Industry 4.0 Asset Administration Shell (AAS): Interoperable Skill-Based Service-Robots

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Abstract—This paper describes our use of Industry 4.0 Asset Administration Shells (AASs) in the context of service robots. We use AASs with software components of service robots and with complete service robot systems. The AAS for a software component serves as a standardized digital data sheet. It helps system builders at design time in finding and selecting software components that match system-level requirements of the systems to be built. The AAS for a system comprises a data sheet for the system and furthermore collects at runtime operational data and it allows for skill-level commanding of the service robot. AASs are generated and filled as part of our model-driven development and composition workflow for service robotics. AASs can serve as a key enabler for a standardized integration and interaction with service robots.

Index Terms—service robotics, asset administration shell, skill-based, model-driven software development

I. INTRODUCTION

An advanced service robot is the promise of a multipurpose flexible machine. It shall robustly fulfill tasks even in open-ended environments and in workspaces shared with e.g., persons. Users want to use a service robot as an assistant that can be adapted with low effort to new tasks. Service robots are not isolated machines anymore but they have to interact with complex infrastructure and machinery (fig. 1). Identifying and selecting service robots that match upcoming tasks is crucial as it is the identification and selection of fitting software components to equip a service robot with the required capabilities.

The AAS is one of the key concepts of Industry 4.0 to achieve flexibility and variability within factories and across value networks. An Industry 4.0 Asset Administration Shell (AAS) describes an asset in a standardized manner. It envisions a standardized exchange of information about an asset and describes how to interact with it. Submodels structure information and one can present even the same information within different and co-existing submodels that all address a different domain.

At present many standardization efforts for submodels [1] and efforts for harmonizing AASs take place and a bunch of new AAS submodel templates are under development [2]. Nevertheless, there is still a tremendous need for real-world examples that underpin what makes a reasonable scope and a good template for a concrete AAS submodel and which kind of submodels come with real benefits.

We extended SMARTMDSD [3] to support the generation of AASs for software components and service robot systems, respectively. The implementation of the AAS uses the Eclipse BaSyx SDK [4]. As first use-cases, the AAS allows at runtime to command a service robot at skill-level and to collect individual performance indicators. The gained insights now shape our next steps in extending our AAS submodels for service robots.

II. THE SERVICE ROBOTICS BUSINESS ECOSYSTEM

The business ecosystem for service robotic software components and systems now gains more and more momentum [5] [6] [7] [8] [9]. Fig. 2 gives an overview on the service robotics business ecosystem with selected roles, assets, market

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places and role-specific tool support. The core is to manage the interfaces between the different roles and the different assets such that all the participants can work independently of each other. The overall objective is to enable composability and compositionality of the assets in the ecosystem while adhering to the principle of separation of roles. Of course, this comes with structures like service-oriented software components with e.g. standardized state automats and configuration interfaces to enable composition of control flows and data flows at design time (see fig. 3 and 4) and even at runtime. The full details can be found in [5].

**Fig. 2.** Overview on the service robotics ecosystem with different roles, assets with digital data sheets, tool support and market places. It is based on composability, compositionality and separation of roles. The open-source and free-to-use Eclipse-based model-driven toolchain SMARTMDSD is the easiest way to participate in the service robotics software business ecosystem as it provides role-specific support for the different ecosystem participants (such as component developers, system builders, and others).

**Fig. 3.** The toolchain SMARTMDSD can be extended by plugins (e.g. to support the generation of AASs). Mixed-Port Components interface between composable software components (indicated by the red ports: these fully adhere to the ecosystem composition structures) and other worlds (such as ROS, OPC UA, and others: these do not adhere to the ecosystem composition structures but there is a need to interface to them).

Although these composition structures have been driven by the needs of service robot systems, they are in line with the needs and the concepts of many industry 4.0 scenarios. For example, the digital data sheet represents all the information you need to know in order to predict how this asset behaves in your setting and to decide whether it fits your needs. A digital data sheet is a model of the asset comprising all the information a user needs to know. It is not suited for synthesis of an asset and does not disclose internals. In that sense, the various aspects of a digital data sheet of the service robotics ecosystem are in line with submodels of an AAS.

## III. AAS at Design Time

### A. AAS for a Software Component at Design Time

**Fig. 4.** The view of the system builder in SMARTMDSD: component selection, component composition, adding task plots and performing deployment.

**Fig. 5.** shows an AAS of a software component. The semantics of the submodels and their elements is either defined by a pre-given standard for a submodel or it is given via the reference into the (domain-specific) models used by the model-driven toolchain SMARTMDSD.

The submodel ComponentDefinition gets directly filled from the model of the software component used in SMARTMDSD by the component developer to develop and build the software component. In the same way, the submodel Capabilities gets filled by the skills assigned by component developers to the (sets of) software component(s) and available in the SMARTMDSD model(s) of the (sets of) software component(s). The submodel TechnicalData comprises typical data sheet information in the form of name/value pairs like the license, the kind of environment in which the asset can be used etc. The submodel Operations comprises a standard set of operations to invoke the skills listed in the Capabilities.

There exist different interaction patterns for AASs [11]: file exchange is called type 1, access via an API is called type 2 and peer-to-peer interaction is called type 3. We use an AAS for a (set of) software component(s) as type 1 AAS (download the AAS by the system builder as AASX XML file to find, check, select software components) or as type 2 AAS (use an API to a local server of the downloaded AAS to view, extract and process relevant information for making your decisions).
B. AAS for a System at Design Time

Fig. 6 shows an AAS of a service robot system. Again, the submodels get filled from the models available via SMART-MDSD when composing the system as system builder. The BillOfMaterials lists the components used in the system composition and the Capabilities is the complete list of all skills given by all the used software components and all the task plots added in the system composition step. However, there are good reasons to present only a subset of the skills and task plots to the outside and it might even be of interest to not give full insight into the bill of materials. Thus, in the future, we intend to exploit the access control mechanisms of AASs.

For a service robot system, we again use the AAS of the system as type 1 AAS (download of the AAS file) for finding, checking and selecting a service robot or as type 2 AAS (use an API to a local server of the downloaded AAS file to view, extract and process relevant information for making your decision). The AAS of a service robot system can also hold accumulated operational data to support decisions such as e.g. hours of operation, maintenance data and more.

IV. AAS AT Runtime

A. AAS for Software Components at Runtime

Right now, we do not use the AASs of the software components onboard of a service robot system at runtime to interact with individual software components (parameterizing software components, invoking their skills, etc.). At runtime, the parameterizations of software components, the selection of modes and the invocation of capabilities (in our terms skills) onboard the robot is done without the indirectation of the AAS as we have access to the first class citizen models of the software components which come straight from the model-driven software development, composition and deployment processes.

B. AAS for a System at Runtime

Fig. 7 shows the type 2 use of an AAS of a service robotic system at runtime. The Capabilities can be used with Operations. Individual instances of a capability can be pushed (command it for execution) which returns an identifier that is then used for the get status operation (query the state of execution of the referenced command), the get output operation (get its result) and the delete operation (remove the referenced command either before its execution or remove it after its completion and after you got its output).

A commanded capability can be in the states pending (execution not yet started), executing (in execution), success (execution successfully completed), error (completed but without success or with errors) or deleted (the identifier does not refer to a known commanded instance of a capability).

We do not provide an individual operation per capability but a generic set of operations to be used with all the capabilities. You can also push several instances of the same capability as they all get unique identifiers. It is the robot which arranges the order of the execution by itself. A robot rejects a pushed command if e.g. the parameters or constraints do not fit or cannot be matched. It then runs immediately into an error for that command with further details in the result so that the reason for the reject can be checked.

This kind of command interface is quite typical for complex systems like service robots which have their own management of resources and skills. We do not make an allocation of the service robot, select a particular mode, set the parameters for
Fig. 6. The XML file of the AAS of the robot system Larry deployed in the Webots robot simulator displayed via the AASX Package Explorer. The AAS of a service robotic system comprises the submodules BillOfMaterials, TechnicalData, Operations, Nameplate, Documentation and Capabilities.

Fig. 7. Using the AAS of a service robot system at runtime for commanding tasks and for reporting operational data. The outside access to the AAS conforms to the standardized structures of the AAS information models and be done via whatever technology is supported by the BaSyx SDK. Inside the AAS, we connect to a Mixed Port Component via Web Sockets (yellow ports). The AAS is implemented via the Java version of the BaSyx SDK while the software built with SMARTMDS is C++. We could also use e.g. OPC UA for the yellow ports given that the BaSyx SDK fully covers the needed mechanisms. The yellow ports could be removed in case the BaSyx C++ SDK is completed. The Mixed Port Component holds the business logic to interact with the composable software components of the robotic system (red ports). The advantage of the decoupling via the yellow ports is that we are free to implement any business logic inside the Mixed Port Component.
this very mode and then invoke the related operation. We also do not let the service robot go into a bidding process for offered jobs (as would be the case with a type 3 AAS). Instead, we enable every entitled entity to push a job to the robot for execution and have both, the immediate rejection by the robot without execution as well as the execution with either success or error and details of the outcome reported via the results.

Another important part of the runtime use of the AAS is to collect all the operational data such as kilometers travelled, success rates of task completion, time needed for tasks etc. It got obvious that a type 1 AAS can serve as a digital data sheet whereas a type 2 AAS with a skill-based approach fits best for embedding service robots into Industry 4.0 settings [11].

Already now, one can use the virtual machine and the related tutorials to get an impression and to play around with our AASs for service robotic systems.

The next steps are extensions of the skill-based interface to better include a kind of bidding in the commanding so that we do not just end up in an error state with rejected as explanation. Thereto, we will extend both, the set of constraints and parameters that can be given with a push and enrich the information that is returned in acknowledging respectively rejecting a given command.

It is important to note that we can easily adjust our submodel templates to upcoming standardizations as we use a model-driven approach with DSLs (domain specific languages) to map from our SMARTMDSD models to AAS submodel templates.

V. CONCLUSION AND FUTURE WORK

An AAS for a service robot has valuable use-cases at design time and at runtime. It is not meant to have all the communication inside a service robot organized via an AAS or by only using OPC UA. It is about the right granularity of providing a standardized access to complex machines and let them interact via standardized means and protocols. It got obvious that a type 1 AAS can serve as a digital data sheet whereas a type 2 AAS with a skill-based approach fits best for embedding service robots into Industry 4.0 settings [11].

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RESOURCES

Ready-to-run downloads and tutorials:

- https://wiki.servicerobotik-ulm.de/virtual-machine
- https://wiki.servicerobotik-ulm.de/tutorials:start

AAS for components and systems:

- https://wiki.servicerobotik-ulm.de/tutorials:start#adding_aas_to_components_and_systems
- https://wiki.servicerobotik-ulm.de/tutorials:start#interacting_with_the_aas

A bigger picture of the kind of service robotic systems and applications we are addressing:

- https://www.youtube.com/user/RoboticsAtHsUlm/videos

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