Exploration of the advantages and an algorithm for the implementation of the digital twin concept

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The paper presents a research into the concept of digital twins based on a virtual prototype and the advantages it has. Also presented are the inner workings of the digital twin method and the possible algorithms for implementing it in the manufacturing workflow. Additionally, software products that take care of that process by guiding the user and helping them to implement the vast quantities of data and the sensor data acquisition the needed components from the Internet of Things methodology.

Presented are the summarized advantages and reasons for implementing the digital twin methodology.

Keywords: Digital Twins, CAE, IoT, Industry 4.0

I. Introduction

With the massive integration of intelligent systems and the industrialization of Internet of Things (IoT), a conceptual model has emerged that has become an intersection between them and the concept of Digital twin.

In essence, the Digital twin is informationally linked to a specific physical object and is built based on systems for modeling and simulation technologies which are essential for supporting the engineering cycle into a loop enclosed into an interconnected cyber-physical system.

There are many definitions mentioned in the literature for the Digital twin concept. Some of them include the following:

- The Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin. [1]
- Coupled model of the real machine that operates in the cloud platform and simulates the health condition with an integrated knowledge from both data driven analytical algorithms as well as other available physical knowledge [2]
- The digital twin is a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them. [3]
- The digital twin is a dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning. [4]
- Using a digital copy of the physical system to perform real-time optimization [5]
- A digital twin is a digital replica of a living or non-living physical entity. By bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the physical entity. [6]

It is easy to see that there are many and very different definitions of the Digital Twin concept, which can lead to confusion towards the concept as a whole. This in turn demonstrates the novelty and the relatively early stage of the concept development which is currently in a stage of strong innovation. These innovations are expected to continue between 5 and 10 years before the expected slowdown in development. [7]

The development concerns the presentation of the advantages and an exemplary algorithm for the implementation of the concept of Digital Twins.

II. Nature and Application of the Digital Twins Concept

The concept of a digital twin finds its application in situations where a physically working product can bring more useful information than existing virtual prototypes while using the Internet of Things as a communication medium between the twin and the real object. This is a very valuable feature of the digital twin, especially when it comes to complexity in determining the load on the construction in an analytical way. [8]

The transfer of traditional mechanical products to a new generation of products with built-in connectivity and intelligence is new and therefore unknown to the industry. Solving problems through physical prototyping is a classic solution for mechanical system issues and has its place. In turn, virtual prototyping by product modeling and simulation is faster in reaching a good result in the prototyping process compared to physical prototyping [9]. This approach has an even greater advantage in the use of Intelligent Systems and IoT platforms.

Based on the study, it is necessary to precisely define the differences between the virtual prototype and the digital twin because of the apparent similarities between them. The main differences are described as follows:

- **The virtual prototype is an information and simulation "duplicate" but for a nominal physical object, thus not taking into account the specific features of the specific physical object. In addition, the virtual prototype is used and generates information for the product in an abstract rather than real time.**
- **The digital twin is not an abstract information and simulation "duplicate" of a nominal physical object, but is specific and individual to the physical**

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object in question. In this way, it takes into account its specific features and is specific to it.

- **The digital twin also includes the real time parameter – that is, it collects data about the behavior of the physical object with respect to time in an informational database that is an integral part of the twin. These data are obtained through a built-in sensor system by feedback to the digital twin, measuring the values for important parameters. These measurements are not only under certain conditions, but also a function of time.**

III. AN APPROACH TO BUILDING A DIGITAL TWIN ON THE BASIS OF A PHYSICAL PROTOTYPE

An intelligent integrated digital twin product development approach that is linked to the Internet of Things (IoT) platform can be addressed by building a partial or full physical prototype. Once it is built, a sensor system is integrated on it and that system needs to be connected to an IoT platform that is responsible for collecting and processing the measured data. The processed data should be translated into a usable format for the digital twin, thus generating large amounts of data on the behavior of the physical prototype and being compared to a virtual prototype in order to improve it.

In the case of digital twins based on a physical prototype, there are limitations on the experiments due to the possibility of destruction of the physical prototype, limitation of the sensor's positioning due to lack of space or impossibility of attachment, electromagnetic, vibrational or other disturbances. Particular attention should be paid to electromagnetic fields due to the possibility of interfering the communication between the sensor and the Digital Twin. This determines the careful determination of these parameters.

An example of a cycle of building a Digital Twin is proposed by ANSYS for their ANSYS TwinBuilder package and is shown in Fig. 1.

Fig. 1. Cycle for Creating and Integrating the Digital Twins Concept proposed by ANSYS

IV. PRACTICAL INTERPRETATION OF A DIGITAL TWIN

Digital twins are widely used in connected and intelligent products and IoT platforms. They also further develop the functions of the virtual prototype.

This is done through the following approaches:

- **Implementation of the virtual prototype to predict the behavior of physical devices.** This option uses expert systems and artificial intelligence in combination with logical and mathematical algorithms to process and evaluate the data collected and their degree of influence on the investigated product by correlating against data from existing events. In such a way, it is possible to predict future behavior based on statistical data.

- **0D simulation** – the model may have no geometric dimension and is only functional. For these simulations, the only variable that is important for it is time. These simulation models are only used for functional verification of a system.

- **1D simulation** – these models are a combination of separate validated blocks that simulate the operation of multidisciplinary engineering systems in a certain one-dimensional direction (tracking and predicting the change of a given parameter). They can provide a deeper insight into the current work of the physical object by analyzing the possible changes to the product.

- **3D simulation** – these models are used to predict the structural and dynamic indicators of the studied products. [10] They have the opportunity to gain in-depth knowledge of the current operation of the product as well as to study the behavior of the product in difficult reproducible and unfavorable working modes of the product in order to improve or prevent failure of the product.

- For digital twins based on engineering simulations with a virtual prototype and in the absence of a physical one, there is an opportunity to accumulate knowledge about the abstract behavior of the virtual prototype in different conditions. In the absence of a physical prototype that feeds the virtual one with data and transforms it into a complete digital twin, it remains at the virtual prototype level.

- With "historical" data derived from such products, virtual prototypes can be transformed into digital twins as there is information to feed the integrated digital twin database.

V. AN ALGORITHM FOR THE INTEGRATION OF THE CONCEPT OF DIGITAL TWINS WITH THE HELP OF ANSYS TWINBUILDER

Based on the capabilities provided by ANSYS TwinBuilder, a methodology has been developed for their implementation. ANSYS TwinBuilder is a special module designed to facilitate the implementation and use of digital twins by providing different languages and development domains. This way, a very high level of abstraction can be achieved to precisely build the digital twin. Some of these languages and domains are as follows:

- Multi-Domain Systems
- Co-Simulation
- Block Diagrams
- Circuits
- Test Data
- Reduced-Order Models – Example from 3D to 1D simulation
- Digital/Mixed-Signal
- C-Code, FMU, VHDL-AMS, Modelica, etc.

In addition, ANSYS Twin Builder allows the use of 0D simulation models as part of the digital twin with the help of built-in dedicated libraries for modeling control, hydraulic, mechanical, digital, electrical, power, manufacturing, automotive, aerospace and other systems that are interconnected.

Based on the rich toolset of the software, an algorithm for digital twinning is proposed. This algorithm is shown in Fig. 2 and is explained in detail below.

- **Stage 1: Creating a Virtual Computing Model of the Product.** At this stage, a multiphysical or a physical model of the product may be created depending on the digital twin's desire for detail.
- **Stage 2: Creation of a Reduced-Order Model** At this stage, a simplified model is created based on created functional surfaces describing its behavior. The goal of this reduced-order model is to reduce the occupied computing space, as well as speeding up the computing process. Of course, this is achieved as an optimum between the calculation time and satisfactory data accuracy.
- **Stage 3: Defining the input parameters for the Reduced-Order Model.** At this stage it is selected which input parameters are important to the model. An example of such data may be the magnitude of the current for an electric asynchronous motor.
- **Stage 4: Defining the input parameters for the Reduced-Order Model.** Similar to Stage 3, the output parameters relevant to the digital twin are selected here. Continuing with the example for an electric asynchronous motor such data can be the magnitude of the torque and the maximum engine operating temperature.
- **Stage 5: Using test data for the input parameters.** At this stage, input parameters from pre-collected real-time data are used to duplicate its behavior and are fed to the input parameters of the Reduced-Order model.
- **Stage 6: Executing a system simulation of the product.** In this stage, the input parameters are calculated based on the values of the output parameters for the digital twin. These calculations are based on the approximate values of the calculated response surfaces.
- **Stage 7: Processing the calculated output data.** At this stage, based on the output parameters, an overall assessment of the monitored product data is made – in the case of an asynchronous electric motor this can be the calculated life of the product.
- **Stage 8: Generating of the digital twin.** After the results are obtained, ANSYS TwinBuilder provides the opportunity to create a digital twin model based on the performed system simulations.

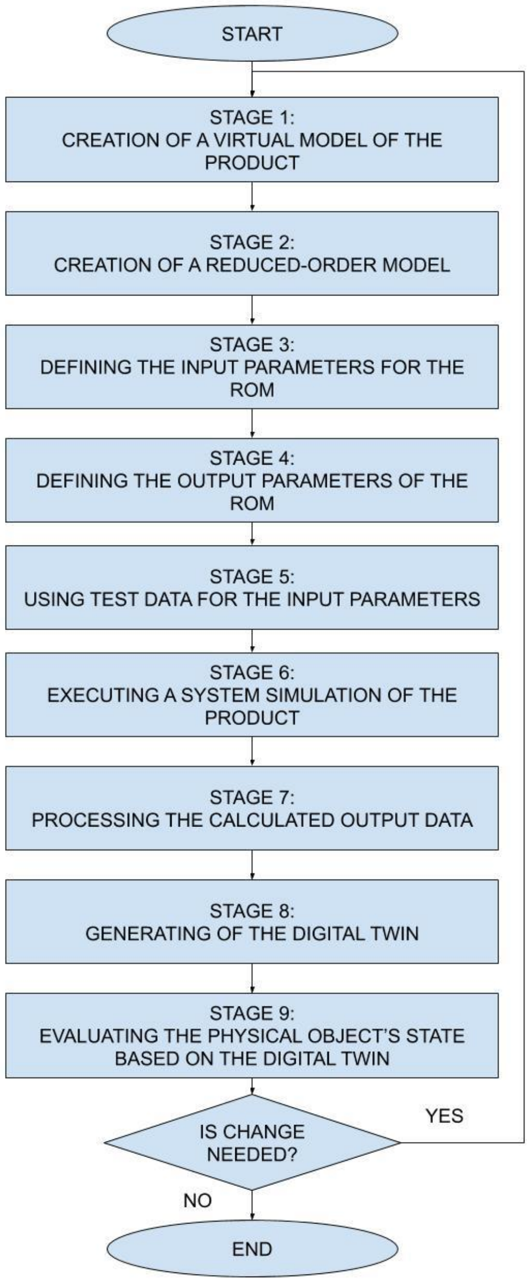

Fig. 2. Suggested algorithm for implementation of the Digital Twin concept using ANSYS Twin Builder

- **Stage 9: Evaluating the physical object's state based on the digital twin.** At this stage, an actual product can be evaluated, even if it is remotely placed. In this way, the operating modes and the wear of hard-to-reach objects can be assessed. An example of such an object is an electric wind turbine in the ocean.

If an adjustment to the operating modes or the product itself for future items is needed, it is necessary to repeat the evaluation stage. However, if the results from the taken steps are satisfactory, the cycle is closed.

VI. CONCLUSIONS

The advantages and application of digital twins are presented in the modern conditions of a highly modernized industry, which uses technologies from Internet of Things to achieve intelligent connected systems.

The set of previous definitions of a Digital Twins is outlined and a new one is proposed that differentiates it from virtual prototypes. An algorithm for the implementation of a digital twin is also proposed using the ANSYS TwinBuilder software module. The result of the study is the determination of Digital Twins and their place in terms of Industry 4.0.

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