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Merging enriched Finite Element triangle meshes for fast prototyping of alternate solutions in the context of industrial maintenance

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ABSTRACT

A new approach to the merging of Finite Element (FE) triangle meshes is proposed. Not only it takes into account the geometric aspects, but it also considers the way the semantic information possibly associated to the groups of entities (nodes, faces) can be maintained. Such high level modification capabilities are of major importance in all the engineering activities requiring fast modifications of meshes without going back to the CAD model. This is especially true in the context of industrial maintenance where the engineers often have to solve critical problems in very short time. Indeed, in this case, the product is already designed, the CAD models are not necessarily available and the FE models might be tuned. Thus, the product behaviour has to be studied and improved during its exploitation while prototyping directly several alternate solutions. Such a framework also finds interest in the preliminary design phases where alternative solutions have to be simulated. The algorithm first removes the intersecting faces in an n-ring neighbourhood so that the filling of the created holes produces triangles whose sizes smoothly evolve according to the possibly heterogeneous sizes of the surrounding triangles. The hole-filling algorithm is driven by an aspect ratio factor which ensures that the produced triangulation fits well the FE requirements. It is also constrained by the boundaries of the groups of entities gathering together the simulation semantic. The filled areas are then deformed to blend smoothly with the surroundings meshes.

1. Introduction

Nowadays, the mainstream methodology for product behaviour analysis and conceptual solution assessment relies on the following steps: conceptual phase, Computer-Aided Design (CAD) modelling, meshing and simulation model preparation, Finite Element (FE) simulation, result analysis and optimization loops [1,2]. However, in the context of maintenance and lifecycle problem analysis, the product is already designed, the CAD models are not necessarily available and the product behaviour has to be studied and improved during its exploitation. Companies exploiting complex installations are currently subjected to various constraints crucial from a production point of view. They can be relative to the time and cost of the production process stops, to the efficiency of maintenance solutions, to production safety criteria, etc. For example, in the field of power production, it is critical to identify the problem source and to provide the appropriate solution while taking care of the triptych: Time, Quality and Cost. As a reference, for the Electricité de France (EDF) Group, the total cost of one day of stop of a nuclear power station represents several hundreds of thousands of euros.

In this context, it is clear that the optimization of the stop times necessarily goes through the optimization of the time spent for the various numerical simulations (e.g. mechanical resistance assessment, vibration analysis, contra-expertise). Sometime, the model preparation step, including the CAD modelling, the development of complex meshes adapted to specific FE simulations, the accurate identification of the unknown parameters, the prototyping and assessment of the proposed solution can exceed 50% of the time required for the full operational study.

In this paper, we present a new research direction allowing reducing the time of the studies. The newly developed prototyping method does not necessarily go back to the CAD models and set up a framework for the definition of a CAD-less approach. Actually, the idea is to enable direct modification of complex meshes. This approach enables to avoid multiple and time-consuming iterative updatings of the CAD models, as well as the tedious remeshing of potentially complex shapes. Not only it takes into account the geometric aspects, but it also considers the way the semantic information possibly associated to the groups of FE entities can be

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maintained during the modifications. These semantic data enrich the FE mesh models with information that are classically relative to the defining materials, boundary conditions and external forces. A new algorithm is proposed and enables the merging of triangle meshes while taking into account the boundaries of FE groups. Thus, many underlying problems are circumvented and the time of study is reduced. The proposed approach is particularly efficient in the case of fast prototyping of local structural modifications.

The paper is organized as follows. First, the specificities in the field of production machinery maintenance are presented on some EDF engineering projects (Section 2). The new prototyping framework is also proposed. Section 3 depicts a state-of-the-art of the methods enabling local mesh modifications. Based on this analysis, we introduce our new triangle meshes merging approach together with the associated algorithms (Sections 4 and 5). The overall process and algorithms are finally tested on several examples including an example relative to an EDF project (Section 6). The last section concludes this paper while coming back on the achieved results and potential future developments.

2. From current industrial practices to our fast prototyping framework

2.1. Industrial study context

The expertise of problems on production sites corresponds to the analysis of the equipments' normal functioning. Such expertises generally concern planned preventative and/or occasional maintenance of machineries, lifecycle assessments or some improvements of the production equipment behaviours. To avoid the stop of production cells, it is critical to provide quickly the optimized solution and to ensure its effectiveness while conforming to the production safety criteria. In the nuclear field, if local structural modifications are generally allowed, it is not possible to perform global modifications. Moreover, even a small local modification requires product cycle stops and validation expertise done by the safety authorities. Hence, solutions requiring significant modifications inducing long stops of production sites or complete review of a new production cycle are not realized.

2.2. Current industrial practices and underlying problems

The preparation of FE analyses is generally carried out while successively building the CAD models, generating the meshes, preparing the simulation models adapted to the adopted FE analysis code. Classically, the evaluation of alternate solutions requires several updates of the initial CAD models [2].

If this workflow is widespread, its use is not well adapted to the maintenance context. Actually, it requires the access to the CAD model construction tree [3] which is not always possible. Furthermore, some complex meshes adapted to the advanced FE simulation might contain many different entities difficult to model using a CAD approach. They correspond to double mesh entities (e.g. 2D elements, nodes), mesh entity groups to define mechanic/geometric parameters as well as to apply specific mechanical relations or boundary conditions (BCs), specific groups to model a complex phenomenon (e.g. crack, contact problems). If the designer has to go back to the CAD model, he/she loses this specific information that will be redefined later on. Sometime, the CAD models are even not available and redesigning them starting from scratch would be too time-consuming.

To illustrate these limits, let us consider the example of Fig. 1 that presents complex models the EDF engineers have to face. Fig. 1a shows the CAD model of a caisson in which a structural modification has to be performed. According to the traditional prototyping method, this study would include the following steps:

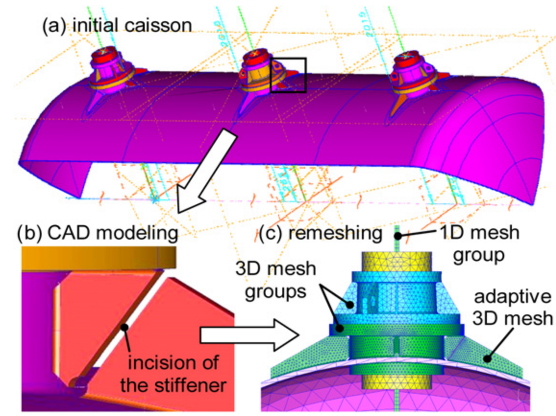

Fig. 1. Local structural modifications of a caisson (a) realized on the CAD model (b) before the remeshing (c) and the redefinition of the semantic data (courtesy EDF R&D).

(1) development of the complex CAD model which does not exist (Fig. 1a);
(2) development of an advanced mesh model taking into account different aspects such as mesh quality criteria, mechanical modelling hypotheses (Fig. 1c);
(3) creation of numerous mesh entity groups on which different FE semantics will be defined in the following step (5). These groups (30 on the example of Fig. 1) can be created either manually one by one, or more automatically while using the partitioning of the initial CAD model. This time-consuming step requires a very good skill;
(4) tuning/validation of the FE model through experimental results;
(5) FE analysis based on the modelling hypotheses and previously defined FE simulation semantics (step 3): description of links between 1D and 3D elements, characterization of the materials and specific geometric/mechanic parameters, definition of BCs and loads;
(6) prototyping of the envisaged solution, i.e. an incision of the stiffener in the present case, through an update of the initial CAD model (Fig. 1b);
(7) going back to the second step in order to evaluate this solution, and so on.

Here, it seems quite clear that going back to the CAD model is not the most appropriate solution. This is especially true when the model contains a huge amount of semantic data. For example, some EDF models can contain up to 500 groups dedicated to the FE analysis as well as particular post-processing. Unfortunately, current commercial CAD systems do not make it possible to automatize the process of enriched mesh modification. Thus, even a small local change necessitates expensive complete updating of the models.

Furthermore, the CAD strategy mainly considers the object outer surfaces as "perfect" in the sense that it idealizes the real structures. This is not adapted to design "as-built" simulation models since all the "imperfections" of the real structures are not captured. Meshes are more adapted since they are tuned to better fit what can be measured "on site".

2.3. A new digital prototyping method

In this paper, we go towards the definition of a CAD-less methodology that works directly at the level of the enriched meshes (Fig. 2). The idea relies on the removing of the hard steps of CAD modification, remeshing and FE complex model preparation in order to bring local modifications directly onto the initial FE mesh