The role of semantic and ontological networks in the digital twin management in manufacturing

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***Abstract*—The paper is devoted to present an overview of the current state of the digital twin development in manufacturing domain in order to determine the place of semantic and ontological networks in digital twin structure. In particular, the current international standards, technical reports and recommendations in the field of Industry 4.0 and Industrial Internet of Things regarding digital twins are considered and analyzed.**

The article is divided into 3 parts: the first part deals with the concept and main functions of digital twin from different points of view, including standards, the second part concentrates on modern systematized, standardized and applied functions of semantic and ontological networks in industry, in the third part the authors present their vision regarding the role of semantic and ontological networks in the digital twin development and implementation in industry.

Keywords – digital twin, Industry 4.0, Industrial Internet of Things, semantic, ontology.

I. Introduction

Today, the technologies of the fourth industrial revolution are becoming increasingly important in various industries. The technologies behind the Industry 4.0 and Industrial Internet of Things (IIoT) concepts offer new opportunities for products and services. Driven by Industry 4.0 and IIoT approaches and the development of Big Data analytics computing power, fast algorithms, and amount of available data allow to model and optimize the physical process with real-time control. The digital representation of the physical twin, known as a digital twin (DT), is one of the most important aspect of the fourth industrial revolution. DT accompanies the relative asset throughout its lifecycle from conception to disposal and even after disposal. For process control systems, which are considered as an asset as well, it is also advisable to develop a digital twin in combination with the controlled object. It is expected that at the operation stage the digital twin of such technological complexes will provide accurate prediction of their future behavior and will help to effectively maintain the quality of technological processes by easy visualization and integration of cognitive capabilities into the real system. However, there is currently no single methodological approach for the development and implementation of DT in manufacturing. Despite the presence of a large number of existing international standards, designers and developers of automated process control systems offer a variety of DT solutions that differ in purpose, functionality, architecture, etc. Alternatively, representatives of specialized software such as SCADA, CAD, MES/MOM offer variant solutions for the implementation of DT at its appropriate level of automation.

II. Digital twin: characteristics and standards

The digital twin concept was first introduced in 2002 at the University of Michigan Executive Course on Product Lifecycle Management by Michael Grieves. At that time, digital representations of actual physical products were relatively new and immature. In addition, the information being collected about the physical product as it was being produced was limited, manually collected, and mostly paper-based. According to the model proposed by Dr. Michael Grieves the Digital Twin concept model (Figure 1) consists of three parts [1]:

- physical products in Real Space;
- virtual products in Virtual Space;
- the connections of data and information that ties the virtual and real products together.

The White Paper, published by the Industrial Internet Consortium (IIC) and Plattform Industrie 4.0 [2], describes the applicability of the digital twin concept in various domains of the Industrial Internet of Things, including smart manufacturing, automotive, supply chains and logistics, building automation, smart cities and critical infrastructures. Today, Digital Twin Consortium is doing the promotion of the digital twins use in various fields, the development of digital twin technologies, the

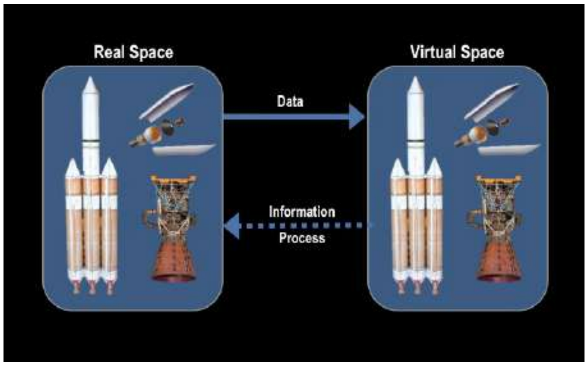

Figure 1. Digital Twin concept model by Dr. Michael Grieves (source – [1])

development of technical guidelines, and requirements for new standards in order to maximize the benefits of digital twins. Unlike IIC and Digital Twin Consortium a German platform Plattform Industrie 4.0 focuses on implementing the concept only in the manufacturing sector focusing on machine industry.

The Consortium released an official definition of a digital twin: “A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity” [3]. In contrast to the concept model of Dr. Michael Grieves, the definition of digital twin focuses on real-world entities, because the things for which virtual representation should be provided can be immaterial things like organizations, supply-chains, work-orders. Official documents from Digital Twin Consortium have not been published yet. However, according to the organization’s work [4], a digital twin is implemented in a digital twin system. It consists of a virtual representation, services, service interfaces and various applications according to the purposes of digital twin use case. A virtual representation includes stored structured information that represents states and attributes of entities and processes, computational algorithms and supporting data that represent entities and processes from a dynamic perspective.

As part of the Industrie 4.0 initiative, the Reference architecture model industry 4.0 (RAMI4.0) was developed to build smart manufacturing. The model provides a representation of all enterprise assets, including personnel and software, in the network form of not hierarchical I4.0 components linked with each other by I4.0-compliant communication. I4.0 components are globally and uniquely identifiable participants capable of communication, and consist of the asset administration shell and the asset (as in Figure 2) with a digital connection within an I4.0 system. An I4.0 component can be a production system, an individual machine or unit, or a module within a machine [5]. Assets shall have a logical representation in the "information world" (virtual world), which is called the asset administration

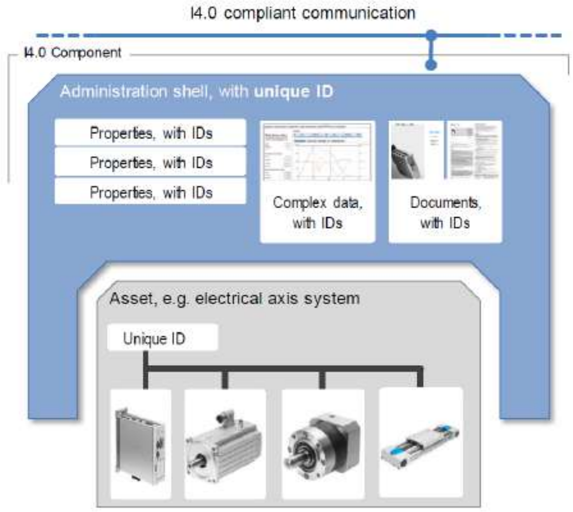

Figure 2. Asset administration shell (source – [6])

shell (AAS). In fact, AAS is an implementation of a digital twin for manufacturing applications. It has been defined and designed to ensure interoperability between companies throughout the value stream. ASS includes asset information collected throughout the lifecycle in a structured manner and real-time data. ASS consists of properties, which are grouped in a submodel according to the relevant domain. Such properties are standardized data elements. It is recommended to use repositories such as IEC CDD (common data dictionary) or ECLASS to define such properties [6]. The worldwide unique identifier associates a property type with a definition, which is a set of well-defined attributes.

There are various activities regarding standardization of digital twins. IEC 62832-1 – “Digital Factory” is a well-established standard, which defines a digital factory framework with the representation of digital factory assets. A lot of standards are on the development stage, such as IEEE P2806.1 – “Standard for Connectivity Requirements of Digital Representation for Physical Objects in Factory Environments”, IEEE P2806 – “System Architecture of Digital Representation for Physical Objects in Factory Environments”, ISO/DIS 23247-1 “Automation systems and integration – Digital Twin framework for manufacturing – Part 1: Overview and general principles”, IEC 63278-1 ED1 Asset administration shell for industrial applications – Part 1: Administration shell structure.

III. Semantic and ontology: place and purpose

Due to the active digitalization of the industrial sector, in particular the widespread use of the Industrial Internet of Things and digital twins, some problems have been revealed:

- absence of a single unified industrial thesaurus;

- variety of large amounts of data that need to be processed;
- absence of a single digital twin model that describes all aspects of the system behavior and its parts from different points of view and is intended for different purposes.

As described in many sources, in particular in [7], there is no single thesaurus that will unite the various branches of the industrial sector. In particular, relevant identified standardization activities of ontological semantics used in IIoT are: eCl@ss (ISO 13584-42 and IEC CDD classes and properties), "Semanz4.0", "AutomationML" (IEC 62714), "WSDL" (Web Services Description Language by W3C), IEC SC3D with IEC 61360, IEC 62656, IEC CDD (the semantic and ontological repository based on IEC 61360 and IEC 62656). On the one hand, the problem with the unity of the digital twin model lies in the need for availability of many different, unrelated and non-unified models. On the other hand, the interconnection of digital twins in a single system [8] requires their interaction, which requires the unification of such interaction at the conceptual level.

An effective way to overcome these problems is to use an ontology. Ontology is classified according to various criteria, including completeness, level of generalization, application domain, purpose or descriptive language. The need for an ontology is indicated in the follow resource [7], however, final view of ontology is not sensible. The only thing written in this document are two ways to use the integrated semantics: to provide an information model (related to a specific ontology) for querying or reasoning purposes, and to provide a system dynamics model supporting checking inconsistencies during interoperation. Both possible interpretations shall be related to semantics web descriptions.

Data models and ontology play different functional roles in the digital twin system. Persistence data models are proposed to be used for stored structured information. Service interfaces embody a logical data model that describes the data structures and types used by the API or protocol. Conceptual data models compatible with the general ontology can be used in the digital twin system that integrates information from several structured data repositories, each of which has persistence and logical data models. A variety of data modeling languages can be used, in particular Digital Twins Definition Language, OWL.

Standardization is involved in the formation of the upper-level ontology (for example, BFO – ISO/IEC 21838-2 [9]), ontology description languages (for example, RDF [10] and OWL [11]), as well as models of preservation and representation of a particular application domain (for example, ISO 15926 [12]). In addition, there are various applications of ontological networks, for example, OSTIS developed in accordance with ISA-88 [13] and highly specialized domains and cores [14].

The RAMI 4.0 architecture defines a number of W3C standards that reflect the semantic representation of the model data in the network, there are OWL, RDF, RDFS [15], SPARQL [16], RIF/SRWL [17, 18]. RDF, OWL and SPARQL underlie the semantic WEB. The first three technologies are used to represent metadata, the fourth one is used to query the ontological database, and the fifth one is used to form axioms and rule interchange format. Such semantics have a number of advantages, such as reasoning over data and working with heterogeneous data sources, the single structure that allows data to be shared and reused across application boundaries.

In fact, these recommendations are not enough to build a comprehensive distributed network for IIoT. Therefore, new recommendations from W3C covering IoT appeared since 2017. They include: OWL-Time [19], SSN ontology [20] and WoT [21]. OWL-Time describes the subclasses and properties of the two generalized classes of temporal position and temporal duration of resources on WEB pages. SSN ontology describes an ontology of sensors and actuators based on a self-contained core ontology (Sensor, Observation, Sample, and Actuator – SOSA) and defines several conceptual modules that cover the key concepts of sensor, actuation and sampling: observation/actuation/sampling, deployment, system, system property, feature, condition, procedure, result. WoT recommends a general concept for the existence of IoT in the network. In particular, thing description, interaction model, protocol binding, WoT interface, etc. are described. Thus, a set of templates for Web of Things is formed.

IV. Results and suggestions

Based on the analysis, the following conclusions can be drawn:

- there are problems that need to be solved by means of unified semantic and ontological approaches during the development of DT;
- there are DT developments based on ontological models in scientific articles, but there is no single approach;
- in the context of DT ontology can be used as:
  - a knowledge base that stores information throughout the asset lifecycle – structured storage for DT;
  - a knowledge base for the application domain modeling, that deals with a regular historical database and extracts the necessary knowledge – a framework for structuring different types of DT models;
  - a database for presenting metainformation about DT to provide the adapted interaction with other components of the system – WoT;

– a mean of DT information support, that works with open ontological databases in the network and serves to provide supporting information – semantic WEB, OSTIS, etc.

However, today there are very few implementations of ontological approaches in DT. In authors‘ opinion the most promising DT model should have: ease of understanding and implementation, openness, a set of ready-made components for deployment (frameworks) and significant added value.

V. Conclusion

The paper discusses some standards and documents regarding the DT development from leading industry organizations and committees such as ISO/IEC, W3C. It has been found that the use of semantic and ontological networks to integrate and formalize different types of DT parts is offered by standards and applied solutions. However, there is currently no single systematized solution.

The authors come to the conclusion that a number of recommendations from W3C is the most promising direction of applying semantic and ontological networks during the DT development. W3C recommendations have significant advantages and can be used today because they provide interoperability, thus it will help to connect parts of different distributed components based on unified interfaces or protocols.

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Роль семантических и онтологических сетей при организации и реализации цифровых двойников промышленных предприятий

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В работе представлен обзор современного состояния области разработки цифровых двойников промышленных предприятий с целью определения семантических и онтологических сетей в их структуре. В частности рассмотрены и проанализированы существующие на сегодня международные стандарты, технические отчеты и рекомендации в области Industry 4.0 и Industrial Internet of Things по направлению, которое касается цифровых двойников.

Статья структурирована следующим образом: в первой части приводится концепция и основные функции цифровых двойников с разных точек зрения, включая стандарты, во второй части рассмотрены современные систематизированые, стандартизированные и прикладные функции семантических и онтологических сетей в промышленности, в третьей части - авторы приводят свое видение и роль онтологических сетей при проектировании и реализации цифровых двойников в промышленности.

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