Development of a best-practice approach to utilise real-time condition monitoring data in digital twins

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Abstract. Digital twins are computer simulations of physical objects that exchange data with their physical counterpart in real-time. Real-time continuous exchange of data allows digital twins to follow a structure through its full life cycle. This starts at the design stage, with prototype testing that would be otherwise difficult or impossible with physical structures for cost, safety or practical reasons. With real-time updating of data from the physical object once in-service through condition monitoring, the digital twin can then be used to inform decisions, e.g., to optimise operations and inform maintenance schedules. Currently, in certain industry sectors, measurement data are very sparse, and where measurements are available, the links to digital twins are non-existent or not well-defined. A survey of current approaches in both the virtual and physical world, defining NDE measurement approaches and digital twin requirements, is used to inform a high-level framework for effective use of condition monitoring data in digital twins.

Possible Sessions

5. Condition Monitoring 22. Structural Health Monitoring

Introduction

The use of digital twins for virtual testing and comparisons between data from the virtual and real worlds are becoming increasingly important in a range of engineering sectors [1]. A digital twin can be defined as “a simulation of a real-world object or system that exchanges data with its real-life counterpart and subsequently proposes behaviour changes based on real-time data” [2]. These digital representations can then be used to carry out prototype testing which would be either impossible, time-consuming or otherwise problematic with the physical object, due to either safety, practical, or budgetary concerns. For instance, analysing the effect of a range of design changes could be relatively simple in the virtual world, but prohibitively expensive or even unsafe in the physical world. Digital twins of engineering infrastructure in-service could also be used to optimise operations and maintenance schedules.

In order for a digital twin to remain a “twin” rather than a representation of the object at a given time, (e.g., a digital shadow or model [3]), it must remain connected to the physical world [3]. Links between digital twins and the physical object they represent are therefore important so that the digital twin is a correct representation of reality, and that its results and predictions are reliable. When an object or system is experiencing changes, due to e.g., testing or in-service use, this therefore requires real-time updating of the twin, e.g., from measurement sensors through structural health monitoring (SHM) or condition monitoring (CM). Non-destructive evaluation (NDE) measurement techniques can be used for this monitoring to provide a range of measurement information which can and should be incorporated into the virtual representation.

Previous work has identified the mechanisms and procedures by which information can be transferred between the virtual and physical world in real-time as a subject which requires development [6]. Here, we investigate current practices in industry, with the aim of determining how to define data requirements for exchange between the digital and physical world, and how information transfer links can be established.

Interviews and thematic analysis

A panel of industry experts with experience in physical measurement approaches or digital twin technology was identified across a broad range of engineering sectors. A series of semi-structured interviews was carried out with these experts, in order to determine (1) the workflows and practices used in NDE, SHM and CM measurement approaches and (2) the requirements for effective digital twin design and exploitation.

The semi-structured interview process was carried out based on the procedure of Kallio et al. [7]. Interview questions were designed to be open-ended and flexible, with the capacity to tailor follow-up questions to individual interviewees for expansion and clarification. The questions were assessed through pilot interviews to check the timing and content coverage, and allow for improvements before the interviews with the experts were carried out.

After the interviews were completed, thematic analysis of the anonymised transcripts was used to identify common subjects, experiences and ambitions for the future use of digital twins.

Results and Discussion

Initial results from the analysis of these semi-structured interviews indicate that there is a wide interpretation of the term “Digital Twin” across sectors and industries, which agrees with the findings of previous work [8]. One of the first challenges to providing a sector agnostic protocol to integrate condition monitoring measurements into digital twins will therefore be the definition of terms in sufficient detail to avoid miscommunication. This definition of terms will be particularly important to ensure interoperability between digital twins from different sources.

It has also been found that there is significant variation in the current application of digital twins across engineering sectors. Some sectors or companies have an advanced uptake of digital twins, using digital tools in some capacity in their day-to-day activity, whereas others have not yet applied digital twin technology to their operations, but are interested in the possibility of application in the near future.

When discussing the advantages or potential advantages of the uses of digital twins, several commonalities across interviews have been identified. For example, a major advantage would be the application of these tools to inform predictive maintenance, resulting in a reduction in down-time of structures and systems, which could decrease labour and capital costs and reduce waste.

However, even in sectors where digital tools are currently used, there are still challenges with the importation and utilisation of NDE data. In particular, there is a lack of measurement data at high enough spatial or temporal resolutions. In some cases, the required measurement data cannot be collected with currently available technologies due to challenging environmental conditions or access, for example in nuclear power plants. Therefore, condition monitoring data is not currently available to inform digital twins in these situations.

Further analysis of these interviews will be used to inform a best-practice protocol for data exchange between a physical structure or system and its digital twin.

Conclusions

A digital twin of a physical structure or system has great potential for use in virtual testing. However, to ensure reliability of results and predictions drawn from a twin, data exchange between the twin and its physical counterpart is required. Methods of data exchange and requirements of measurements and the digital environment are not yet well defined, so establishing a common framework, before individual industry sectors develop independent approaches, would allow for interoperability in the future.

A series of interviews with industry experts have been carried out, with questions targeted towards current and future use of digital twins, and non-destructive evaluation (NDE) and monitoring measurements used in their organisations. A range of uptake of digital twins has been found across industry sectors and companies, with some more advanced than others. However, there was general agreement across interviewees that utilisation of these technologies, combined with measurement inputs, could have significant positive impact in areas such as predictive maintenance, which would work to decrease costs and increase efficiencies. Several areas which require development have been identified, including measurement techniques which can be applied under challenging environmental conditions, such as those found in the nuclear sector.

These findings will inform the establishment of a protocol to link the physical world and the virtual world, with the aim to ensure interoperability between twins from different sources and sectors.

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