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Procedia CIRP 118 (2023) 259–263

www.elsevier.com/locate/procedia

16th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '22, Italy

Integration of Legacy Systems to Cyber-Physical Production Systems using Semantic Adapters

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Abstract

Cyber-Physical Production Systems increasingly use semantic information to meet the grown flexibility requirements. Ontologies are often used to represent and use this semantic information. Existing systems focus on mapping knowledge and less on the exchange with other relevant IT systems (e.g., ERP systems) in which crucial semantic information, often implicit, is contained. This article presents an approach that enables the exchange of semantic information via adapters. The approach is demonstrated by a use case utilizing an MES system and an ERP system.

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Peer-review under responsibility of the scientific committee of the 16th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: CPPS; Ontology; Semantic adapters; Legacy systems

1. Introduction

Modern production systems are increasingly characterized by decentralized approaches [1] and components capable of reacting to changing conditions and solving complex problems through intelligent task distribution. Cyber-Physical Production Systems (CPPSs) as a framework and reference architecture play an increasingly important role in the context. The transformation from traditional systems to modern architecture often occurs stepwise incremental rather than in a radical revolutionary manner. Mainly when using the incremental approach, the currently used IT systems with the available data as the foundation of the knowledge base are of paramount importance for the upcoming newer systems. Completely rebuilding the existing data and knowledge structure is neither quickly feasible in terms of time nor reasonable in terms of resources. The exchange of data between the existing systems and the CPPSs thus represents a vital design task in the construction, maintenance, and expansion of the systems. While traditional systems are often structured in a classical data- and function-oriented way, CPPSs are increasingly oriented toward a more knowledge-oriented [2–4] approach, which means a pure data exchange, without transformation into the underlying paradigm, is insufficient. The paper presents an approach that supports the exchange of data and the necessary transformation to enable a meaningful content transfer.

Section 2 briefly discusses the basic principles and approaches for mapping the knowledge and data structure and the general coupling possibilities. Thereupon, section 3 describes the concept of coupling based on semantic adapters, which is demonstrated in section 4 using an exemplary implementation. Finally, section 5 summarizes the results and outlook on further research.

2. Background and Related Work

2.1. Cyber-Physical Production System and Semantics

[5] defines CPPS as "… systems of systems of autonomous and cooperative elements connecting with each other in situation dependent ways, on and across all levels of

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10.1016/j.procir.2023.06.045

production, from processes through machines up to production and logistics networks, enhancing decision-making processes in real-time, response to unforeseen conditions and evolution along time". The definition allows deriving the essential basic skills (a) communication (Connectedness), (b) Control (Responsiveness), and (c) Computation (Intelligence).

While standards are being established in the area of communication through frameworks such as IMSA, RAMI 4.0, and IIRA, as well as in the area of control, e.g., OPC-UA and MQTT, in the area of computation, standards are only available in rudimentary form. However, the basis of explicit semantics required in this area is being pursued in many current research approaches. The approaches cover a wide range and extend from domain or application-specific concepts to more general solutions.

For instance, [3] use semantics to structure elements and define capabilities in ultra-flexible factories. Here, knowledge is modeled in the form of an ontology to define the properties and capabilities of the components so they can, in turn, be used to ensure flexibility.

[4] as an example of an application-specific approach, use the SOSA ontology as a knowledge base for calculating the Overall Equipment Effectiveness (OEE). The knowledge base combines product-oriented information with production equipment and sensor data. Using the ontology allows for mapping the specifics of the corresponding information objects in detail.

[6] show a general approach to using knowledge orientation with a modeling approach representing the complete smart factory. Based on a generically oriented model (Smart Manufacturing System Ontology), the knowledge base has an explicit semantic representation and is provided to the decision-making level using ruling or reasoning.

The use of semantic information in the approaches refers to local system elements and is also used for the exchange of information or knowledge components between systems. For example, [7] show how the "Manufacturing Execution System as a Service" (MESS) approach is used to communicate and integrate CPPS and MES on a semantic basis. Another approach for semantic exchange is given by [8], who make data analysis usable for semantic structural application in Digital Twins.

2.2. Legacy Systems and Connectivity

Based on the IEC 62264 standard [9], the production-relevant IT systems are divided functionally into the following levels

- Level 4: Business Planning and Logistics
- Level 3: Manufacturing Operations and Control
- Level 2: Monitoring, Supervision, and Control
- Level 1: Sensing and Actuation
- Level 0: Production Process

Within the structure, enterprise resource planning (ERP) and supply chain management systems can be assigned to level 4, manufacturing execution systems (MES) to level 3, and PLC (program logic controller) and SCADA (supervisory control and data acquisition) systems to level 2 to level 0 [10].

While CPPSs represent relatively new approaches, established IT systems in production environments have often been conceptually designed a long time ago. Due to compatibility requirements, the underlying architectural principles (n-tier structures [11]) have remained relatively unchanged over time.

Although efforts are also being made to build systems with a new structure, e.g., MES systems based on ontologies [10, 12], in practice, most systems can still be assumed to have a conventional structure. The legacy systems are usually characterized as follows:

- strong function orientation (conventional or via microservices)
- firmly defined interfaces with implicit semantics and
- high data volume in terms of scope and duration
- transaction orientation

2.3. Integrating Legacy Systems into CPPSs

Increasingly complex decisions require comprehensive data and knowledge bases in modern production systems, so partial integration of the legacy systems' databases into CPPS is necessary and reasonable [13]. The integration thereby allows for the further development of the legacy systems into CPPS [14]. Permanent integration requires appropriate data and knowledge content provision for up-to-dateness and contextual consistency. The concept and technical implementation of integration are presented below.

3. Methodology

3.1. Semantic Adapters

The integration of the legacy systems uses the concept of the "semantic adapter". The semantic adapter establishes the connection between the legacy systems and the CPPS. While the legacy systems are characterized by implicit semantics, the semantic adapter generates an explicit semantic object from the legacy system data. Storing the semantic object preferably uses ontologies located in a central ontology storage accessible by all CPSs. Besides the ontology storage, the semantic knowledge representation could also be located in a single CPS. The acquisition is initiated in each case by the available application interfaces of the legacy systems. The legacy systems usually provide either standard application interfaces, e.g., via function-oriented interfaces such as SOA or microservices or via application-data interfaces that allow access to the corresponding data structure of the legacy systems. Besides transforming, the semantic adapter can also store the implicit information in available centralized or decentralized data structures of the CPSs. Thus supplying systems in which the data and knowledge base are persisted completely or partially in pure data storage structures is possible. Figure 1 accordingly depicts the basic structure.

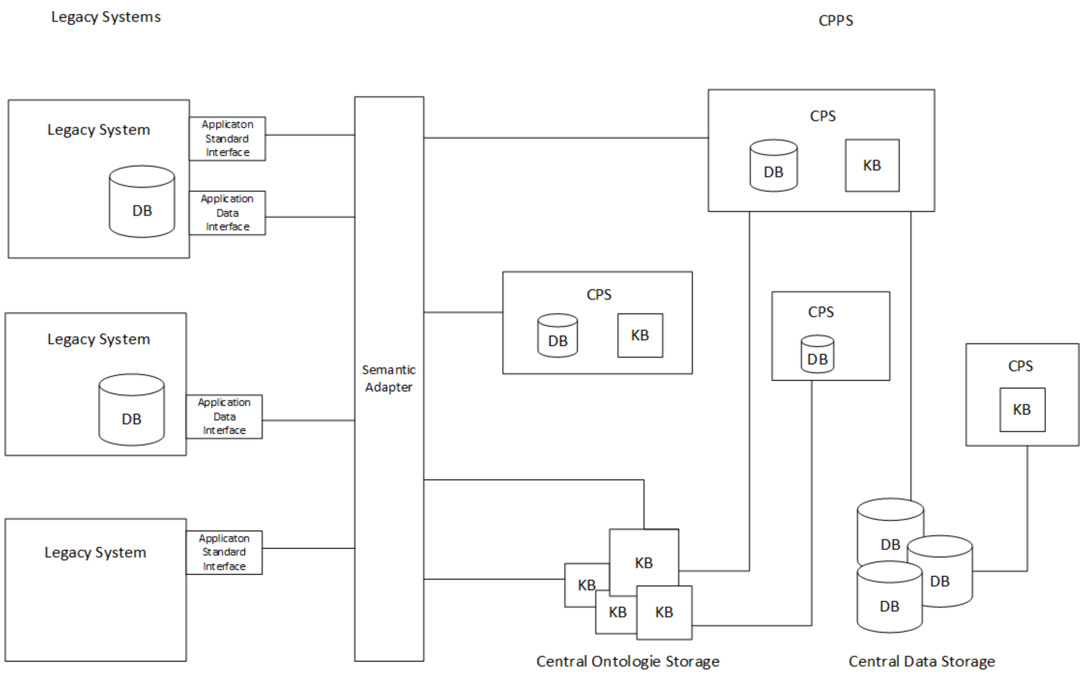

Fig. 1. Schematic integration of a semantic adapter.

3.2. Methodology for developing the semantic adapters

The construction of the semantic adapters is done in the following steps.

1. Scanning of data & knowledge base of existing CPPSs
The first step is to identify the existing data and knowledge bases of the CPSs in use. For each entity, the current origin sources are determined as far as possible.

2. CPPS requirements identification
Besides the current data and knowledge bases, the required data elements are also determined. Analogous to the existing sources, the professional and technical sources of origin for the future knowledge entities are also defined.

3. Determining the knowlegde entities' owner
The respective owner is defined for each knowledge entity. The owner of the knowledge entity has sovereignty over the entity and is responsible for the creation, modification, and updating. The trigger for the change of the knowledge entity can be requested by other systems, but the implementation of the change is done centrally by the owner.

4. Specifying the knowledge entities' persistance-target
After capturing all knowledge entities, persistent storage targets are defined for each entity. The persistence can be done either via an ontology within a CPS or via an ontology repository that is available to all CPSs. Another possibility is the alternative of persisting via a purely data-oriented structure. The structure is always recommended if either a large number of objects are to be persisted or if already existing data-oriented structures are used to connect functionalities (e.g. machine learning).

5. Technical realization of the semantic adapter
The final phase covers the implementation of the technical adapter. Here, the interface (application interface, data interface) through which the knowledge entity can be addressed is defined. Likewise, the mechanism (event, subscribe, polling) that initiates the transfer as well as the transformations that are to be performed during the conversion of the implicit knowledge unit into the explicit knowledge entity are defined.

3.3. Functions of semantic adapters

Within the semantic adapter, the following functionalities must be provided

- Transfer to Resource Description Framework (RDF) Triples for Semantic Reasoning

The implicit semantics as well as the data contents are transformed into the corresponding ontologies using RDF triples [15, 16]. Prior to this, transformation rules can be specified. After the transformation, the corresponding semantic individuals are generated and persisted.

- Create, Read, Update and Delete (CRUD) Functions

For each planned data operation (CRUD) on the knowledge object, corresponding functions are provided in the semantic adapter. Using the functions, corresponding actions are initiated for the respective data operation. The read method takes a special role within the functions. Using the read function, for example, the use of knowledge objects can be designed with regard to the usefulness of individual objects or to secure access.

- Push Notifications

The push notification function class allows other system partners to receive information in quasi-real-time. Integration into a highly reactive system is possible using the function class. Technically, this function class is implemented through the used communication standards (OPC-UA., MTTQ).

4. Use Case

The following use case demonstrates the application of the semantic adapter in the integration of the ERP system S/4 HANA and the MES system SES in the logistics learning factory Werk150 at Reutlingen University.

The starting point for applying the semantic adapter is where (machine or assembly unit) to produce a particular product. The product specification with classification features is available in the ERP system S/4HANA. The machine specifications based on which an assignment of the possible production machines can be made are available in the MES system SES. In addition to the static machine characteristics, dynamic characteristics such as the machine status (ready, in malfunction) and planning-dispositive information such as availabilities are to be taken into account in the selection. This data is also available in the MES system in the data-oriented storage form.

In order to make this information for the appropriate CPS usable the data are to be made usable as knowledge entities for all CPS in the work150. As source the ontology repository IMKOR [17] is used thus. For the two knowledge entities material and machine structures already exist in the RT-SPS ontology, so that these can be used for the filing. Figure 2 schematically shows the structure of the integration of the ERP system SAP and the MES system SES.

4.1. Semantic Adapter ERP-Material

The existing functional interface LO-SCI builds the semantic adapter to the knowledge entity. The interface transfers both master data and transaction data based on SAP interface structures (standard IDocs). The data is transferred to the corresponding target system in an event-oriented manner. The standard interface structure MATMAS (Material Master) is used to transmit the material data. Corresponding additional data (e.g., classification data) can be transferred either via functions (BAPIs) to be called directly or via additional segments in the standard data structure. No special transformation rules are required since a uniform reference to the knowledge entity is assigned via the material number.

4.2. Semantic Adapter MES-Machine

The required information about the machine is available in the used MES, the Self Execution System (SES). Access to SES data is possible either using a passive data-oriented interface or an active event-based interface. Since the data is used for decisions in quasi-real-time, the event-based interface is chosen. As a target for the transmitted machine information, the existing standard ontology RT-SPS [18] is partly used; on the other hand, an individual derived knowledge entity is used for a specific class of production units. Therefore, the knowledge entity is also mapped as a new ontology (mcap) in the central ontology repository IMKOR. Figure 3 shows the two transformation rules and the use of the map structure for semantic linking.

5. Conclusion

The presented approach of integrating legacy systems using semantic adapters provides the existing knowledge, which is often available in the form of an implicit semantic structure, for CPPS and other knowledge-oriented systems. Thereby, both qualitative and quantitative knowledge bases are built up in an improved way, and extended usages are fostered using the existing CPPS. The approach is initially based on the unidirectional transfer from legacy systems to

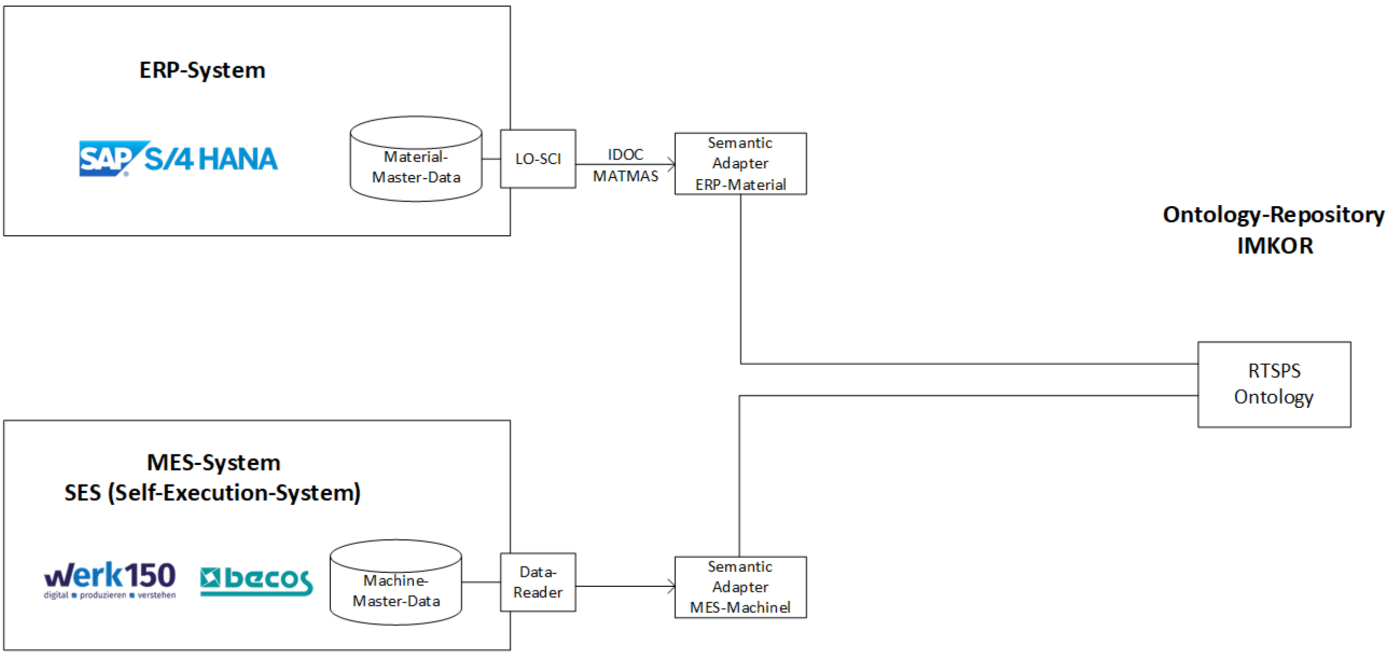

Fig. 2. Implementation of a semantic adapter.

CPPS. Besides the further expansion of practical use cases, as well as developing standard semantic adapters for standard systems, optimized scaling in case of high data volume and critical time requirements, the design of a bidirectional semantic adapter to improve the data quality of the legacy systems also offers starting points for further research activities.

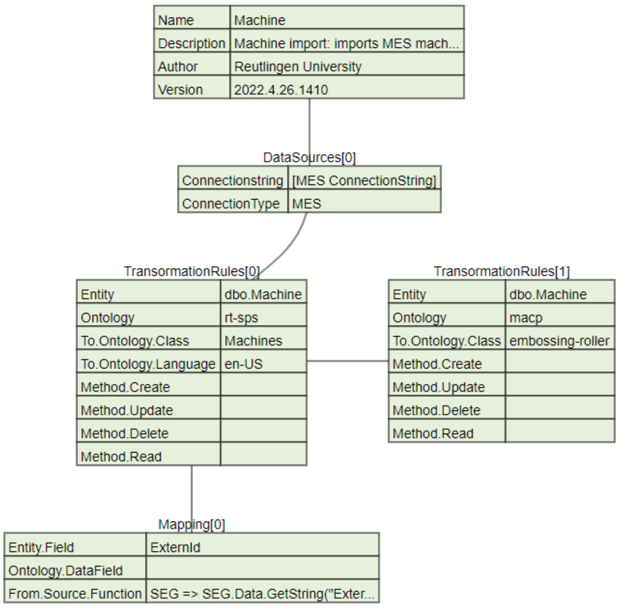

Fig. 3. Map structure for semantic linking.

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