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Letters

Digital twin – Proof of concept

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ABSTRACT

Miniaturization and price decline enable the integration of information, communication and sensor technologies into virtually any product. Products become able to sense their own state as well as the state of their environment. Paired with the ability to process and communicate this data allows for the creation of digital twins. The digital twin is a comprehensive digital representation of an individual product that will play an integral role in a fully digitalized product life cycle. To prove the digital twin concept a cyber-physical bending beam test bench was developed at DiK research lab.

1. Introduction

Industrie 4.0 is the fusion of current manufacturing technologies with modern information- and communication technologies. The driving force behind this development is the rapid digitalization of industry and society [1]. Industrie 4.0 represents another paradigm shift in manufacturing. After the steam engine, assembly line and automation it is often called the fourth industrial revolution [2].

However, digitalization does not stop at the factory level. Smart factories are producing smart products. Miniaturization and price decline enable the integration of information, communication and sensor technologies into even the smallest products [3]. Products become able to sense their own state as well as the state of their environment. Paired with the ability to process and communicate this data allows for the creation of digital twins.

Since the formation of the concept by John Vickers and Dr. Michael Grieves [4] many authors have tried to define the term digital twin, starting in the aerospace industry [5] with a focus on structural mechanics, material science and the long-term performance prediction of air and space crafts [6,7]. With the rise of Industrie 4.0 the focus shifted towards manufacturing and smart products [5]. In this context the digital twin can assist in ensuring information continuity throughout the entire product lifecycle [9,10], virtual commissioning of (manufacturing) systems [11], and decision support and system behavior predictions in the product development phase as well as all subsequent lifecycle phases based on computer-aided simulations [12].

Many authors assume that the digital twin is a collection of all digital artifacts that accumulate during product development linked with all data that is generated during product use. Contrary to this Boschert and Rosen [8] argue that the digital twin is a linked collection of only the relevant data and models. The models that make up the digital twin are specifically designed for their intended purpose.

For the purpose of this publication the digital twin is seen as follows. The digital twin is a comprehensive digital representation of an individual product. It includes the properties, condition and behavior of the real-life object through models and data. The digital twin is a set of realistic models that can simulate its actual behavior in the deployed environment. The digital twin is developed alongside its physical twin and remains its virtual counterpart across the entire product lifecycle. To prove this promising concept a digital twin test bench has been developed at DiK research lab.

2. Materials and methods

A bending beam test bench was chosen, to demonstrate the digital twin concept. The bending beam is easily comprehensible, yet the potentials of the technology can just as easily be demonstrated with this example. As with any digital twin system, the test bench consists of a physical twin, a digital twin and a communication interface that connects the two.

The physical twin consists of two linear actuators in between which the bending beam is clamped. Two load cells are integrated into the holding fixture on one side to measure the resulting force. The displacement is calculated as the difference between the

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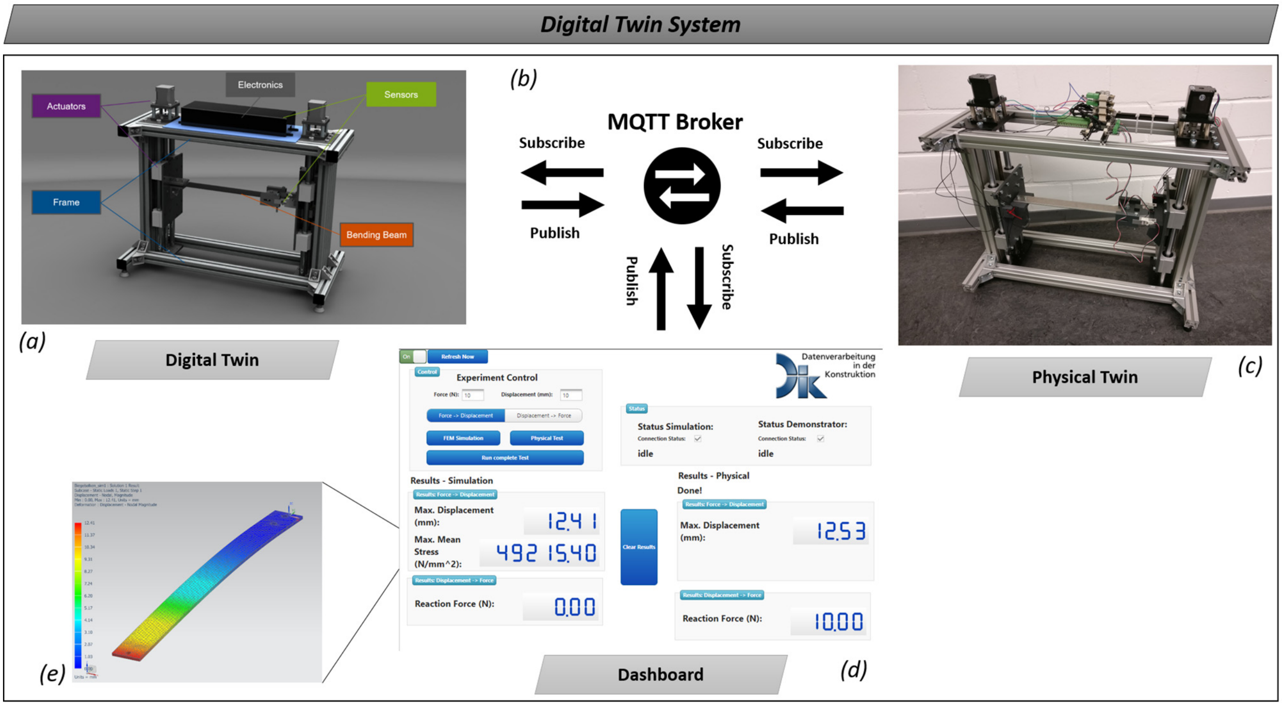

On Refresh Now

Control
Experiment Control
Force (N): 10 Displacement (mm): 10
Force -> Displacement | Displacement -> Force
FEM Simulation | Physical Test
Run complete Test

Status
Status Simulation: Connection Status: ✓ idle
Status Demonstrator: Connection Status: ✓ idle

Results - Simulation
Results: Force -> Displacement
Max. Displacement (mm): 12.41
Max. Mean Stress (N/mm^2): 49215.40
Results: Displacement -> Force
Reaction Force (N): 0.00

Clear Results

Results - Physical
Done!
Results: Force -> Displacement
Max. Displacement (mm): 12.53
Results: Displacement -> Force
Reaction Force (N): 10.00

Fig. 1. Overview of the Digital Twin System. The Digital Twin (a) and the Physical Twin (c) are connected through a broker-client-architecture (b). The system is controlled via a web-based dashboard (d) accessible from any internet-capable device. Running a complete test through the dashboard will trigger the actuators of the physical twin as well as a FEM simulation. Results are shown numerically on the dashboard as well as graphically in the CAD system (e).

positions of both linear actuators. The control unit is set atop the frame. The whole setup can be seen in Fig. 1.

In this first development stage, the digital twin consists only of an exact CAD representation of the bending beam. The holding fixtures and the frame are regarded as rigid. Next stages include the combination of multi body and finite element method simulations in order to accurately mirror the entire test bench in the virtual space.

To connect the physical and the digital twin a publish-subscribe architecture based on the MQTT messaging protocol was chosen. This architecture includes a broker which collects the information published on certain topics and distributes them to interested clients who subscribe to these topics. Using a message broker easily allows the inclusion of further clients into the architecture. One such client is an IoT platform, which was used to control physical and digital twin as well as view the results of the bending beam experiments through a dashboard.

To start the experiment the dashboard (see Fig. 1) is opened in a browser on any internet-capable device. Either the resulting force on the beam or the final displacement of the beam are put in as parameters. Pushing the Run complete test button sends the variables to the broker who distributes them to the physical twin, which then moves to the selected position until either the displacement or the force is reached and measures the other variable respectively. The variable is then sent back to the broker who forwards it to the digital twin and the IoT platform. The digital twin uses the real force or displacement values to start a fully automated FEM analysis. The calculated results are also pushed back to the IoT platform through the broker where they can be compared to the physical results.

3. Results and discussion

First tests show that the deviation between physical and digital beam test are within the margin of error, taking into account measurement as well as manufacturing tolerances. However, the actual goal of the test bench is not to calculate forces or displacements for a given beam but to demonstrate the digital twin concept and how it can be applied to actual systems. From the example of the bending beam the concept can easily be extrapolated to the real-life system of an aircraft wing. Through the integration of various sensors as well as the derivation of an as-built structural model from the original CAD-model as well as a connection between the two numerous possibilities arise. Two examples being a continuous structural health monitoring of the system or the simulation of near future scenarios taking into account actual environment variables based on real-time sensor data. The integration of sensors and ubiquitous computing are already major trends in society as well as industry. However, the development of a digital twin for an individual product is still a time-consuming manual task. In order to be able to implement digital twins for any smart and connected product or system, the unique instantiation from the universal model needs to be automated.

4. Conclusion

A digital twin test bench was successfully developed to prove the concept of the digital twin. The current setup still has limitations, which are the subject of further research. The next step is to model and implement a motion-structural-analysis. In this approach the entire test bench is modeled with joints. All parts are able to move within their specified degrees of freedom. The bending beam itself is integrated as a flexible body. In the finite element analysis of the bending beam the force exerted on the beam is then not put in explicitly but becomes a result of the respective displacement of the linear actuators. The input data comes from the actuators of the physical twin.

However, current CAx models are specifically designed for use in product development. They are not designed to live on as digital twins, which means they are not designed to represent the actual state of the product all through its entire operational phase. Therefore, a paradigm shift is necessary. A template for the digital twin of a product needs to be developed alongside the product throughout all the phases of the product development process. As the physical product is produced and thereby instantiated from its product model, individual digital twins need to be instantiated accordingly from the digital twin template for each product instance. Additionally, traditional data collection and processing methods do not meet the needs of the digital twin paradigm and need to be rethought. These considerations are currently taking place in the domain of big data analysis but need to also be fitted to the domain of manufacturing.

Ultimately, the goal is to automatically derive the digital twin and implement the communication interface with its physical twin in order to make the technology viable for a wide range of products and use cases.

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