Towards Industrie 4.0 Compliant Configuration of Condition Monitoring Services

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***Abstract*—One of the many opportunities Industrie 4.0 (I4.0) offers, is to reduce (re-)configuration effort. Today, a variety of vendor-specific information models prevents an efficient configuration of Condition Monitoring (CM) for adaptable Cyber-Physical Production Systems (CPPS). The manual configuration of signals that should be monitored is a tedious and error-prone task. Standardization efforts for I4.0 focus on a generic interface called Asset Administration Shell (AAS), which could increase configuration efficiency. The AAS should represent information, e.g. about components, machines, and plants, based on properties standardized according to IEC 61360. Although frequently used in planning and procurement, benefits of properties for the integration of CPPS have not yet been demonstrated. Additionally, important details for the implementation of the AAS, e.g. its deployment and technical requirements, have not yet been specified. In this paper, an information model for condition monitoring of a servo motor is defined based on IEC 61360 properties. This information model is included in an AAS that is implemented on the Programmable Logic Controller (PLC) of a work cell from the company Lenze. The PLC communicates with a condition monitoring service via OPC Unified Architecture (OPC UA). Using IEC 61360 properties the type of a servo synchronous motor can be identified and thresholds for this motor can be configured without manual configuration effort. Nevertheless, in order to implement the AAS in an I4.0 compliant way, IT-Security and Message-based I4.0 communication have to be supported by the PLC. The effort for the (re-)configuration of condition monitoring services can be reduced based on IEC 61360 properties. The approach introduced in this work could help to achieve the main goals of I4.0: To improve the flexibility and efficiency of adaptable CPPS. Nevertheless, more properties and information models have to be standardized in the future.**

I. Introduction

The digital transformation of the manufacturing sector could improve efficiency and flexibility of production. It is expected that manufacturing cost could be decreased by 10 - 30 % through an increase in Overall Equipment Effectiveness (OEE) [1]. Maintenance costs are expected to be decreased by 20 - 30 %, e.g. through services like CM [1]. Achieving improvements on this scale requires CPPS that shall adapt to new requirements quickly [2]. It should be possible to configure services, e.g. for CM of adapted CPPS, automatically.

Today, a lot of different communication protocols, interfaces, and information models are the reason for high complexity and thus (re)configuration effort for CPPS [3]. Solving these issues is a major goal of different international initiatives. In the USA the Industrial Internet Consortium (IIC) is a collaboration of companies, universities and government aiming at the realization of interconnected machines, devices and intelligent analytics [4]. In China, the plan "Made in China 2025" wants to upgrade the country's strategic sectors Information and communications technology (ICT), machine tools and robotics, aerospace, maritime-, rail transport and power equipment [5]. In France and Germany, the initiatives "Industrie du futur" and "Industrie 4.0" focus on the future of manufacturing through industrial ICT [4].

On the one hand future CPPS, e.g. machines and plants, should be adaptable to new requirements quickly [2]. On the other hand, they should guarantee high availability and optimized efficiency [6]. CM can prevent failure of CPPS and enables the operator to switch from a time-based to a condition-based maintenance schedule. Nevertheless, the challenge is that adapting CPPS to new requirements, e.g. replacing components, involves adapting the CM service as well. The manual connection of signals that should be monitored is a tedious and error-prone task, since a variety of vendor-specific interfaces and information models exists. Standardized interfaces and information models are required to improve the integration of CPPS in CM services.

This paper focuses on standardization efforts of the German initiative I4.0. First results of standardization are the Reference Architecture Model Industrie 4.0 (RAMI 4.0) and the I4.0 Component [7]. The I4.0 Component comprises asset and AAS. The AAS is the generic interface for I4.0 and represents information, e.g. about components, machines, and plants, based on properties standardized according to IEC 61360. Usually dictionaries for product description are defined based on these properties. Prominent examples include the IEC Common Data Dictionary (CDD) and ecl@ss [8], [9]. Ongoing research focuses on the question if

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properties are appropriate for dynamic interactions between I4.0 Components, e.g. in integration and configuration scenarios [10]. Properties are included in I4.0 compliant information models, so called partial models or sub-models, in the AAS. To date, important details for the implementation of the AAS, e.g. its deployment, and technical requirements have not yet been specified. This paper helps to answer the following research questions (RQ).

- **RQ1:** Can the AAS improve configuration of CM?
- **RQ2:** Can the AAS be deployed to an asset directly?
- **RQ3:** What are technical requirements for the implementation of the AAS?

This paper is organized as follows. Section II introduces related work. Section III presents the solution implemented in this paper. Section IV introduces the implementation and demonstrates achievable results. Section V concludes this paper and identifies open issues for future work.

II. Related work

In the following section, the RAMI 4.0, the I4.0 Component, the AAS, and the concept of property models are introduced. Next, OPC UA is introduced briefly as an example for implementation. Existing I4.0 Components and implementations of the AAS are listed and open issues are identified.

A. RAMI 4.0

Key aspects of I4.0 are brought together in this three-dimensional layered model, which can be used to classify and enhance I4.0 technologies. RAMI 4.0 consists of three axis and is depicted in Figure 1. The right horizontal axis shows hierarchy levels according to IEC 62264 and is used to classify different functionality within factories [11]. IEC 62264 is a standard for enterprise control system integration based upon the ISA-95 standard [12]. IEC 62264 and ISA95 standards apply to various industries and processes, like batch, continuous, and repetitive processes [11], [12]. In I4.0 the product is added at the bottom and a connected world level is added on top of IEC 62264/ISA-95. On the connected world level, all participants of the value-added chain communicate and offer services. The left horizontal axis of Figure 1 shows the life cycle of facilities and products based on IEC 62890 [13]. RAMI 4.0 distinguishes between types and instances. Asset information can be maintained at different locations on the life cycle axis. For example, manufacturers will maintain data in the type area while product users will add data for specific product instances, e.g. for condition monitoring and maintenance purposes. Furthermore, RAMI 4.0 is structured into six vertical layers, which are used to decompose an I4.0 system into its properties [7]. Starting at the bottom layer, a real world asset is integrated into the virtual world on the integration layer. The communication layer defines how information and functionality modeled in the layers on top can be accessed. Finally, the business layer specifies business processes and organization [7].

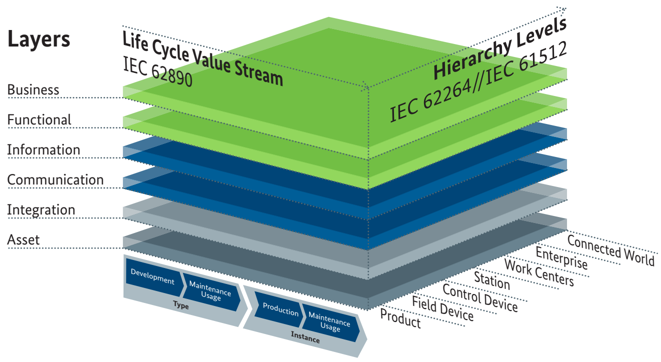

Fig. 1. Reference Architecture Model Industrie 4.0 (RAMI4.0) from [7].

B. I4.0 Component

The I4.0 Component is a Cyber-Physical-System (CPS) connecting real and virtual objects with the objective to create a unique virtual representation for types and instances in RAMI 4.0 [7]. I4.0 Components cover volumes in RAMI 4.0, each integrating different layers and using its axes to a different extent [7]. The I4.0 Component is depicted in Figure 2 and composed of two mandatory elements: Asset and AAS. The asset can be anything of value to an organization, e.g. a machine or a component of a machine like a servo motor [7].

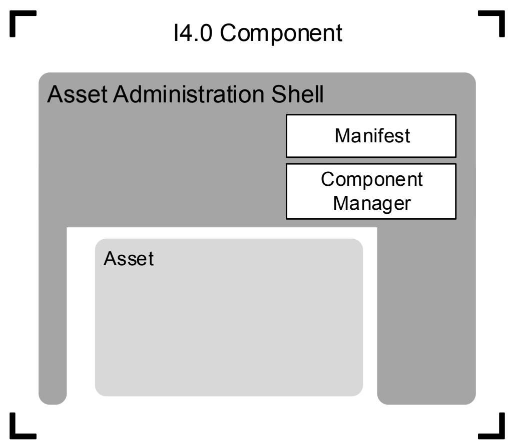

Fig. 2. The I4.0 Component based on [14].

C. Asset Administration Shell (AAS)

The AAS is the virtual representation of the Asset and comprises Manifest and Component Manager. The manifest contains references to all information, data, and functionality of the asset and the Component Manager provides maintenance and query services for the AAS [7]. Furthermore, the AAS is divided into two parts: DF Header and DF Body. This concept stems from the standard for the Digital Factory (DF) and is depicted in Figure 3 [15].

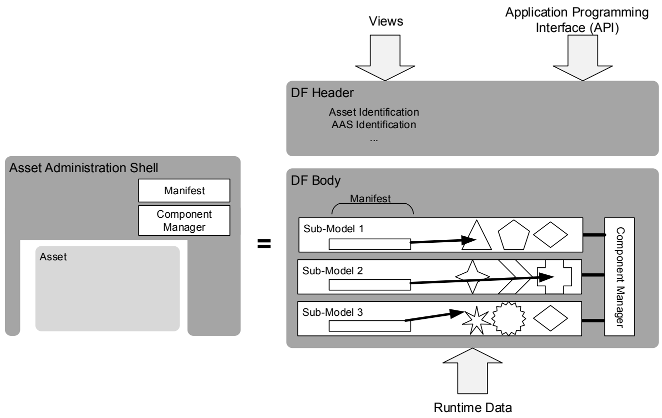

Fig. 3. The AAS based on [14].

DF Header represents information for identification, administration, and usage of Asset and AAS [7]. It references an asset's functionalities and views. DF Body comprises information about the asset's properties and functions in independently maintained partial models for different domains [7]. Properties are hierarchically organized and refer to individual information and functions (white geometric elements in Figure 3). Properties are defined according to IEC 61360-1, and IEC 61360-2 [16].

At the time of writing a lively debate focuses on the deployment of the AAS. According to the standard DIN SPEC 91345, the AAS might be located in a subordinate IT-System or, if the asset comprises I4.0 compliant communication, it can also be deployed to the asset directly [7]. An example for the latter could be a machine's AAS on a Programmable Logic Controller (PLC).

D. *Property Models (IEC 61360)*

Properties classify a system and can be expressed through a simple value. Properties can be considered static for the observation period, while states, i.e. conditions, can change dynamically [17]. In Industrie 4.0 it should be possible to share information between a multitude of systems located on the different axes of RAMI 4.0. For example, information should be shared in different life cycle stages, e.g. engineering and maintenance of automation systems. Although it is not feasible to define one information model for all information systems, property models help to achieve a level of interoperability [17]. Property Value Statements (PVS) can be made for certain property carriers with regards to an actual state (measurement), assurance, requirement, or setting [18]. PVS can be used for a number of engineering and technical communication tasks, e.g. for system configuration [17].

Properties should be defined in an unambiguous way, e.g. in the form of hierarchically structured dictionaries [17]. An example for such a dictionary is the well-known property system ecl@ss [9]. On a meta-level, properties can be described through properties themselves. An example for such a meta-model is the standard IEC 61360 defining content and structure of a general property, as well as the organization of the property system itself (e.g. versions) [16].

In order to reference a general property, it has to be uniquely identified [17]. The IEC's Common Data Dictionary (CDD) and ecl@ss use the International Registration Data Identifier (IRDI) for identification. It is based on standards ISO/IEC 11179-6, ISO 29002 and ISO 6532.

E. *OPC Unified Architecture*

OPC UA is the major contender for I4.0 Communication and standardized in IEC 62541. OPC UA defines services for the interaction with a server-side object-oriented information model [19]. To make use of the information model, an OPC UA Client has to establish a secure connection to an OPC UA Server [20]. OPC UA information models are based on an address space consisting of uniquely identifiable nodes. Nodes are connected via references, that are hierarchical (i.e. parent-child relationships) or non-hierarchical (i.e. type-of relationship) [19]. The general OPC UA information model is defined in IEC 62541-5, and describes standardized nodes of a server's (empty) address space [21]. Based on the standardized address space and general information model, custom information models can be defined. The information model can be introspected and modified during runtime via the services standardized in IEC 62541-4 [19]. Reusable information models for specific domains of interest are released as Companion Specifications for increased interoperability.

F. *Existing Implementations of the AAS*

Palm et al. [22] are working on the implementation of the AAS based on an existing runtime system called ACPLT and an open source OPC UA implementation (open62541) in a project called *openAAS*. The *openAAS* approach defines a property-based information model, services for the interaction with the property model, and message based interactions between multiple AAS [18].

Gonzalez et al. [23] introduced the concept of the Semantic AAS based on the Resource Description Framework (RDF). In this approach, SPARQL (SPARQL Protocol And RDF Query

Language) queries are used to retrieve information from the Semantic AAS.

Langmann et al. [24] implemented an AAS for a PLC. In this approach, a device gateway on a standard PLC enables the connection to the PLC's AAS via Webservices.

So far, the AAS has not been deployed to an existing PLC directly. To date, no implementations of partial models and applications of the AAS for configuration of a condition monitoring service are known.

III. Solution Approach

In this section, our approach for the configuration of a CM service is introduced. Firstly, a real-world use case is presented and involved challenges are introduced. Secondly, an AAS model compliant to the current state of I4.0 standardization is introduced. The solution approach is based on Property Value Statements (PVS) about properties standardized in the ecl@ss dictionary [9].

A. Use Case and I4.0 Components

The use case scenario focuses on the connection of the pick and place work cell depicted in Figure 4 to a CM service. Today, the main challenge for a system integrator is to select signals that should be monitored by interpreting their semantics defined in different documents, file formats, and automation projects, manually. In this use case, the AAS is used as I4.0 compliant interface that should simplify the integration of the work cell into services, e.g. for CM. Information included in I4.0 compliant information models in the AAS, i.e. partial models, could help to select correct signals and configure parameters, e.g. thresholds, automatically. In this use case, the CM service should observe if a threshold for a torque value specified for a servo synchronous motor is reached. Therefore, the actual torque is monitored and compared to the threshold.

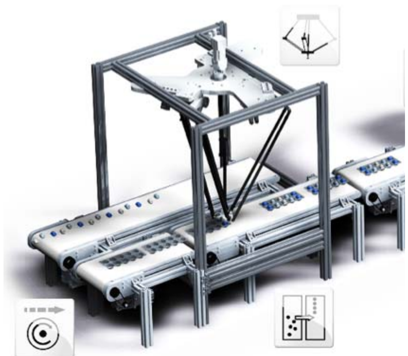

Fig. 4. Work Cell for the Use Case [25].

The work cell depicted in Figure 4 comprises a solution called delta picker and two conveyor belts. One conveyor belt delivers transported units that should be placed inside packages on the second conveyor belt by a delta robot. The work cell includes sub-components motor, inverter, and PLC. The inverter is connected to the PLC via the Industrial Ethernet solution EtherCAT. The PLC implements basic motion, track pick and place and kinematics functionality (icons in Figure 4 from left to right) of the work cell and includes an OPC UA Server.

If the asset comprises I4.0 compliant communication, the AAS can be deployed to the asset directly [7]. I4.0 compliant communication is based on a SOA and comprises self-describing information [7]. The motor of the work cell is connected to the inverter electrically and can not communicate actively. The inverter communicates with the PLC via EtherCAT, which is not based on a SOA and does not include self-describing information. OPC UA available on the PLC fulfills the requirements for I4.0 compliant communication. In order to answer the RQ introduced in Section I, the AAS is implemented on the PLC. As depicted in Figure 5, the AAS is deployed to the PLC and comprises information about work cell and servo motor in form of IEC 61360 properties. According to DIN SPEC 91345 one AAS can represent multiple assets [7]. Technical requirements for the implementation should be evaluated and the question should be answered, if IEC 61360 properties could help with the configuration of CM.

B. AAS Model

To date, no models have yet been standardized for the AAS. For this reason, content of the AAS is defined as an example in this section. Examples are defined according to the current state of I4.0 standardization from Section II.

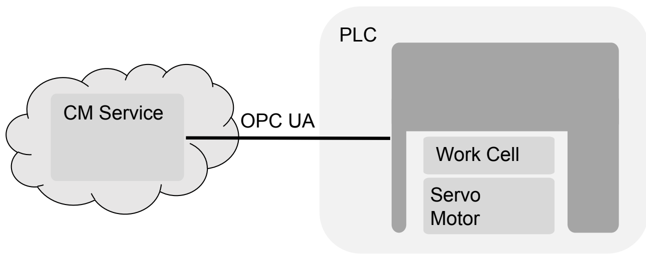

Fig. 5. The Use Case.

The **DF Header** of the AAS is depicted in Figure 6 and contains identifiers for asset (AssetId) and AAS (AAS ID). With reference to the state of the art of I4.0 standardization, identifiers are included in Property Value Statements (PVS) in the DF Header [18]. PVS reference properties, e.g. identified via an Uniform Resource Identifier (URI). The identifiers in Figure 6 are examples that have to be specified in the future.

The **DF Body** is depicted in Figure 7 and includes the partial model for CM. The partial model's identifier (modelId) is an example for the short version of an ISO 29002-5 identifier (ADA015). This type of identifier is used in the ecl@ss and IEC CDD dictionaries. The partial model contains information about a servo synchronous motor in the Property Value Statement List (PVSL) *List1*. The PVSL contains PVS "Torque" and "Max Torque". The expression semantic of the PVS

Fig. 6. DF Header of the AAS.

”Torque” is set to ”Measurement” and its value is connected to an IEC 61131-3 variable in the PLC (Axis.lrActTorque). The PVS ”Max Torque” refers to the property of a servo synchronous motor with the ecl@ss classifier 27-02-26-02. The ecl@ss property ”Max Torque” comprises the ISO identifier `0173-1#02-BAE098#003`. The expression semantic of this PVS is set to *Assurance*, since the manufacturer assures that operation is possible up to this threshold.

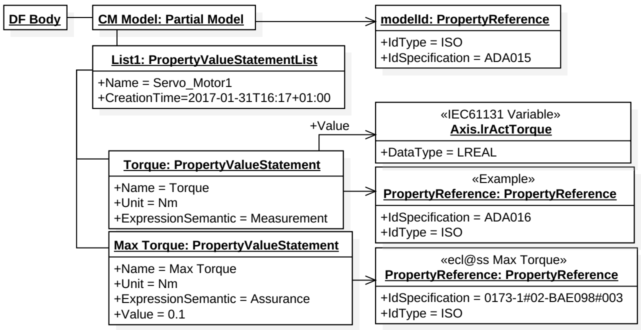

Fig. 7. DF Body of the AAS.

IV. Implementation and First Results

This section introduces our implementation of the previously introduced solution approach and our first results.

A. Implementation

For implementation, a PLC comprising the IEC 61131-3 runtime environment CoDeSys and OPC UA Server is used [26]. The AAS is implemented in form of the IEC 61131-3 Function Block (FB) depicted in Figure 8. The FB comprises inputs (Velocity, Torque, State) and outputs (Header, CMModel). The input Torque is connected to the variable Axis.lrActTorque depicted in Figure 7. The variable represents the torque value of the servo synchronous motor. The outputs are connected to structures that are made available via OPC UA (IO.Header, IO.CM_Model). Header comprises the information depicted in Figure 6 and CMModel comprises the information of the partial model for CM depicted in Figure 7. The OPC UA Server used for implementation does not support IT-Security and OPC UA Method calls. Additionally, no new OPC UA object types, e.g. for PVS, can be created in the OPC UA Server and the position of the AAS in the OPC UA server’s address space can not be configured.

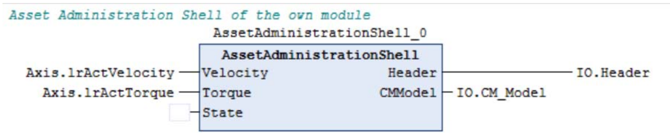

Fig. 8. The implemented AAS.

B. First Results

For evaluation purposes the OPC UA Client depicted in Figure 9 is used to connect to the OPC UA Server on the PLC. The OPC UA Client browses the OPC UA Server’s address space and finds the AAS. Next, the partial model for CM is detected and the type of the synchronous servo motor is found by the specified URI. The PVS ”Max Torque” is used to configure the threshold in the CM service automatically. The service depicted in Figure 9 can monitor the servo motors condition and detect if the threshold is exceeded.

C. Research Questions

This section summarizes the results found during implementation of the AAS and answers the RQ from Section I.

RQ1: Can the AAS improve configuration of CM? Standardized information models and identifiers according to ISO 29002-5 or in the form of a URI can help to configure a CM service. The CM service can search for a standardized partial model and identifiers for configuration. In comparison to the state of the art, this could reduce (re)configuration effort. Today, signals without standardized identifiers, names, and semantics are used, which have to be configured manually.

RQ2: Can the AAS be deployed to an asset directly? In order to deploy the AAS to the asset itself it has to comprise I4.0 compliant communication [7]. OPC UA fulfills the requirements of I4.0 compliant communication. Therefore, the AAS can be deployed to the asset directly if it comprises OPC UA communication.

RQ3: What are technical requirements for the implementation of the AAS? OPC UA includes certain profiles with distinct functionality. I4.0 components should consider IT-Security in a sufficient manner [7]. Therefore, a profile supporting OPC UA IT-Security mechanisms (UA Security) should be chosen. Additionally, it is expected that I4.0 message communication between multiple AAS will be based on OPC UA method calls [18]. In conclusion, at least the OCP UA profile *Embedded UA Server* should be chosen. This profile supports IT-Security and OPC UA method calls. Additionally, an OPC UA implementation should allow the definition of object types and their position in the OPC UA Server's address space.

V. Summary and Future Work

In this paper, a solution for the I4.0 compliant configuration of a CM service was proposed. In Section II, work related to I4.0 standardization has been introduced. Currently, property type definitions according to IEC 61360 are at the heart of I4.0 standardization. The standardized I4.0 interface AAS is based on properties. Section III defines an AAS that includes a partial model for CM. The partial model references a property type definition from the ecl@ss dictionary. This property type definition is used for the unique identification of a statement about the maximum torque value of a specific servo synchronous motor. Section IV introduces the implementation of the AAS on a PLC. Standardized AAS structures are implemented in IEC 61131-3 and made available via OPC UA. In Section IV, an OPC UA Client is used to connect to the AAS on the PLC. AAS and partial model can be browsed and the type of servo motor and threshold for maximum torque can be configured automatically.

As future work, partial models have to be standardized for usage in I4.0. The partial model used in this work uses examples for identifiers that have not yet been standardized. In the future, the OPC UA Server on the PLC should support IT-Security and OPC UA method calls. Based on OPC UA method calls, I4.0 message services specified for communication between multiple AAS could be used to access and modify PVS [18]. Components of the work cell used in this work could comprise their own AAS. If these AAS should be deployed to the components directly, e.g. to an inverter, the components must comprise I4.0 communication, e.g. via OPC UA.

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