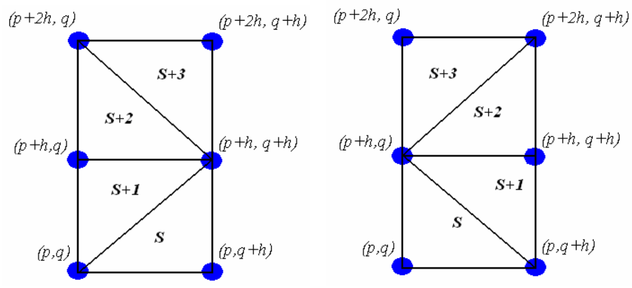

Fig.6. Finite Element Generation. Column *k* (left), and *k+1* (right).

where *h* is the distance between the pixels selected as nodes. The nodes are related in a different way for each pixel. The pixels that are inside of each Finite Elements are related to them. The algorithm to generate this mesh is shown in Fig.7.

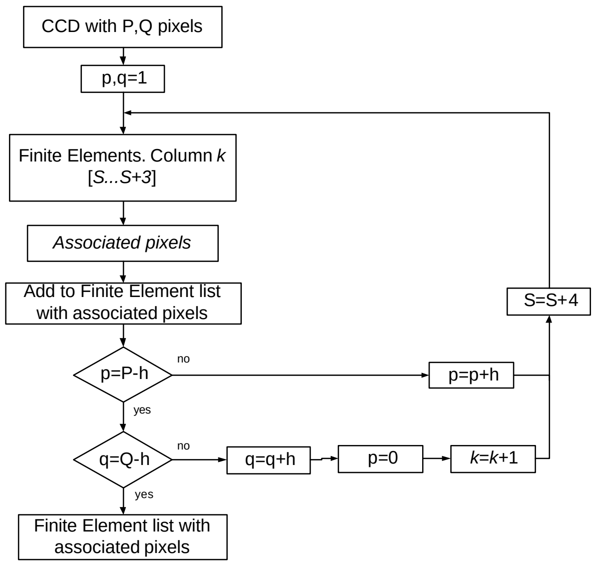

Fig.7. CCD to FEM algorithm

This algorithm establishes a non-dimensional mesh in the CCD camera sensor. The dimensions of the Finite Elements are selected to $\sqrt{2} \cdot h$ in the diagonal axis and *h* in the vertical and horizontal axis. The value of *h* depends on the distance between CCD light sensors and the number of pixels used to define the Finite Elements.

The resulting non-dimensional mesh is projected to the scene obtaining a space discretization with Finite Elements. Therefore, the mould allocated in the scene is meshed by the camera. The projection permits to identify the real node coordinates. For instance, a 2D mould allocated in parallel with the CCD sensor, just only needs to scale the non-dimensional mesh using the camera parameters. For a 2.5D mould, it is necessary to include multiple cameras, calibrating the field of view using for instance light-sheet triangulation and relate the pixels of the cameras with stereovision techniques. In this application, there are some Finite Elements that are detected for more than one camera. This issue permits a full a 2.5D mesh generation that is perceived by multiple cameras.

2.2 *Numerical technique proposal for the space discretization through Finite Elements compatible with the artificial vision sensor.*

In the hereinbefore subsection, the CCD sensor permits a space discretization, relating pixels with Finite Elements. In the same sense, it is also possible establishing the opposite process, which is, given a mould mesh; relate some pixels to each Finite Element. In this case, first the mould must be located in the image. The technique of finding some objects in the image is well-known as *matching*. There are several techniques to locate an object, for instance, using the geometry, contour, area, etc. After the mould is located in the image, each pixel can be associated with each Finite Element as shown in Fig.8. In Fig.9.(left) is shown an example of this relation between pixels and Finite Elements. The filled pixels determine the percentage at which each Finite Element is filled, see Fig.9. (right). The techniques to relate a predefined mesh as well as using a mesh projection to the CCD camera sensor permit a real comparative between FEM simulation and the real process.

3 CONCLUSIONS

Artificial vision is defined as a sensor of resin infusion processes. Different active control systems reported in the literature suffer from various limitations and cannot be applied properly. The system described in this paper permits to identify the pixels of the CCD camera as nodes, generating a space discretization. Pixel association allows defining the sensed Finite Elements. The reference of the control loop must be defined and compared with the sensor measurement to obtain the error with low computational costs.

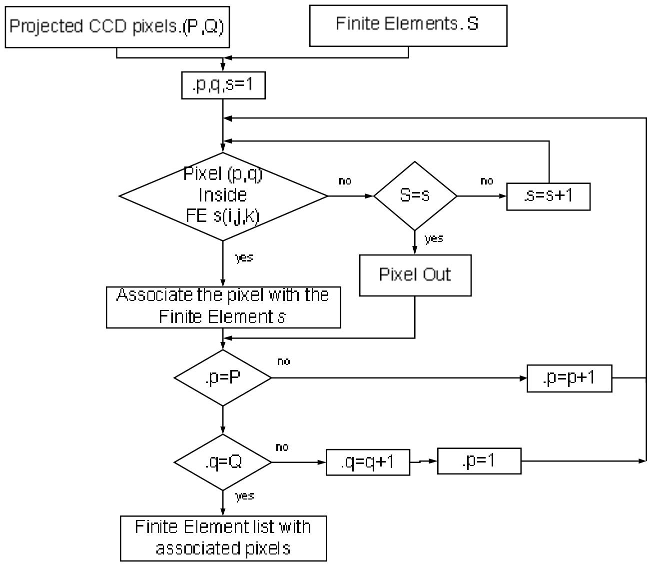

Fig.8. Associated pixels with each Finite Element

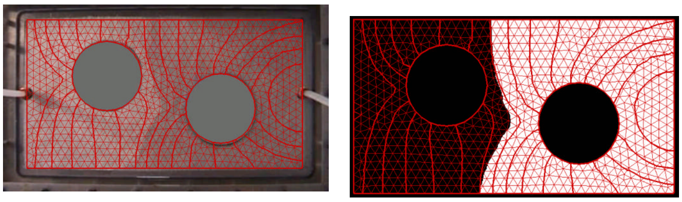

Fig.9. Example of FEM-CCD association

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