Trustworthy virtual experiments and digital twins (ViDiT) - Uncertainty evaluation for Digital Twins

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Extended Abstract

Digital Twins (DTs) are key enabling technologies to achieve and realise European strategic policies devoted to sustainability and digitalisation within Industry 4.0 and the European Green Deal [He(2021)]. DTs are simulation models that accurately replicate physical systems in a virtual environment and include dynamic updates of the virtual model according to the observed state of its real counterpart to achieve a physical control of the latter. They consist of two parts, a Physical to Virtual (P2V) connection modelling the considered system, and a Virtual to Physical (V2P) connection, which implements prevention and control strategies to achieve the target accuracy in the physical system [Jones(2020)]. DTs find application in several strategic manufacturing fields [de Ketelaere(2022)] but, within manufacturing processes, the DT's creation often neglects quality control measurements [Xin(2022)]. By neglecting measurements for quality control, their traceability, and the related uncertainty, the overall DT's results, at process level, lack traceability and they cannot be associated with a confidence level in the prediction [Zheng(2020)]. Very few examples of DTs measurement related are reported in the literature

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[Jones(2020)], and even less literature discusses DT uncertainty evaluation [Kochunas(2021)].

DTs require complex modelling which often leads to data driven approaches rather than explicit analytical models to comply with big data management and real time control. This challenges GUM application for uncertainty evaluation and rather calls for Bayesian and non-parametric approaches, often requiring a task-based evaluation. Furthermore, currently available methods for DT's uncertainty evaluation often neglect coupling with the different parts of the DT, especially the links to the closed-loop feedback control and the V2P connection. This is particularly critical because it introduces a closed-loop feedback and time-dependent control. Therefore, the precision and the accuracy of the prediction are a time and system state dependent function, which shall be evaluated and managed accordingly. Bayesian approaches with iterative update of the distribution of the DT's output variables will allow a rigorous management of such coupling effect while allowing for the prior distribution estimation by non-parametric approaches, e.g. bootstrap sampling, to better condition the problem and achieve faster convergence. A rigorous definition of DT's metrological characteristics is unavailable. Both accuracy and precision shall be defined catering for the V2P closed-loop feedback control.

ViDiT project, funded by the European Partnership on Metrology, will progress beyond the state of the art by developing methods, suitable to cope with the above mentioned challenges, for uncertainty quantification for DTs representing complex measurement processes and mechanisms for four different applications (nanoindentation, NanoCyl, 3D robotic measurement, electrical measurement). Specifically, a case study for nanoindentation will be developed at Politecnico di Torino and Università degli Studi di Padova. In nanoindentation applications, the wear state of the indentation tip is a critical factor, and its shape needs to be continuously controlled to update the calibration or to know when it needs to be disposed of. Similarly, the thermal flux between the sample and the indenter is a critical factor biasing the results if the test is not performed a conditioned environment. Moreover, nanoindentation is highly sensitive to vibrations. A trustworthy DT of this process needs to be established to allow the status of the indentation tip to be monitored along with the correction of real time thermal and vibration effects.

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