Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 118 (2023) 935–939

www.elsevier.com/locate/procedia

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

Reducing commissioning efforts for hybrid assembly systems using a data-driven approach

Florian Kalscheuer[a,*], Julian Koch[a], Thorsten Schüppstuhl[a]

[a]Hamburg University of Technology, Institute for Aircraft Production Technology, Denickestraße 17, 20173 Hamburg, Germany

* Corresponding author. Tel.: +49 40 428 78 - 2012; *E-mail address:* florian.kalscheuer@tuhh.de

Abstract

The required flexibility for the assembly of high variant and low volume products such as aircraft components is often met with manual processes. Historically grown and poorly optimized processes are reaching their limits in terms of production rates. The growing demand for these products and increased competitive pressure from low-wage countries are driving companies to increase the level of automation in production, which can be achieved ever more cost-effectively through interconnected resources and digitization. Hybrid assembly systems, consisting of digital assistance systems and automation resources such as projection devices or cobots offer a flexible solution with manageable investment. However, task- and product-specific programming and the commissioning of several sensors and actuators require automation expertise and lead to high costs not only during implementation but also during operation. Furthermore, small and medium-sized enterprises (SMEs) are confronted with the challenge of a low degree of digitalization within their manual processes, high cost for automation expert knowledge, or simply manpower. Therefore, expanding from manual to hybrid assembly systems, several transformation and assignment problems occur and data flow as well as media discontinuity have to be considered. To close this gap, a solution approach consisting of an information model and data transformation pipeline is derived, that can be used as a supplementation for existing planning methodologies. The goal is to reduce the effort for commissioning and operation of automation technology, support engineers on the shopfloor level with missing expert knowledge, and increase transparency in late planning phases during assembly planning. This approach is intended to support the expansion of manual to partially automated assembly systems without the need to adapt the product or plan a new assembly system from scratch.

© 2023 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 16th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Hybrid assembly; Commissioning; Information modeling

1. Introduction and problem statement

The assembly of customized products in small quantities, such as those found in the aircraft industry [1], is still characterized by manual processes offering flexibility, but limiting production rates. Growing demand and increasing competitive pressure due to production in low-wage countries present companies with the challenge of constantly improving their processes. More and more frequently, they are responding by increasing the degree of automation. By increasing the degree of automation in assembly, companies expect not only to increase productivity but also to improve quality while reducing costs.

The increase in the level of automation (LoA) for assembling customized products, can be achieved with different approaches. Constructive influence on product design is responsible for up to 75% of the product costs, which are caused in the course of the product development process. Design for assembly (or design for automation) therefore is a prerequisite for rationalization during assembly [2]. However, due to approval restrictions or simply very high product development

2212-8271 © 2023 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the 16th CIRP Conference on Intelligent Computation in Manufacturing Engineering
10.1016/j.procir.2023.06.161

costs, in many industries, a change in product design is not possible.

Another option for assembling highly variant products is the use of modular, fully automated assembly systems. However, these involve high development and investment costs, which in turn raises the hurdle for use with an existing product range. Moreover, these systems still require hardware retooling in response to new product variants. Often, their advantages are most visible for products in the unit-volume range of several hundred thousand per year [3] which in this case are out of scope.

Semi-automated, hybrid assembly systems offer the possibility of flexibly assembling small batch sizes with a manageable investment. Due to current developments, it is possible to further reduce investment costs by resorting to low-cost automation technology. This includes, for example, industrial robots, cobots, and sensor technology. Likewise, a continuous digital process chain from product development to production can also ensure a high degree of flexibility with batch size 1.

Although the implementation of low-cost automation might appear manageable and their benefits on the existing processes become clear in advance during planning, commissioning and operation create high efforts. The scope of the stated problem is shown in Fig. 1.

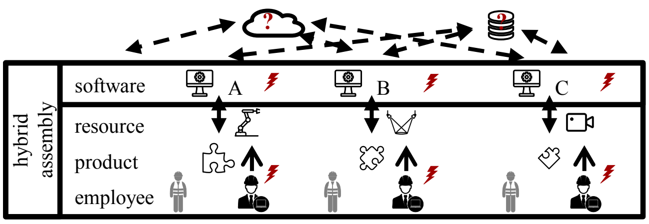

Fig. 1. Scope of the problem during commissioning and operation of hybrid assembly systems.

It shows three different products, their respective required employees, resources, and software. Each resource is used to assist or carry out one of the existing assembly tasks. Compared to manual assembly systems, two types of personnel are required. Skilled workers are needed for the manual assembly tasks that continue to exist. However, instead of only assisting these workers, resource-specific experts are required for commissioning and operating the automation hardware. Furthermore, in most cases hardware-specific, often proprietary software is required for control purposes. In a paper-based environment with decentralized information sources considered here, this leads to media discontinuities and an interrupted data flow. In summary, increasing the LoA in a manual assembly system leads to an increased need for expert knowledge, information transformation and assignment problems for additional software and hardware, higher demand for a continuous flow of data, and at best, resource neutral exchange formats (see par. 3). This contrasts with a low level of digitization, decentralized knowledge, and a lack of automation experience.

For the planning of assembly systems, several methodologies exist in the broad field of research. The often top-down structured approaches provide SMEs with good results for rough planning and the definition of requirements. However, system development, commissioning and ramp-up are the responsibility of automation service providers which lack transparency. The hurdle that must be overcome for flexible operation remains with the SMEs, which often lack digitization, methodology, expert knowledge, and manpower. Therefore, a commissioning-specific solution approach is required. It should create transparency about the effort involved in hardware implementation in an early stage of the planning process, before contracting service providers.

This paper aims to derive a commissioning-specific approach that supports SMEs during the expansion from manual to hybrid assembly systems, reduces commissioning efforts, and increases the transparency about the required information. First, the state of the art will be discussed. Deficits in existing methodologies will be identified and other modeling approaches will be explained. Subsequently, commissioning in assembly and virtual commissioning (VC) will be introduced and the applicability of VC to the stated problem discussed, as well as existing industrial solutions, will be stated. After a solution framework is introduced, discussed and validation approaches for future sub-problems are stated.

2. Planning and commissioning of assembly systems

The following section describes the relevant state of the art regarding assembly planning and virtual commissioning. Existing solutions for the problem stated above will be described and their deficits and the corresponding need for action are presented.

2.1. Assembly planning methodologies

Assembly planning methodologies commonly follow a top-down approach which can be broken down into 5 steps [2, 4–6]:

- Task description and concept development
- Rough planning
- Fine planning
- Commissioning and ramp-up
- Operation

These steps can be divided into several sub-steps such as product analysis, assembly sequence planning, cycle time planning, layout planning, budgeting, availability planning, or optimization steps. Publications in the field of research may be categorized by the planning phase, the production system considered, and their solution approach. The planning phase addresses the sub-steps mentioned above, production systems can be e.g. manual serial assembly, human-robot-collaboration, serial assembly, or the assembly of a specific product, such as car engines Several methodologies are supplemented by different models e.g. capability-based models, a feature model or a knowledge repository. They support layout planning, hardware selection, and design, evaluation of different system variants, assembly sequence planning, or assembly scheduling. They also have in common, that they assist the planner e.g. by automating planning tasks, an automated combination of product, resource, and process characteristics, semi-automated extraction of process relevant information from CAD data, or by providing a transparent overview of the planning problem. [3, 7–11] In the first three steps, many different approaches already exist, especially with a focus on assembly sequence planning, cycle time planning, layout planning, or availability planning [7, 12]. However, the last two steps lack research in specific methodologies. Especially the requirements and challenges during commissioning and ramp-up have not been mirrored on the early planning steps, which leads to an underestimation before and during these phases which can increase costs due to additional expert knowledge. For the challenges mentioned above in connection with the classical commissioning of partially automated assembly systems, a model-based approach, therefore, represents a suitable solution.

2.2. Virtual commissioning

The commissioning of an assembly system can be described as one category of assembly tasks shown in Table 1. Commissioning tasks include e.g. adjustment, parameterizing and functional test [13].

Table 1. Assembly tasks. [13, 14].

joining	handling	commissioning	auxiliary tasks	additional tasks
composing	feeding	adjustment	inspection	cleaning
screwing	moving	parameterizing	heating, cooling	packing
adhesive bonding	securing	functional test	storing	labeling

For hybrid assembly systems, utilizing hardware such as cobots, projection devices, or sensors, commissioning tasks include calibration, referencing, path planning/generation, control, and communication, which require cross-functional expert knowledge and can lead to high ramp-up time.

To reduce ramp-up time and to save costs during the commissioning process, e,g. the functional test of production systems can be previously carried out using virtual commissioning (VC) [15]. It is usually applied in the fields of logistics, assembly, manufacturing, and testbeds and contributes to the level of automation, especially in the optimization and validation of PLC code [16]. Each component of the production system, in this case, assembly systems, requires a specific model as a virtual representation e.g. a kinematic, geometric, electric, or control model. However, the manual assembly environments considered here do not have a sufficiently accurate digital product and process description and are predominantly paper-based. The effort for implementing VC is comparatively high when only a flexible low-cost automation system has to be implemented.

From the previously discussed state of the art, three main deficits regarding the increase of the LoA in manual assembly systems using flexible automation technology can be identified:

1. High effort for commissioning and operation of automation technology
2. Lack of digitization and expert knowledge in SMEs
3. Lack of detail in late phases of planning methodologies

In the following section, a solution approach is introduced that addresses these deficits and describes an idea, of how it can contribute to automate manual assembly environments. This requires information models or databases, which cannot be assumed present at the considered enterprises. With a simplified description of commissioning requirements, transparency could be increased and implementation effort reduced. Furthermore, a central database with a transformation pipeline is required enabling low digitized SMEs for automating their assembly processes and operating low-cost automation systems economically with less expert knowledge. Furthermore, the benefit of using these tools as supplementation of existing planning methodologies will be discussed.

3. Data-driven planning and commissioning

The solution approach consists of two different modules. First, a commissioning-specific information model is introduced, and afterward, a transformation pipeline is described. They both contribute as supplementation for existing assembly planning methodologies and especially affect the last two steps, the commissioning, and ramp-up as well as operation.

Commissioning-specific information model

The information model is used to represent the commissioning problem from the point of view of the automation engineer, assembly planner, and requirements from automation technology integrated on the shopfloor.

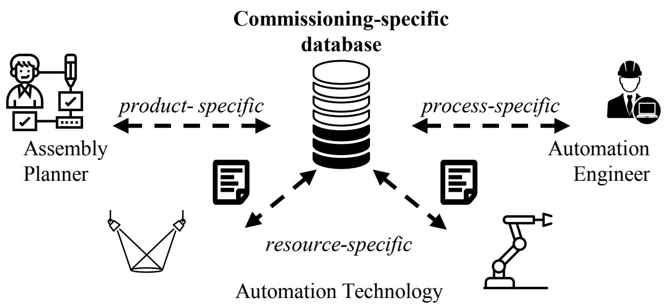

Fig. 2. Commissioning-specific information model for assembly.

Its information can be divided into product-, process- and resource-specific parameters (see Fig. 2) which can be used multi-directionally during the implementation of new automation technology. The resource-specific information leads to transparency about commissioning specific requirements, which can support the assembly planner in the early phases of the planning process since relevant data can be identified. Process-specific information can be gathered by the automation engineer and connected with product-specific data to support customized assembly operationally. Furthermore, product-specific information can also be accessed during the commissioning process, which is described in the following section. This sets a baseline for seamless integration of automation resources in manual assembly systems.

Rule-based transformation pipeline

The three categories of parameters contain datasets, which can be considered partly persistent and partly transient (see Fig. 3). Persistent data is data, that is gathered once for general commissioning purposes such as calibration information, workspace, or initial position of the resource. Transient data changes during the process such as work object dimensions, process parameters, or projection positions. Furthermore, data needs to be converted to fit the resource-specific format and communication protocol. E.g. although cobots or projection systems can come with low-code software, initially they require different data for commissioning as well as different points of reference during operation.

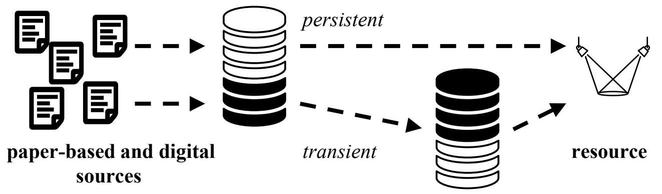

Fig. 3. Rule-based transformation pipeline for persistent and transient assembly information.

A rule-based transformation pipeline automates transformation and assignment problems and assists the engineer that is commissioning, and the employee on the shopfloor operating the hybrid assembly system by generating a commissioning-specific flow of data in the resource-specific format. It facilitates parameters from the information model, such as coordinate systems, position accuracy, workpiece orientation, transmission rates, or initial reference points to automate functions such as calibration, assigning coordinate systems to the workspace, or identification of new workpiece parameters. Therefore, less expert knowledge is required for initial commissioning and later adaption of resources and product-specific operation can be accelerated.

Supplementing existing planning methodologies

With a commissioning-specific information modeling approach and a rule-based transformation pipeline, existing assembly planning methodologies can be supplemented by tools that are intended to support the expansion of manual to partially automated assembly systems without the need to adapt the product or plan the system from scratch. The transformation pipeline primarily supports operational activities that take the workload off the engineer during commissioning. However, the model, in particular, can be facilitated to generate transparency in the early phases of existing assembly planning methodologies by visualizing and gathering commissioning-specific data and its related information centrally with low effort. It contains a description of the respective sources to allow a more targeted retrieval of relevant information, to accelerate the planning process.

4. Discussion

The goal of the abovementioned approach is to reduce commissioning effort for automation technology, support SMEs during the implementation on the shopfloor and increase transparency in late assembly planning phases. Implementation and validation of the presented solution modules are still pending. Nevertheless, it can be assumed that the described modules will contribute to the fulfillment of these goals. For a complete commissioning-specific information model, commissioning tasks have to be analyzed concerning the required information. To support the planner, these can be divided into product-, process-, resource-, and also workspace-specific information, so that the source can be identified. The transferability of the model to other resources and products in different workspaces can be validated by applying it to different industrial use-cases. The information model provides a low-threshold contribution to the structured digitization of information, which sets a baseline for further assembly process automation and therefore increased productivity. Easily understandable programming languages and resource-neutral data exchange formats enable the implementation of a simply accessible data pipeline that can be adapted to new resources. This requires broad analysis of typical commissioning processes and derivation of respective semantics. Although the transformation of information can be supported or even automated, adding data from different paper-based sources need specific user interfaces, which have to be investigated. The effect on ramp-up and also operation can be validated practically by comparing process times during the commissioning of automation resources. By extending a skill-oriented description with a commissioning-oriented description, transparency can be increased in the late assembly planning phases, containing ramp-up and operation. Future work has to show how the data acquisition, modeling, and automation affect the phases. This can be carried out by comparing the amount of missing or difficult to locate information compared to using existing methodologies without the new supplementation. The effect on early stages of assembly planning, such as the assembly system configuration, layout planning, or scheduling is not obvious and remains to be proven as the work continues.

5. Summary and future work

The work presented in this paper addresses the topic of increasing the LoA in manual assembly systems with flexible automation technology. As the planning and commissioning create high efforts due to automation expertise and lack of digitization, a solution approach consisting of an information model and data transformation pipeline is introduced to allow SMEs to implement automation technology in assembly with low boundaries to increase productivity.

Future research has to be carried out regarding a suitable modeling systematic, a broad analysis of data sources and data sinks during the commissioning process and a practical validation has to prove the decrease of commissioning effort and utilization of the solution approach for supplementation of assembly planning methodologies. Regarding the information model, a suitable data format, such as AutomationML, XML, YAML, or JSON can be used and adapted to store the specific information. A skill-based description of hardware can be extended by a commissioning-specific description, which includes parameters e.g. calibration or different systems of coordinates or accuracy characteristics. Furthermore, a cross-platform or document-oriented database can be implemented and structured to handle paper-based, digital, or manually entered information. This requires an analysis of information for the commissioning of different resources that can be generalized and parametrized. This generalized structure can be used to assist the assembly planner to identify information gaps in early planning phases for example, by mapping the information to the respective source.

With the results of an analysis of the resource-specific requirements regarding data formats and communication protocols, the rule-based transformation functions (semantics) can be derived. Existing data engineering approaches for extracting, transforming, and loading (ETL) the gathered data and publisher/subscriber protocols such as ROS or MQTT will be used to accelerate the commissioning on the shopfloor level. Furthermore, it will reduce the operation effort during the assembly of varying products. Lastly, the solution modules will be applied to a use-case from the aircraft interior production, which can be used as a representative example of the deficits described above.

Acknowledgments

The work presented in this paper is carried out in a project funded by the Federal Ministry for Economic Affairs and Climate Action of Germany (BMWK):

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

References

[1] Kalscheuer F, Eschen H, Schüppstuhl T (2022) Towards Semi Automated Pre-assembly for Aircraft Interior Production. In: Schüppstuhl T, Tracht K, Raatz A (Hrsg) Annals of Scientific Society for Assembly, Handling and Industrial Robotics 2021. Springer International Publishing, Cham, S 203–213

[2] Lotter B, Wiendahl H-P (2012) Montage in der industriellen Produktion. Springer Berlin Heidelberg, Berlin, Heidelberg

[3] Kluge S, Westkämper E (2011) Methodik zur fähigkeitsbasierten Planung modularer Montagesysteme. Zugl.: Stuttgart, Universität Stuttgart, Diss., 2011. IPA-IAO-Forschung und Praxis, Bd 510. Universitätsbibliothek der Universität Stuttgart, Stuttgart

[4] Bullinger H-J, Ammer D (Hrsg) (1986) Systematische Montageplanung. Handbuch für die Praxis. Hanser, München

[5] Spur G, Stöferle T (1986) Fügen, Handhaben und Montieren. Handbuch der Fertigungstechnik, / hrsg. von Günter Spur und Theodor Stöferle ; Bd. 5. Hanser, München

[6] Konold P, Reger H (2009) Praxis der Montagetechnik. Produktdesign, Planung, Systemgestaltung, 2. Aufl. Vieweg Praxiswissen. Vieweg, Wiesbaden

[7] Michniewicz J, Reinhart G, Franke J (2019) Automatische simulationsgestützte Arbeitsplanung in der Montage

[8] Müller R, Eilers J, Hermanns L, Gerdes R (2017) Modellunterstützte Baubarkeitsprüfung in der Montageplanung*/Model-Assisted mountability check of engines in assembly planning. wt 107(04):253–260. doi:10.37544/1436-4980-2017-04-57

[9] Beumelburg K (2005) Fähigkeitsorientierte Montageablaufplanung in der direkten Mensch-Roboter-Kooperation. Zugl.: Stuttgart, Univ., Diss, 2005. IPA-IAO-Forschung und -Praxis, Bd 413. Jost-Jetter, Heimsheim

[10] Westkämper E, Spingler JC, Beumelburg K (2003) Skill Oriented Planning of Semi Automated Assembly Systems. IFAC Proceedings Volumes 36(22):111–116. doi:10.1016/S1474-6670(17)37702-9

[11] Dipl.-Ing. Robert Weidner (2014) Konzept zur Planung und Beurteilung von Montagesystemen in der Luftfahrtindustrie, Helmut-Schmidt-Universität

[12] Roßgoderer U (2002) System zur effizienten Layout- und Prozessplanung von hybriden Montageanlagen. Forschungsberichte / IWB. Utz, München

[13] Müller R (2021) Montagegerecht. In: Bender B, Gericke K (Hrsg) Pahl/Beitz Konstruktionslehre. Springer Berlin Heidelberg, Berlin, Heidelberg, S 725–754

[14] VDI (1990) VDI 2860. Montage- und Handhabungstechnik, Handhabungsfunktionen, Handhabungseinrichtungen; Begriffe, Definitionen, Symbole. Beuth. Zugegriffen: 20. Januar 2022

[15] Zäh MF, Wünsch G, Hensel T, Lindworsky A (2006) Nutzen der virtuellen Inbetriebnahme: Ein Experiment. Zeitschrift für wirtschaftlichen Fabrikbetrieb 101(10):595–599. doi:10.3139/104.101070

[16] Lechler T, Fischer E, Metzner M, Mayr A, Franke J (2019) Virtual Commissioning – Scientific review and exploratory use cases in advanced production systems. Procedia CIRP 81:1125–1130. doi:10.1016/j.procir.2019.03.27