1st Conference on Production Systems and Logistics

Virtual Asset Representation for enabling Adaptive Assembly at the Example of Electric Vehicle Production

Peter Burggräf[1,2], Matthias Dannapfel[2], Tobias Adlon[2], Viviane Hahn[2], Aaron Riegauf[3], Patricia Casla[4], Angelo Marguglio[5], Izaskun Fernandez[4]

[1] IPEM of University of Siegen, Siegen, Germany
[2] Laboratory of Machine Tools and Production Engineering WZL of RWTH Aachen University, Aachen, Germany
[3] Chair of Production Engineering of E-Mobility Components PEM of RWTH Aachen University, Aachen, Germany
[4] Fundación Tekniker, Eibar, Gipuzkoa, Spain
[5] Engineering Ingegneria Informatica S.p.A, Rome, Italy

Abstract

Manufacturing companies are confronted with the challenge of adapting to ever-changing requirements of markets in order to remain competitive. Besides the rising number of product variants, increasingly frequent product changes require a continuous adaptation of assembly processes including its work instructions. Adaptive and highly connected agile assembly systems are designed to meet these challenges by enabling the interaction of various assets in assembly. A successful implementation of such Industry 4.0 (I4.0) solutions requires the development of a semantic oriented adaptive framework, which connects the physical with the virtual world. It enables interactive and situation-aware solutions such as Augmented Reality applications to adapt to worker capabilities and to improve worker satisfaction by providing information, based on individual experience, skills and personal preferences. A central part of the adaptive framework is the semantic representation of tangible and intangible assets through a Virtual Asset Representation containing all relevant asset information for adaptive assembly. This paper shows a three levels structure for adaptive assembly implementation, consisting of the adaptive framework level, the Virtual Asset Representation (VAR) ontology level and the use case level. The implementation of an adaptive assembly system is shown in the use case of a rear light assembly process of an electric vehicle in the context of the EU funded project A4BLUE. Based on the gained experiences a critical reflection on target fulfilment and user-friendliness of the VAR is given.

Keywords

Internet of Things; Industry 4.0; Agile Assembly; Adaptive Assembly; Virtual Asset Representation; Semantic Technology

1. Introduction

The globalisation, increasingly individualized products and complex production processes require flexible, responsive production systems and personnel. At the same time productivity and quality should be held on a constant high level. [1] Innovative solutions in production from the field of I4.0 are used to encounter these challenges. [2] Agile assembly systems enable the required flexibility and responsiveness offering the opportunity to consider individual and short-term customer wishes related to a product. Even small batches of lot size one can become profitable due to integrated digital engineering [3]. Dynamic process design through ad-hoc connectivity of cyber-physical production systems (CPPS) can lead to fast, flexible reaction and decision-making ability and enable to react to changes in the surround. Furthermore, the productivity of many processes can be increased by using intelligent assembly assistance solutions like Computer Aided Assembly Systems, worker guidance tools or Augmented Reality (AR). [4] Using the described technologies and further intelligent assistance systems, a consistent quality in production can be ensured. [5] While connectivity is a prerequisite, these technologies enable to react adaptively to changes. This paper addresses the research question of how a VAR functions within a semantic oriented adaptive framework and how such a framework can be used to enable agile and adaptive assembly.

2. Frameworks for enabling Adaptive Assembly

2.1 Adaptive automation assembly

Assembly systems enhanced by digital technologies and intelligent automation need to be easily reconfigurable to achieve improvements in system adaptability and a minimisation of installation efforts. [6] For this, the I4.0 revolution is driving the development and introduction of new technologies and automation for adaptive assembly systems. [7] Adaptive systems are able to adapt to changes in the production environment as well as to different operators whereby the latter is focused in this paper. The system considers the user as well as the assembly task and provides optimal ways of interaction and assistance. [8] The ambition in this context is an ideal collaboration of humans and technology with the exploitation of their respective strengths in hybrid assembly systems. [9]

2.2 Industry 4.0 assembly devices

Various I4.0 technologies are designed to improve assembly processes while the solutions address different areas of manual assembly and have different levels of technological maturity. Applications can roughly be subdivided into two groups. Technologies to improve interactivity are, for example: [9]

- Electronic Lifting Aids/Exoskeletons (Lifting Aids)
- Collaborative Robots (Cobots)
- Driverless Transportation Systems (DTS)
- Optical Control Systems (Optical Control)

Technologies for improving adaptivity: [9]

- Interactive/Adaptive Interaction Mechanisms (Interaction)
- Augmented Reality/Assisted Reality/ Virtual Reality (AR)
- Adaptive/Self-Learning Production Control (Prod Control)

are focused in this paper.

2.3 VAR within A4BLUE Adaptive Framework

In order to enable the functioning of I4.0 elements, different systems must be connected to each other. The structure for the integration of systems like AR Guidance or a Decision Support System (cf. Figure 1) and the resulting interfaces can be defined in a semantic oriented framework. The development of the A4BLUE Adaptive Framework is based on well-known reference architectures for digital industry such as RAMI 4.0, IIRA and FIWARE for Industry. The Reference Architecture Model Industry 4.0 (RAMI 4.0) is a three-dimensional layer model in which the essential elements of Industry 4.0 are brought together. Industry 4.0 technologies can be systematically classified in this model. [10] Industrial Internet Reference Architecture (IIRA) is a standard-based open architecture for Industrial Internet Systems (IISs). The description and presentation of the architecture are generic and at a high level of abstraction to support the required broad industry applicability. [11] FIWARE for Industries is an open-source smart manufacturing platform based on industry standards and open source components facilitating the development of apps for Smart Industry solutions. [12]

The Adaptive Framework was specified in A4BLUE in-line with recently introduced reference architectures for the manufacturing industry. It envisions automation and adaptation functionalities in combination with factory physical processes, including real-time operations and taking into account process, product as well as operator variability. One module of the framework is the Virtual Asset Representation (VAR) functioning as a central semantic repository. [9] The VAR is based on an otology, which are generally used to represent knowledge. Domain-specific vocabulary is combined with statements about relations of the entities to which the vocabulary belongs. Natural language is replaced by a structure from which the information can be consistently retrieved. [13] The A4BLUE Adaptive Framework is built on the pillars: virtualisation, adaptation management, worker assistance support and monitoring. Adaption management supports continuous data gathering, analysis and reaction to relevant events, which leads to the triggering of real time adaptation actions. Worker assistance support contributes to context aware work instruction via VR/AR hardware and software components. Also, the transfer of knowledge from skilled to less experienced workers should be facilitated. Monitoring enables the evaluation process by supporting the acquisition and visualisation of performance indicators (KPIs) to assess the impact from an economic and social perspective. [14]

3. VAR for Assembly Structure

The VAR ontology forms the basis for the actual semantic repository. It follows a modular approach to virtually represent production resources and thus enabling connectivity. To understand the VAR structure and its integration within the Adaptive Framework three hierarchical levels can be distinguished (see Figure 1). The first level consists of the Adaptive Framework, which enables event-based control of I4.0 solutions during assembly. The represented assets like AR devices or tools are defined in the ontology which is part of the assembly level. The conceptual foundations for designing such an ontology are described in the following (see chapter 3.1). The VAR for assembly can be divided into four modules: Manufacturing Assets, Plug&Produce; Traceability; and Interaction [15]. Individual classes of each module are detailed on the use case level. Exemplary classes of the Manufacturing Assets module are product, equipment and personnel (physical assets) as well as processes (intangible assets). Object properties define the relations between individual classes of different modules. The characteristics of individual classes are described by a set of datatype properties.

3.1 Conceptual Foundations for the VAR for Assembly

The semantic repository VAR enables the information exchange from and to diverse agents in the assembly. In order to enhance interoperability with external sources (e.g. legacy systems such as ERP or MES) its ontology's design has been based on the B2MML standard. It supports the assembly functionality and is a central part of the modular and functional architecture of the A4BLUE Adaptive Framework for adaptive assembly systems.

Functional applications of the VAR ontology can be defined as:

- Adaption: The used assembly devices meet the level of experience/preferences of the worker.
- Interaction: The VAR is connected to other elements of the Adaptive Framework in order to enable information exchange as a basis for the management of events (initiation or reaction).

Non-functional applications of the VAR ontology also comply with general attributes such as:

- Standard-based to support interoperability and reusability.

- Flexibility and sustainability: The ontology is able to evolve along time to correctly represent reality when changes to the assembly system occur. It is able to be easily extended to fit new circumstances, e.g. by adding custom domain concepts.
- Worker assistance and optimal degree of automation: The VAR supports socio-economical evaluations for determining optimal automation configurations by including parameters for cost and worker satisfaction.
- Compatibility and adaptability: The VAR is compatible to various connected components accessing the contained information. The connected components adapt to changing circumstances and as a result, the VAR ontology is dynamic as well.

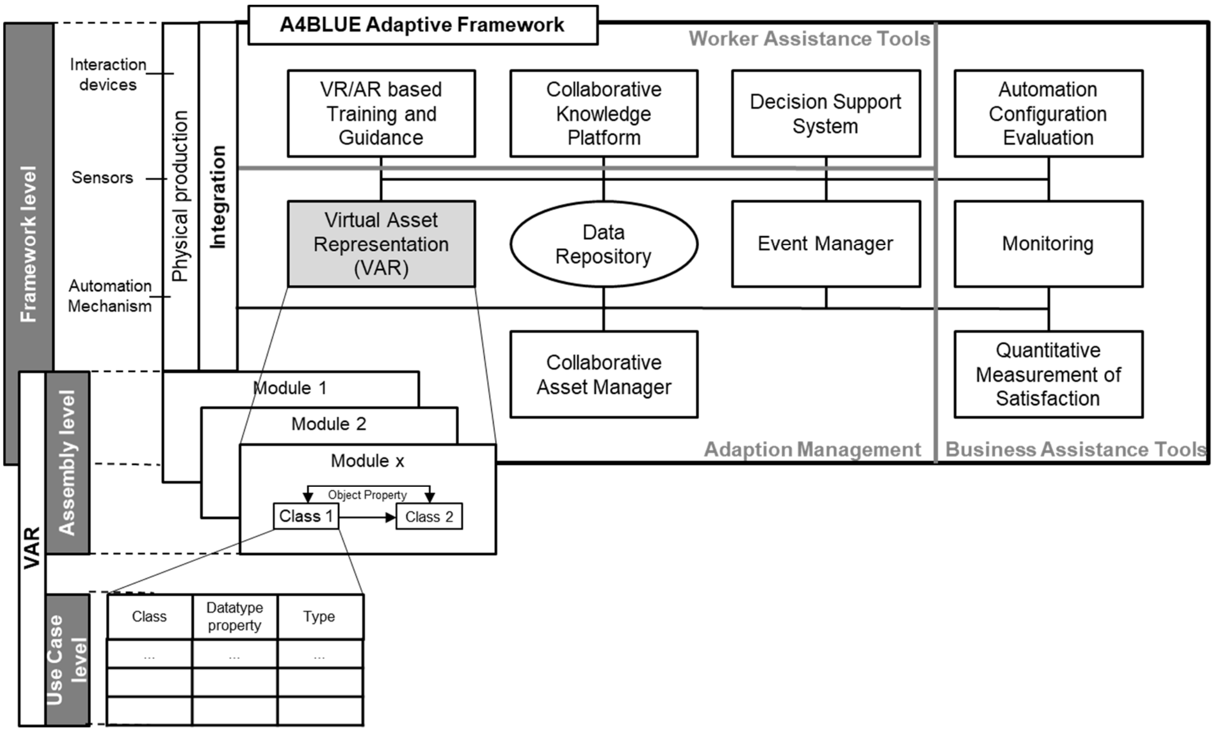

Figure 1: VAR level structure [based on 14]

3.2 VAR Application Scenario in Electric Vehicle Assembly

To explain the use case level and the application of the framework in combination with the VAR, a few steps of a rear light assembly process of an electric vehicle are exemplary shown (cf. Figure 2). The production scenario of this laboratory use case is characterised by a high number of product variants and low production volumes as well as frequent production ramp-ups. The assembly takes place in the Ramp-Up Factory Aachen of RWTH Aachen University.

The operation starts by scanning a QR-code while the assembly operator wears an AR-device. For this step, the AR guidance needs an interface to the framework. The VAR instantiation includes the level of expertise for a person in a specific type of process, comparable to a skills matrix. Besides this, the operator can choose from a set of skill levels in an adaptable manner. For example, the operator obtains more detailed work instructions by the AR-device if a lower skill level is chosen (novice) than if a higher skill level (expert) is selected. The next assembly step comprises grasping of required rear light components. The AR-device visualises a picking list and the demanded part. The information for instructions are given by the job order and CAD data that are activated via the AR guidance of the framework. After this, the AR-device supports in finding the right position of the rivet nuts while illustrating how to use the rivet tool correctly. The use case shows that assembling the parts is made possible for novice as well as experienced users, enabled by the VAR embedded in the A4BLUE Adaptive Framework.

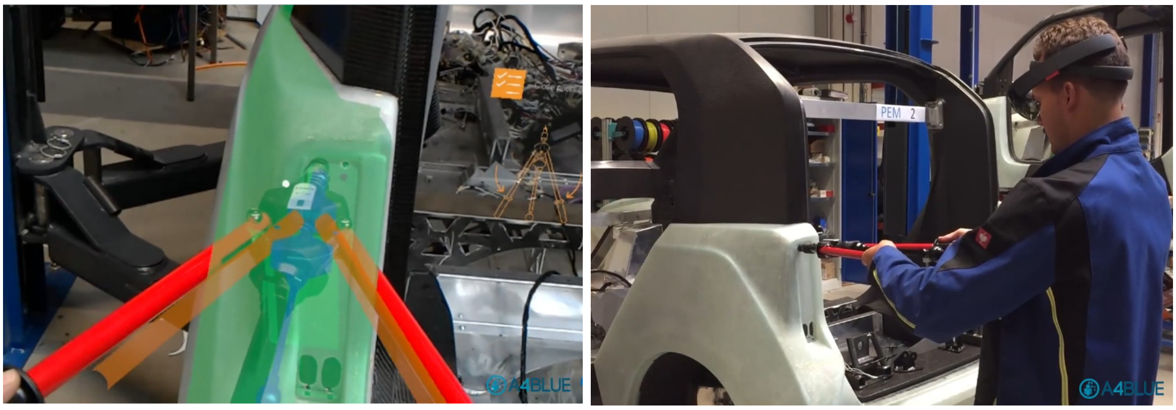

Figure 2: AR-guided rear light assembly process of A4BLUE use case

4. Functionality Evaluation and Critical Reflection

The following evaluation is a critical reflection regarding target fulfilment (cf. table 1) and user-friendliness of the VAR for assembly. The evaluation is based on the gained experience during the A4BLUE project execution at the example of the RWTH Aachen University use case from a production engineering perspective. The evaluation criteria, which can be derived from the acatech Industry 4.0 Maturity Index, are named and described in the following Table 1: [16]

Table 1: Explanation of evaluation criteria

Evaluation criteria	Description
Usability	Describes the operation and modification effort as well as the required skill set for adapting the instantiated VAR in assembly. The rating scale ranges from programming/modeling expert to an intuitive operation by the operator during assembly. The objective is to achieve the highest possible usability by allowing as many people as possible to use and adapt the ontology with lowest possible effort.
Adaptivity	Consideration of the adaptivity of the I4.0 solutions to the individual employee. Different skill levels should be adjustable. For example, an unskilled assembly operator should receive more detailed instructions than a skilled assembly operator. The criterion assesses whether the VAR does not meet these requirements, meets only partially or completely for all potential properties and characteristics.
Vertical integration	Considers the system integration capability by providing interfaces across multiple levels of the enterprise system structure. For example, an interface between the ERP and MES systems can be listed here.
Complexity ability	The criterion describes the ability to model a certain degree of complexity of an assembly system, i.e. the variety of system elements (equipment, assistance systems, processes, product variants etc.) and their characteristics.

The evaluation of the VAR was carried out qualitatively using a five-level item specific scale. It is derived from initial experience with the implementation of the ontology model. The evaluation serves as a basis to improve any identified deficiencies of the VAR and is shown in Figure 3. The prototypical implementation of the RWTH use case is evaluated within the five-digit scale while the best evaluation corresponds to a “5”.

Criteria	Scale				
	1	2	3	4	5
Usability	Programming expert/ Modeling expert				Intuitive operation by the worker
Adaptivity	No processes are adaptive				All processes are adaptive
Vertical integration	No interfaces provided in model				Complete vertical integration provided
Complexity ability	Low				High

Figure 3: VAR evaluation based on RWTH Aachen University Use Case

The *usability* is evaluated with “1”, because ontology instantiation changes have to be performed by means of an ontology editor (i.e. Protégé). As a result knowledge of the used program and access to the programming interface must be available, which is usually not possible for workers in production. Consequently, with regard to usability and adaptability, operation by an expert is required.

Moreover, the *adaptivity* assessment for the VAR is evaluated as a “4” which means "almost complete". Three levels of worker experience can be differentiated within the VAR (novice, trained, expert). The level selection can be done via an AR application and is user-friendly. However, new levels or changes to them have to be elaborately programmed and scripted.

Since no ERP/MES systems are used in the RWTH Aachen use case, no interfaces are triggered via the current VAR. Hence, the VAR is rated “2” in the evaluation of the *vertical integration* based on the example of electric vehicle production.

Furthermore, the ontology is arbitrarily expandable and therefore the complexity is scalable. In the beginning not every single assembly application is modeled in classes. However, only classes relevant for the use case are instantiated in the VAR. Because of these reasons, the *complexity abilit*y is evaluated as “3” which means medium.

Summarising, the VAR ontology enables adaptive assembly applications in the RWTH Aachen University use case. It hence fulfils the main objective to enable data exchange from and to diverse assembly components to reduce complexity in the assembly process. The operator support works perfectly for the applications implemented. However, to add further functions and devices the knowledge of a programming expert is required. While the vertical integration capability of the VAR is generally given, it was not implemented in this use case scenario. It has been proven in the other A4BLUE use cases though.

5. Summary and Outlook

The VAR embedded in the A4BLUE Adaptive Framework is used to enable intelligent, adaptive assembly systems. These are designed to improve worker satisfaction by providing information based on individual experience, skills and personal preferences. Furthermore, training times for new employees as well as during launch of new products and product variants can be reduced. Process efficiency can be improved by reducing errors in picking of variant parts, tools and connecting elements through interacting information provision systems. In this paper three levels of the VAR for assembly are described (adaptive framework level, VAR level and use case level). The VAR enables the integration of adaptive technological solutions to support workers during assembly. This was implemented and demonstrated in the A4BLUE project - amongst others - by means of AR solutions. In the context of the described use case in electric vehicle assembly, the VAR was critically evaluated. In the future, the VAR could be transferred to other areas within production, such as logistics. Already existing reference architectures as well as the presented adaptive framework need to be enhanced to further facilitate the introduction of I4.0 solutions throughout all areas of production. Further research is needed regarding future staff qualification. With the increasing use of adaptive information technology, it is important to further examine the impact on working environments. An aspect in this context are the capabilities and skills of an assembly operator being required within a progressively adaptive information technology environment. With regard to the application of adaptive technologies and their underlying semantic oriented frameworks in industrial practice, the quantitative benefits need to be worked out more precisely.

Acknowledgements

This research work has been elaborated within the project A4BLUE (Adaptive Automation in Assembly For BLUE collar workers satisfaction in Evolvable context) which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 723828.

References

[1] Stock, Seliger 2016: Opportunities of Sustainable Manufacturing in Industry 4.0, Procedia CIRP, Vol. 40, p. 536-541.

[2] Hu 2013: Evolving paradigms of manufacturing: From mass production to mass customization and personalization, Procedia CIRP, Vol. 7, p. 3–8.

[3] PWC 2014: Industry 4.0 – Opportunities and Challenges of the Industrial Internet, p. 16.

[4] Hinrichsen, Bendzioch 2018: How Digital Assistance Systems Improve Work Productivity in Assembly, AHFE 2018: Advances in Human Factors and Systems Interaction, p. 332-342.

[5] Monostori 2014: Cyber-physical Production Systems: Roots, Expectations and R&D Challenges, Procedia CIRP, Vol. 17, p. 9-13.

[6] Chryssolouris, Mavirkios, Papkostas, Mourtzis, Michalos, Georgoulias 2009: Digital manufacturing: History, perspectives, and outlook, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 223(5), p. 451–462.

[7] Hermann, Pentek, Otto 2016: Design principles for Industrie 4.0 scenarios, IEEE System sciences (HICSS), 2016: 49th Hawaii international conference on System Sciences, p. 3928– 3937.

[8] Norcio, Stanley 1989: Adaptive human-computer interfaces - A literature survey and perspective. IEEE Transactions on Systems, Man, and Cybernetics, 19(2), 399–408.

[9] Fletscher, Johnson, Adlon, Larreina, Casla, Parigot, Alfaro, Del mar Otero 2017: Adaptive automation assembly: Identifying system requirements for technical efficiency and worker satisfaction, Computers & Industrial Engineering, Vol 139.

[10] Hankel, Rexroth 2015: Industrie 4.0: The Reference Architectural Model Industrie 4.0 (RAMI 4.0), ZVEI - German Electrical and Electronic Manufacturers' Association.

[11] Industrial Internet Consortium 2015: Industrial Internet Reference Architecture, IIC:PUB:G1:V1.07:PB:20150601, p. 10.

[12] Van der Klaauw 2019: IoT Platforms for Cities: a Comparative Survey, The Academy for Smarter Communities.

[13] Popescu, Xu 2009: Data Mining in Biomedicine Using Ontologies, Artech House, p. 1-6.

[14] Burggräf, Kampker, Kreisköther, Adlon, Riegauf, Dorn, Casla, Marguglio, Donvito 2019: Enabling Smart Workplaces by Implementing an Adaptive Software Framework, AHFE 2019: Advances in Human Factors and Systems Interaction, p. 116-127.

[15] Fernandez, Casla, Esnaola, Parigot, Marguglio 2020: Towards Adaptive, Interactive, Assistive and Collaborative Assembly Workplaces through Semantic Technologies, 10th International Conference on Interoperability for Enterprise Systems and Applications (I-Esa2020).

[16] Schuh, Anderl, Gausemeier, ten Hompel, Wahlster 2017: Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies (acatech STUDY), Herbert Utz Verlag.

Biography

Prof. Dr.-Ing. Peter Burggräf (*1980) is scientific head of the Department of Factory Planning at the Laboratory of Machine Tools and Production Engineering WZL of RWTH Aachen University and has been head of the Institute of International Production Engineering and Management at the University of Siegen since 2017.

Matthias Dannapfel (*1986) has been head of department of Factory Planning at the Laboratory of Machine Tools and Production Engineering WZL of RWTH Aachen University since 2017.

Tobias Adlon (*1989) has been group leader Assembly Planning at the Laboratory of Machine Tools and Production Engineering WZL of RWTH Aachen University since 2017.

Viviane Hahn (*1991) has been research associate in the department of Factory Planning at the Laboratory of Machine Tools and Production Engineering WZL of RWTH Aachen University since 2018.

Aaron Riegauf, (*1991) has been research associate at the chair of Production Engineering of E-Mobility Components (PEM) of RWTH Aachen University since 2017.

Patricia Casla (*1968) is Health and Social Technology Coordinator as well as Project Manager at Industrial Management and Innovation Unit of TEKNIKER.

Angelo Marguglio (*1982) is Research Area Manager and Head of the "Smart Industry and Agrifood" Unit of the Research and Development division at Engineering Ingegneria Informatica Spa.

Izaskun Fernandez (*1980) is senior researcher in the Intelligent Information System Unit of TEKNIKER.