A flexible finite element tool for digital twin services

A.M.D.Jensen[1] and G.Abbiati[1]

Department of Civial and Architectural Engineering, Aarhus University, Aarhus, Denmark

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1 Introduction

Engineering structures such as bridges and wind farms need to have a long useful lifetime. Structural Health Monitoring (SHM) via predictive simulations may be valuable towards lifetime extension. Digital Twins (DTs) are a suitable technology for such SHM, automated interventions, and providing analytical insights. As part of the tech stack of a DT, this work demonstrates a newly developed model solver "Yet another Finite Element Method" (YaFEM). YaFEM is developed for the Digital Twin as a Service (DTaaS) platform, used for virtual sensing and fatigue estimation of a physical system and with the aim of distribution, flexibility and maintainability. Contemporary finite element analysis tools provide high-performance and accurate modeling capabilities; however, they often exhibit limited flexibility for seamless integration within broader computational ecosystems, such as DT frameworks. The DTaaS platform aims to ease the task of building, using, and sharing DTs in a collaborative environment. The DTaaS provides real-time communication capabilities to link DTs with engineering structures, which helps with updating the models used in the DTs and thereby improving the prediction accuracy offered by SHM systems.

2 Digital twin as a service for structural health monitoring

The Fig. 1 illustrates a DT workflow specific to mechanical and civil engineering structures. When engineering structures are deployed, they vibrate, and vibration data can be highly informative. Within the suggested DT framework, sensors capture the vibration data, which is subsequently analyzed by a chain of dedicated structural vibration methods. Some of the methods involve a numerical model of the considered PT. The data, model, and method chain altogether form a DT of the PT.

3 Finite-element tool

As part of this DT framework, YaFEM (Yet another Finite Element Method) is a newly developed finite element method (FEM) tool focused on flexibility,

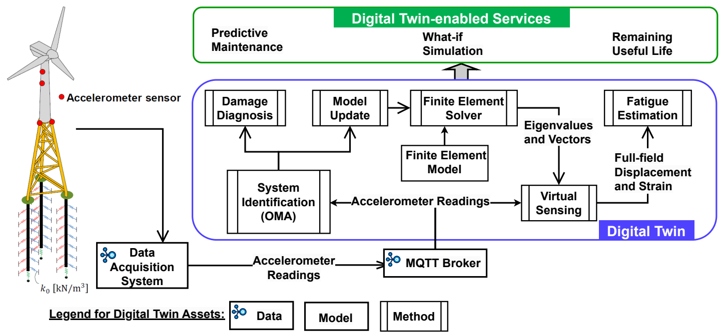

Fig. 1. The DT workflow, from the accelerometer sensors to the DT and subsequently to DT-enabled services. The data, method chain and model constitute the DT.

interoperability, and ease of use. It exposes all model quantities for detailed control and analysis, supports object-oriented programming for maintainability, and is fully portable. YaFEM is designed to integrate seamlessly with established pre-processing tools such as Gmsh and ParaView, reuses existing technologies to maximize efficiency, and provides a customizable solver core suited for simulation-driven digital twin applications. YaFEM is written in Python and uses optimized libraries, such as Numpy and JAX, to increase the computation speed. With the aim of high flexibility, the software is supported in all major operating systems and interfaces seamlessly with the rest of the DTaaS tech stack. YaFEM is free, open-source and will not require a license. The architecture of the software is demonstrated in Fig. 2 consisting of four major classes, "nodes", "elem", "model" and "simulation". The "nodes" class contains the nodal Cartesian coordinates, which afterwards are topologically linked using a library of elements from the "elem" class. The nodes and elements are funneled into the "model" class which generates the global mass and stiffness matrix as well as being capable of providing the eigen frequencies and eigenmodes of the system. The model can be passed further to the "simulation" class, which can generate time history analysis of static and dynamic responses.

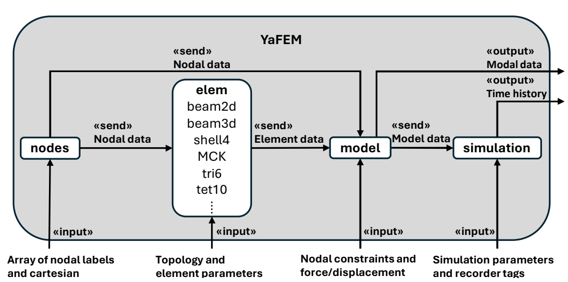

Fig. 2. YaFEM architecture