PHD POSITION

Title : Development of the Digital Twin of a reconfigurable bridge with active control system

Titre (Fr) : Développement du jumeau numérique d'un pont reconfigurable équipé d'un système de contrôle actif

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Abstract:

In a context of urban eco-mobility of the city of tomorrow, the franco-taiwaneese *ANR-NSTC NEMELIFT* project aims to develop an agile and reconfigurable crossing technology. Based on a modular design and integrating an innovative control technology referred to as "Virtual Pier", this innovative structure will be designed to significantly reduce installation time in comparison with assembled truss bridges with pin connexions. A Digital Twin of the controlled bridge will be implemented to update control models throughout the whole lifetime of the bridge, to update high-fidelity models for designers, to monitor structural health of the bridge and to ensure safety requirements of this unconventionnal crossing structure.

The complete implementation of the Digital Twin of the bridge requires to link the physical world and the digital world to continuously update numerical models throughout the lifecycle of the bridge. Computer vision systems provide full field non-intrusive measurement at relatively low cost and the hardware improvement in last decade allows high speed and high-resolution acquisition. Nevertheless, the online dynamical characterization of large-scale structures using computer vision-based techniques remains an ongoing challenge.

This PhD aims to develop a non-intrusive measurement system for continuous data acquisition and to implement a dedicated framework for online high-fidelity models updating.

Context:

The ANR-NSTC NEMELIFT project is a franco-taiwanese collaborative research project aiming at developing an innovative crossing technology to address urban mobility issues of the city of tomorrow. The agility of the solution makes its originality. The project gathers 4 international research laboratories specialized in vibrations and contact (ISAE-SUPMECA, France) and in active control systems for civil engineering applications (NCNU, NCKU, NCUT and NUK Taiwan), and 1 industrial partner (LOCAPAL) specialized in temporary footbridges and steel structures. It is divided into 3 technical Work Packages (WP) dedicated to the development of numerical tools for the robust design of light slender assembled structure (WP1, Leader SUPMECA), the control of the bridge deflection using continuous parameters identification (WP2, Leader NCNU) and the *development of a Digital Twin of this innovative technology of bridge (WP3, Leader SUPMECA). This PhD position is part of WP3.*

Thesis objectives:

The aim of this PhD is to implement a Digital Twin of a lightweight pedestrian bridge equipped with an active control mechanism.The Digital Twin to be developed in the NEMELIFT project will be mainly dedicated to model and control law updating and to risk assessment to ensure the highest safety for users. The developed DT will also address flow of people monitoring to optimize soft transport mode networks at the scale of the city.

The implementation of a DT relies on key technologies categorized between: data related technologies, high-fidelity modelling technologies, and model-based simulation technologies. Modelling and simulation technologies are addressed in WP1. This PhD thesis will thus focuses on data acquisition and on the connection between the actual behaviour of the bridge and the associated numerical models. Virtual sensor based on image processing and computer vision techniques will be developed to provide a non-intrusive and easy to setup measurement system for the real-time characterization of civil engineering structures. Data fusion and data processing techniques will be integrated in the virtual sensor to provide meta-data relevant for high-fidelity models and control law updating. Classical probabilistic tools and uncertainty propagation techniques associated with data stream and continuously updated physical models will be considered to define indicators for predictive maintenance and risk assessment.

Roadmap proposition:

1- Review of the technologies required to implement a DT and their readiness level. The consistency of these technologies with constraints related to Civil Engineering structures (e.g.: outdoor environment, energy supply, safety, risk assessment) will be investigated. *This first step aims to define the hardware and software layout of the DT*.

2- The measurement system is a key point of the DT. It is required to generate the data necessary to update high fidelity models of the bridge and control law parameters. A non-intrusive camera-based measurement system will be considered to characterize the mechanical behaviour of the bridge structure. The system and the associated images processing algorithms will be used to characterize the dynamic of the bridge online [Goeller2018][Renaud2020] and subpixel measurement techniques will be considered to overcome the resolution limitations of the camera sensor [Shih2020]. As computer vision allows full field measurement, this solution would provide a large number of virtual sensors at relatively low cost (with a single measurement system) in comparison with non-image based sensors. *This step will be based on earlier work of the NEMELIFT consortium. It will focus on the software and algorithmic developments to meet the measurement accuracy and the computation time requirements of the DT.*

3- The hardware and software architecture for high fidelity models updating is the second main component of the DT. This task includes on one hand the selection of data mapping, application layer protocol and communication technologies among available technologies [schroeder2016]. And on the other hand the implementation of data assimilation algorithms dedicated to the online continuous update of high-fidelity parameters. *Data mapping, layer protocol and communication technologies will be used as ready-to-use technologies, no research developments will be done on this topic. Data assimilation techniques, notably relying on the Observer/Kalman Filter Identification*

(OKID), on the Eigensystem Realization Algorithm (ERA) or on the On-line Recursive Least-Squares (RLS) techniques [Chu 2011, Dion2013, Stephan2017, Goeller2018, Chu 2021] will be investigated in first instance. Their performances and their implementation in the DT will be evaluated.

4- A scaled-down assembled bridge will be tested in the 8m*8m long-stroke shaking table in the southern lab. of NCREE (NCKU, Taiwan). This large scale test will be used to validate the implementation of the DT. *This experiment will validate the high-fidelity models identification process of the DT. The DT of the bridge will then be used to compute key indicators for risk assessment and predictive maintenance.*

5- Risk assessment tools will be studied and implemented as part of the bridge DT. These performance indicators will be used to monitor the structural health of the bridge, to introduce predictive maintenance and to ensure maximum safety for bridge users throughout the bridge lifecycle. Probability based approach and uncertainty propagation techniques [Ghienne2017, Blatman2010] will be considered to compute key indicators as probability-of-failure or remaining useful life. The effects of inspections and repairs would be considered [Millwater2019]. The results of the risk assessment will be imported into the Virtual Pier control system to define a fail-safe procedure.

This roadmap proposition is provided for information purposes only and would be amended depending on the progression of the thesis project.

Keywords: Digital Twin, Lightweight Bridge, camera-based measurement system, real time identification techniques, non-linear dynamics

Expected skills: autonomous, critical thinking, scientific approach, software development, familiar with linux operating systems
Software and programming languages: python, matlab, C++, (this list is indicative, other software and languages could be proposed by the candidate if relevant)
Communication: proficiency in English (in word and writting)

Application requirements:

- Resume
- Cover letter
- Master degree records

Practical organization

The start of the thesis is expected for October 2023. The main location of the thesis activities is ISAE-Supméca (3, rue fernand Hainaut, 93400 Saint-Ouen-Sur Seine). Regular meeting with the supervisory team will be organized, these meeting may be held at ISAE-Supméca or at Le Cnam (2 rue Conté - 75003 Paris). Regular workshops with taiwaneese partners will be organized. These workshop would be remote or on-site. Short or long stays in Taiwan could be organized (subject to an associated financing request). The net monthly salary will be of 2080€, including half of transport costs.

ISAE-Supméca

The research activities at ISAE-Supméca are integrated since 2015 in the Quartz laboratory (EA7393) (https://www.quartz-lab.fr/) and are concentrated around 4 main themes: Tribology & Materials, Vibration Acoustics Structures & Mechanical Forms

(VAST-FM), Sustainable Systems, Mechatronics and Multiphysics Systems Engineering. On the ISAE-Supméca side, the thesis will be carried out within the VAST-FM theme, whose activities focus on the development of methodologies to improve the reliability of the prediction and control of dynamic behaviors: vibration, shock and noise. The issues addressed in the VAST-FM theme concern the dynamics, monitoring and diagnosis of systems, structures and materials, and more particularly dissipative behaviors (damping). The historical and recurrent works concern viscoelasticity, contact dynamics, and structured materials. The emerging themes of the team concern the use of Machine Learning and video processing technologies and their applications in dynamics and vibrations.

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