Modelling of Sensor Devices with AutomationML

An enabler for the Digital Twin and new business models

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***Abstract*— The basis for electronic data exchange between manufacturers and system integrators of automation components such as sensor devices is the availability of standardized data models and an exchange data format for such automation components. These models need to cover the mechanical, electrical and sensing properties of the sensor device. This paper describes the results of the work of an industrial consortium within the AutomationML association providing a generic modeling methodology for automation components including electrical interfaces as well as proposals for modelling the detection properties of a sensor. It is also shown how the semantics of attributes are defined and how proprietary naming conventions can be easily integrated.**

Keywords—AutomationML, cable, component, device, interface, model, sensor, semantics

I. Introduction

The present corona crisis highlights that digitizable business processes can enormously support the industry, its partners and customers. Digitalization can ensure and increase the competitiveness of companies in the market. This is true wherever *value chains* require interaction between people and software tools. The basis for the digitalization of value chains is digitized data.

Especially the value creation chain along industrial component manufacturers, trade organizations, project planners, electrical planners, system integrators and end customers require the availability of digital data models for automation components and their interfaces (i.e. electrical cabling) in a generally accepted modelling standard. Digital models of automation components in a machine-readable standardized data format would allow a number of interesting use cases and applications with economic advantages, such as:

- *Plant designers* can model their requirement specifications for e.g. sensor devices with their electric interfaces and cabling requirements in machine-readable form and send them to electrical cabinet makers, cable manufacturers or assembly companies.
- *Cable manufacturers*, *electrical cabinet makers* and *assembly companies* can simplify the order flow by accepting orders in the form of such machine-readable requirement specifications and thus automate their production. Typical errors and misunderstandings caused by classic requirement descriptions (telephone, texts, tables) are eliminated.
- *Component manufacturers* can provide product catalogues in a machine-readable and algorithmically testable manner and make them processable in MCAD and ECAD tools.
- *Electrical designers* can seamlessly integrate this information into their ECAD tools and perform automated plausibility checks of the interconnections.

In order to exploit these advantages, standardized machine-readable data models for automation devices like sensors and their interfaces are required, to be able to map a holistic model of a sensor device to be used as basis for virtual engineering, simulation and operation. However, a suitable standard to fully describe sensor devices has not been produced yet.

To provide a holistic solution for all this, an industrial consortium within AutomationML e.V. has developed a generic modelling methodology for automation components, their sub-models and interfaces (electrical, mechanical and others).

The intention of this paper is to describe a generic approach to model sensor devices with AutomationML as holistic basis for digital twins.

II. Related Work with respect to sensor modelling

A number of standards deal with the definition of data models for sensors.

IEC 23005-5 [1] is targeting the multimedia industry, specifying syntax and semantics to provide a standardized format for interfacing actuators and sensors in virtual environments by defining an XML schema-based language named Interaction Information Description Language (IIDL). Describing actuator commands and sensed information, this language also allows the specification of actuator and sensor capabilities.

Automation industry specific standards like IEC 60947-5-2 [2], dealing with proximity limit switches, define mainly mechanical (especially housing outlines) and electrical properties, detection range characteristics and environmental parameters of a certain range of industrial sensors. The goal is to provide the required standardized criteria to achieve vendor-exchangeability for industrial-grade sensor products. Some standardized semantics is inherently defined, but as they are delivered as text within PDF files, they are not really machine-processable to be used as basis for the description of digital twins. To overcome this limitation, a working group “Industrie 4.0 in der Sensorik” within the ZVEI [3] is currently defining a machine-readable semantic

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description of the IEC 60947-5-2 sensor devices and their properties (see Fig. 1).

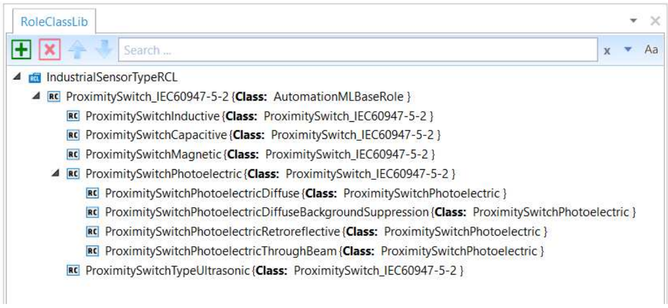

Fig. 1: Structural description of IEC 60947-5-2 with AutomationML

Within the *IEEE Instrumentation and Measurement Society*, the *Sensor Technology Technical Committee* has developed IEEE 1451, a series of documents that take industrialization aspects for transducers (sensors or actuators) into account [4][5]. One of the key elements of these standards is the definition of Transducer electronic data sheets (TEDS) to model the transducer identification, calibration, correction data, and manufacturer-related information that is also electronically accessible within the transducer device.

The *Microelectromechanical Systems Standards Development Committee* within the *IEEE Electron Devices Society* has created the IEEE Std. 2700 "Standard for Sensor Performance Parameter Definitions", to define a common framework for sensor performance specification terminology, units, conditions and limits. Specifically, the accelerometer, magnetometer, gyrometer/gyroscope, barometer/pressure sensors, hygrometer/humidity sensors, temperature sensors, ambient light sensors, and proximity sensors are discussed [6].

The SensorML standard developed by OGC was applied in [7] to a conceptual model for sensor description. With this method, all the information required to describe the sensor will be divided into three categories with defining the necessary elements, optional elements and element format for each category: Identification, Capabilities and Contact.

Conceptually very similar to IEEE 1451, the German-based IO-Link consortium under the head of the PNO has developed the IO-Link standard [8] and integrated into the PLC standard IEC 61131-9 as "Single-drop digital communication interface for small sensors and actuators" (SDCI) [9]. IO-Link was able to gain a strong acceptance in the automation market. The equivalent to the TEDS description file within IO-Link is the so called "IO Device Description" (IODD), also using an XML-based modelling language to describe a defined set of sensor/actuator device properties, but mostly limited to device identification, parametrization and process data layout. Other properties like mechanical characteristics, sensor properties, secondary interfaces and so on cannot be modelled.

Unfortunately, each of the device description approaches described above are incompatible to each other and provide only limited modelling scopes for sensor devices. This was also highlighted by Monte, who proposed that in the same way that the IEEE 1451 standards were created, signal parameters themselves should be standardized [10], which was the goal of IEEE 2700 [11].

A promising solution to overcome both the issues of interoperability and lack of modelling capabilities is AutomationML [12][13] as a neutral data format based on XML and CAEX [14]. It is standardized in IEC 62714 and has an architecture capable to interconnect existing established file formats of different domains and allows to store object models following the object-oriented paradigm, covering class libraries, interfaces, attributes, links, and instances modelled in instance hierarchies. Furthermore, it is able to reference external formats. AutomationML covers also the modeling of geometry via the file format COLLADA and discrete logics via PLCopen XML.

Working groups within the AutomationML community have developed methodologies on how to model automation component descriptions [15] and communication networks [16] with AutomationML. Several application examples were presented in [17][18][19][20]. The generic approach is structuring the overall model in clearly identifiable domain specific submodels and interlinking them. Software tools importing such a model can select the submodels, they are able to work with and process them further while leaving the other submodels untouched.

The concept of semantically defining identification parameters and assembling various submodels together via a neutral exchange language format is the key success factor of the approach presented in this work.

III. Proposal for sensor modelling with AutomationML

A. *Data format and working mode*

The methodical approach is based on AutomationML as the data format, in which class libraries can be developed step by step along the associated standards for sensors, electrical connectors and other assets of interest. Since standardization usually takes years, the working mode of the authors followed the rules of speed standardization [20], which focusses on stepwise standardization of singular and needed entities rather than standardization of a comprehensive world model. This resolves the problem of typical standardization deadlocks described in [20].

B. *Modelling of identification data*

To identify automation components unambiguously, a standardized identification data model has been defined (see Fig. 2).

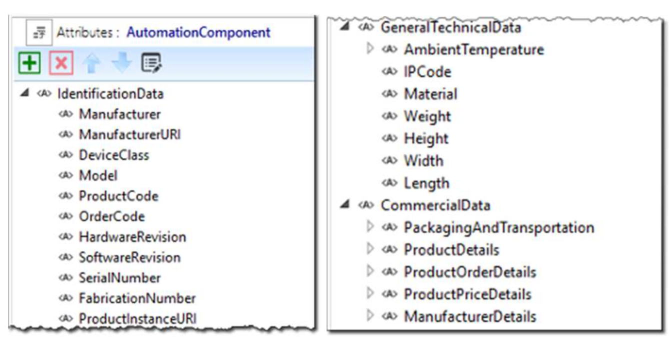

Fig. 2: Component identification attributes

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C. Modelling of Submodel Elements and Interfaces

Every automation device is characterized by submodels to describe its static and dynamic properties and interfaces to interact with its environment. The AutomationML component model provides a range of standard role classes to describe the typical submodels and external interfaces (Fig. 3).

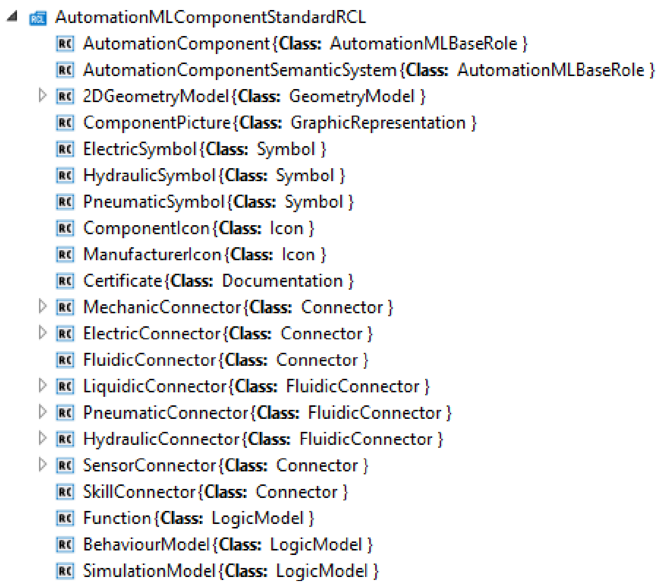

Fig. 3: Component Submodels and Interface connectors

For example, the "*SensorConnector*" can point to a model of the spatial sensor detection geometry as part of the overall mechanical CAD model. The "*Behaviouralmodel*" could then describe the dynamic behavior of the sensor, when objects are moved into the detection space.

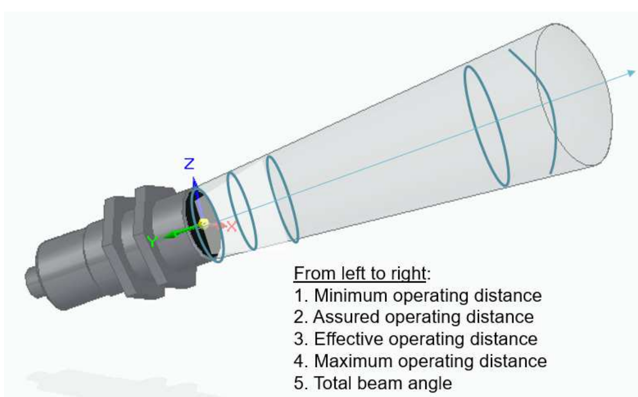

Fig. 4: Depiction of spatial detection geometry according to IEC 60947-5-2

D. Modelling of electric interfaces

Since basically every automation device has an electric interface, a modelling concept for this is obviously essential. To be generic and flexible also for further electric interfaces, it is distinguished between the abstract interface function (e.g. Ethernet, IO-Link or power supply), the mechanical characteristics of the connector (e.g. in the form of an A-coded M12 connector with 4 pins) and the actual physical electrical connector (the pin), see Fig. 5. This allows to model e.g. an M12 connector independent of its later usage and even open wires can be modeled.

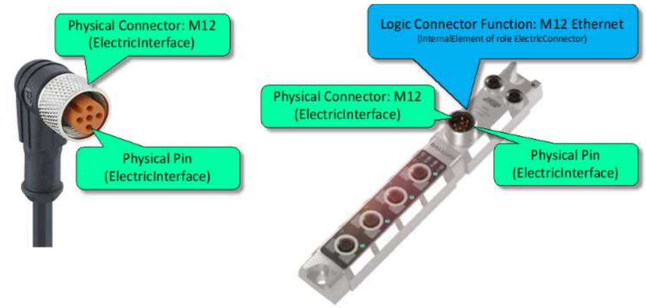

Fig. 5: Structure of electrical interfaces

Based on these principles, the authors developed libraries of electric interfaces for established and standardized electrical connectors such as M12, M8, M5, RJ45 and USB. These libraries can be understood as a machine-readable electronic data model of the associated standard documents, i.e. IEC 61076. The underlying methodology is generic and manufacturer-neutral, it allows to extend the libraries with any types of electrical interfaces. More details and the electrical interface library are provided in [22].

Fig. 6: Industrial sensor with electrical interface M12 or open wires

E. Modelling semantics

Another classical problem of digitization is semantics: how to model the meaning of features or objects? How does the receivers of the data find out what is meant? The typical solution is semantic standardization: a consortium collects and standardizes features and defines their designation and meaning. In this way, a variety of company standards, local standards, country standards or domain standards have emerged. The presented approach pursues a more flexible solution. As the example in Fig. 7 shows, AutomationML can provide references to available semantic dictionaries for each attribute, here the IEC Common Data Dictionary (IEC-CDD) [23] and eCl@ss [24].

```
<Attribute  Name="Blind zone" AttributeDataType="xs:float" Unit="mm">
  <Description>Zone before a sensor in which an object or reflector is not recognized,
        measured from active surface </Description>
  <Value>10</Value>
  <RefSemantic CorrespondingAttributePath="IRDI:0112/2///62683#ACE252#001" />
  <RefSemantic CorrespondingAttributePath="IRDI:0173-1#02-BAD822#004" />
</Attribute>
```

Fig. 7: AutomationML description of a sensor attribute with semantic referencing into IEC-CDD and eCl@ss

A side effect is that this makes the actual naming of the attributes (here "Blind zone") irrelevant and thus freely selectable. Semantics are decoupled from the naming, so that multi-lingualism and proprietary naming conventions in derived *digital twins* of concrete products are easily possible.

IV. Summary

This paper proposes a concept for standardized machine-readable digital data modeling for sensors as basis for digital workflows and the introduction of digital twins. This is the ground for a wide range of innovations e.g.in virtual engineering, simulation, team interaction, version management and plant operation, and is useful for any value creation chains e.g. between plant designers, cable manufacturer, electrical cabinet providers, assembly companies and component manufacturers.

To provide a holistic solution for all this, an industrial consortium within AutomationML e.V. has developed a generic modelling methodology for general automation components, their submodels and interfaces (electrical, mechanical and others). The authors developed this approach for the application to sensors, this paper describes a generic approach to model sensor devices with AutomationML as holistic basis for digital twins.

The presented concept combines a series of recent developments and innovations: the use of AutomationML in order to inherit its benefits for neutral and object oriented modelling, the modelling of identification data as basis for data exchange, the modelling of the different aspects of sensors based on submodels, the modelling of electrical interfaces according to related standards, and the modelling of semantics referencing on related semantic standards. A pattern of this method is the re-use and digital modelling of existing proven standards and their innovative combination, which is the key spirit of AutomationML and a fruitful basis for broad acceptance.

The development of the basic libraries for automation components and electric interfaces and the process methodology was carried out in close coordination with the Automation Component Working Group in AutomationML e.V. and was included in the Best Practice Recommendations there. The resulting libraries and documents are freely available [15][22].

The next step of this ongoing work is to finalize and publish an industry consortia whitepaper with an associated template library to provide manufacturers with the ability to create standard conforming sensor models.

The authors intention is to encourage the sensor community to join and support these ongoing activities. Interested readers of this paper are invited to participate in the application and further development of this future-oriented standard for data exchange.

References

[1] IEC 23005-5, "Information technology — Media context and control — Part 5: Data formats for interaction devices", accessible at https://www.iso.org/obp/ui/#iso:std:iso-iec:23005:-5:ed-4:v1:en

[2] IEC 60947-5-2, "Low-voltage switchgear and controlgear-Part 5-2: Control circuit devices and switching elements-Proximity switches", Geneva, Switzerland, Edition 3.0, 2007.

[3] ZVEI, Working Group "Industrie 4.0 in der Sensorik", https://link.springer.com/referenceworkentry/10.1007%2F978-3-662-45537-1_142-1

[4] ISO/IEC/IEEE Standard for Information technology -- Smart transducer interface for sensors and actuators -- Part 4: Mixed-mode communication protocols and Transducer Electronic Data Sheet (TEDS) formats," in ISO/IEC/IEEE 21451-4:2010(E) , vol., no., pp.1-448, 20 May 2010, doi: 10.1109/IEEESTD.2010.5668460.

[5] D. Wobschall, "IEEE 1451—a universal transducer protocol standard," 2007 IEEE Autotestcon, Baltimore, MD, 2007, pp. 359-363, doi: 10.1109/AUTEST.2007.4374241.

[6] Mike Botts, "OpenGIS Sensor Model Language (SensorML) Implementation Specification", OGC Inc, 2007

[7] X. Xie, X. Liu, J. Mao, J. Fan and F. Ye, "Fast Sensor Process Modeling and Registration in Sensor Web," 2015 Sixth International Conference on Intelligent Systems Design and Engineering Applications (ISDEA), Guiyang, 2015, pp. 393-397, doi: 10.1109/ISDEA.2015.104.

[8] IO-Link-consortium: "IO-Link Interface and System Specification", Version 1.1.2 July 2013, available at http://www.io-link.org

[9] IEC 61131-9: Programmable controllers – Part 9: Single-drop digital communication interface for small sensors and actuators (SDCI)

[10] G. Monte, "A proposal of a new standard for sensor signal analysis," 2010 IEEE International Conference on Industrial Technology, Vina del Mar, 2010, pp. 1637-1642, doi: 10.1109/ICIT.2010.5472448.

[11] IEEE Approved Draft Standard for Sensor Performance Parameter Definitions," in IEEE P2700/D3, April 2017 , vol., no., pp.1-68, 1 Jan. 2017.

[12] IEC 62714-1 ED2: IEC 62714: Engineering data exchange format for use in industrial automation systems engineering – Automation Markup Language – Part 1: Architecture and general requirements (2018).

[13] Drath, R.: Datenaustausch in der Anlagenplanung mit AutomationML, Springer Verlag Berlin Heidelberg, 2010, ISBN: 978-3-642-04673-5.

[14] IEC 62424: Representation of process control engineering - Request in P&I diagrams and data exchange between P&ID tools and PCE-CAE tools. 2016.

[15] White Paper – Description of AutomationML components https://www.automationml.org/o.red.c/dateien.html, to be published 2020.

[16] Riedl M., Lüder A., Heines B., Drath R., „Kommunikation mit AutomationML beschreiben. Formale Modellierung industrieller Kommunikationssysteme", in atp 11/2014, S. 44-51, Oldenbourg-Verlag 2014.

[17] F. Bendik, A.Lüder, N. Schmidt, "Exchange of engineering data for communication systems based on AutomationML using an EtherNet/IP example", ODVA 2015 Industry Conference, Frisco, Texas, USA.

[18] Rentschler M., Drath R., "Vendor-Independent modeling and exchange of Fieldbus Topologies with AutomationML", ETFA 2018, September 4-7, Torino, Italy.

[19] Drath R., Rentschler M., "Modeling and Exchange of IO-Link Configurations with AutomationML", CASE 2018, August 20-24, Munich, Germany.

[20] Drath R., Rentschler M., Hoffmeister M., "The AutomationML Component Description in the context of the Asset Administration Shell", ETFA 2019, September 10-13, Zaragossa, Spain.

[21] Bigvand P., Drath R., Scholz A., Schüller A., "Agile Standardization by means of PCE Requests – Data Exchange via NAMUR Data Container", ETFA 2015, Barcelona, Spain.

[22] Draft BPR 011E – Modelling of electric Interfaces, https://www.automationml.org/o.red.c/dateien.html, 2020.

[23] IEC-CDD: IEC 61360 - Common Data Dictionary, available at: https://cdd.iec.ch/.

[24] eCl@ss: STANDARD FOR MASTER DATA AND SEMANTICS FOR DIGITALIZATION. Available at: www.eclass.eu, 2020.

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