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A Concept towards Automated Data-Driven Reconfiguration of Digital Assistance Systems

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Abstract

Constantly changing assembly tasks and reduced production cycles increase the risk of cognitive stress of operators. A large number of digital assistance systems implemented in assembly lines contribute to operator's stress reduction. However, small and medium sized companies confront major challenges in implementing digital assistance solutions due to high investment costs and high customization effort. In addition, technological risks are mainly summarized as i) choosing the right assistance system, ii) realizing suitable interfaces within the in-house IT landscape for machine-to-machine and machine-to-human communication and iii) creating assembly instructions and configuring data systems in terms of supplying specific and adaptable information. Considering the aforementioned challenges and related technological risks, this paper presents a concept for automated data-driven reconfiguration of digital assistance systems. We discuss its impact on certain use cases defined in the TU Wien Pilot Factory Industry 4.0. Finally, we outline learning design principles for students and industrial stakeholders to implement automated reconfigurable digital assistance systems.

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Keywords: Cyber Physical Assembly Systems; Digital Assistance; System Independent Data-Driven Reconfiguration; Flexiblity

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1. Introduction

Increasing digitalization and demographic change present enormous challenges for manufacturing companies concerning adaptability. The trend from mass- to customer-oriented production implies an increasing number of variants, shorter product life cycles and higher product complexity [1, 2]. This trend especially affects assembly processes [3] and increases the economic demand for higher flexibility and configurability [4]. Despite the observable increase of automation, there is still a high amount of manual tasks – especially when complex and skillful operations are to be executed [5]. According to Claeys et al., an emerging amount of different product models and high model variety increases cognitive workload on assembly operators. As a result, process quality and throughput rate decrease significantly [6].

In manual assembly processes, paper based work instructions are a common way to support operators with task information, e.g. sequence of assembly steps, tools to use and process parameters. Due to raising complexity and dynamic assembly tasks, operator guidance systems reach their economic and technical limit [7]. Recently, various digital assistance systems (DAS) appeared, replacing paper based work instructions with digital information using different technical components concerning different devices, sensory and information representation technologies [8]. Dynamic operator guidance enables cost efficient assembly of high variant products, provides ad hoc quality assurance during the process and reduces cognitive stress of operators [9, 10, 11]. However, DAS require information data relevant to an individual operator, e.g. step-by-step instructions, visual representations and specific process parameters, in order to enable appropriate support [12]. Moreover, efficient implementation of a DAS solution in the context of smart factories requires new didactical concepts [13].

Considering the above discussion, this paper describes a pragmatic concept for automated data-driven reconfiguration of DAS in Smart Factories and discusses its impact, based on use cases in TU Wien Pilot Factory Industry 4.0. Furthermore, we outline a learning design for students and industrial stakeholders to implement automated reconfigurable digital assistance systems.

2. State of the Art in Configuration and Implementation of Digital Assistance Systems

According to Hinrichsen et al., assembly assistance systems are technical systems that receive and process information to assist operators in carrying out their assembly tasks [2]. These systems are distinguished between physical and information assistance. While physical assistance systems are aimed at reducing physical work load of operators, information assistance systems are designed to avoid uncertainties and cognitive work load [2]. In this context, dynamic and complex assembly tasks are often guided by text based step-by-step instructions, images, animations, binary signals or artificial text-to-speech sequences via modern ICT based (Information and Communication Technology) human-machine interfaces.

By connecting information processing systems of DAS with peripheral equipment, tact synchronization and context-awareness become additional characteristics of assistance systems [14]. This leads to production relevant benefits, such as user-friendly human-machine interactions, ad hoc quality assurance during assembly processes or situation dependent rearrangements of assembly sequences. For example smart tools, such as screwdrivers, can be controlled by DAS, ensuring a safeguarded and task specific activation of screwing programs by simultaneous documentation of process results [15]. However, the variety of assembly assistance systems on the market leads to a need to get accustomed to different system-specific uploading interfaces simultaneously.

From a technical point of view, DAS consist of the components depicted in Figure 1. An **Assembly Operator** interacts with a specific **Interaction Device** through different human senses, e.g. optic, acoustic or haptic stimuli [2]. The design and user-friendliness of the device is crucial for the quality of the human-machine interaction, discussed in several publications [16], e.g. touchscreens [17], smart glasses [18], augmented reality headsets [11], projectors [19], and smart watches [20]. The interaction device is controlled by a software instance. Especially in case of optic (visual) information representation, an additional graphical user interface (GUI) is provided to display assembly relevant information. This software instance downloads needed information from a **Server or Database**, which in most cases is not located on the shop floor, but in a separate server room. The database is used to store relevant

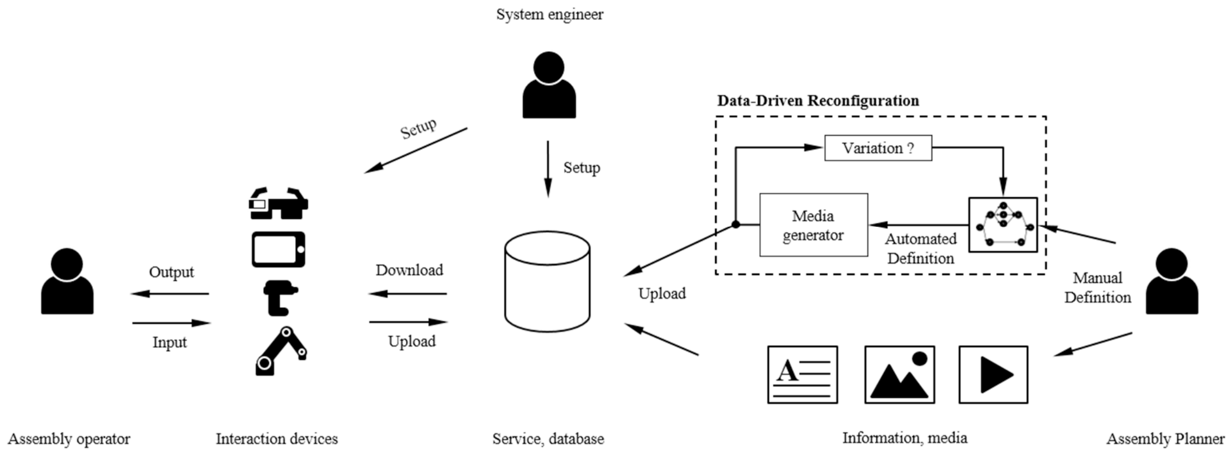

Fig. 1. Schematic Structure of a Digital Assistance System.

assembly **Information and Media Files,** while the server acts as a central node for peripheral signals and data streams (upload, download).

The aforementioned assembly information and media files need to be generated in order to upload – respectively transfer – them to the database of the DAS. A pragmatic way to accomplish this task is the manual generation of instruction media "hands on" by an **Assembly Planner**, using human-formulated text based work instructions, such as simple screenshots from CAD software or real life photos and videos. Most of today's DAS are delivered with system specific graphical editor software tools to upload generated information to a database [21]. Nevertheless, creating and transferring suitable media files to a database is a time consuming process. In addition, this process has to be repeated as soon as a product variant or a product feature changes [8]. Another approach suggests the usage of ergonomic optimized utility video sequences [22]. In contrast to traditional video sequences with a linear course, a utility video sequence consists of a clip structure with sequence forks, which enables the assistance system to adapt to operator information demand, experience and learning habits [22]. Here, there is a high amount of initial creation effort, since every feasible assembly sequence has to be recorded using special hardware and software equipment. The video sequences are cut in parts with small duration. By joining these parts together, an easy adoption for different product variants is feasible. Funk et al. proposed a concept - programming by demonstration - that automatically detects work steps and creates a semantically rich assembly instruction while an assembly is performed using a depth camera for recording movements and a projector as interaction device. Furthermore, Funk et al. mention that the current version of their system has certain limitations, e.g. only one part per work step can be recorded and these parts have to be visible to a top mounted Kinect sensor [12].

To sum up, there is a demand on generating and uploading assembly information to a database in an efficient way for a more efficient configuration of DAS, especially for high variant and low volume assembly systems.

3. Data-Driven Reconfiguration Concept of Digital Assistance Systems

Based on the detected state of the art gaps, the proposed reconfiguration concept should meet the following requirements:

- **Efficiency**: An economic efficient generation of assembly information (assembly sequence, text based step-by-step instructions, images, animations) should be supported.
- **Automation**: The upload of generated assembly information to the database needs to be automated in order to save crucial reconfiguration time.
- **System independency**: Generation and upload of information into assembly systems should be generic and independent from DAS.

- **Reusablity**: Generated assembly information from similar product variants have to be reused in order to enable timesaving reconfiguration of DAS.
  Figure 2 illustrates the process and information flow for reconfiguring DAS based on 3D CAD files.

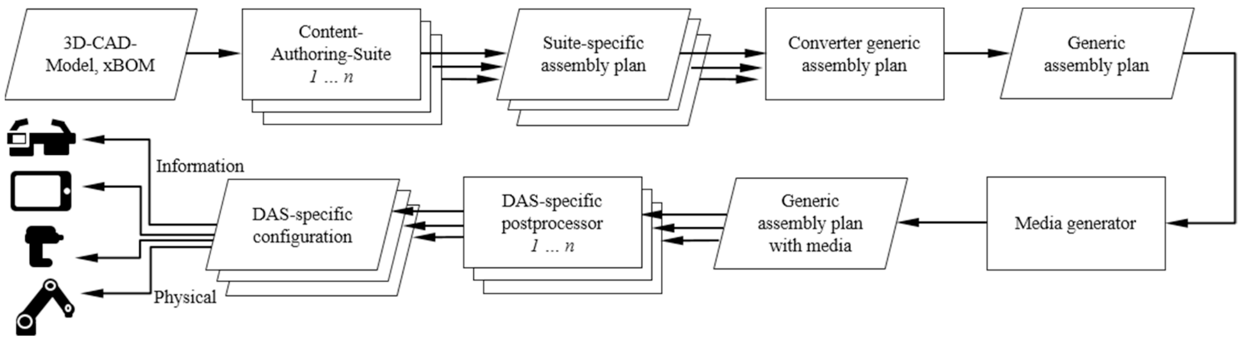

Fig. 2. Illustrated Concept for Data-Driven Reconfiguration of Digital Assistance Systems (DAS).

Using a *3D CAD model* and *bill of material information*, an assembly planner determines the order of assembly steps by means of a **Content Authoring Suite** (software package). The assembly planner specifies intermediate steps that cannot be extracted from CAD-model automatically, e.g. greasing operations and requested screwing-torque. Afterwards, the generated information is exported as a file containing an *authoring-suite-specific assembly plan*. There are several software solutions that may be suitable for this task, e.g. Cortona3D RapidManual [23]. The authoring-suite-specific assembly plan is then converted to a generic, *system independent assembly plan* using a **Converter Software**. This process step can be accomplished automatically and results in a *generic assembly plan*. The following **Media Generator** generates assembly instruction media – e.g. text based work instructions, images, animations – automatically, using the supplied data in the generic assembly plan. As a result, the generic assembly plan is enriched with automatically generated *media files*. Finally, the generated generic assembly information can be uploaded automatically to different **DAS** using tailor-made **DAS-Specific Postprocessors**.

This schematic concept leads to a system independent and standardized way for dynamic reconfiguration of DAS, even at lot size 1. Assembly planners are supported by authoring-suites and by a media generator, which automatically creates instruction texts, images and animations. Furthermore, the upload of generated information into system specific databases is done automatically. This implies a better flexibility and configurability of DAS.

4. Learning Design for Applying the Concept

The proposed concept will be implemented in the assembly planning process of TU Wien Pilot Factory Industry 4.0. In this context, there are different information systems of assistance that need to be reconfigured, e.g. digital assistance systems from three different manufacturers, a smart Wi-Fi connected nut runner and several force limited collaborative robots [24]. By applying the proposed data-driven reconfiguration concept, assembly operators appear in following roles:

- **Information Consumer**: Suitable assembly information (e.g. text based instructions, images and animations) is provided by DAS. This information is used and consumed by assembly operators to execute various complex assembly tasks.
- **Information Author**: Suitable assembly information is generated and authored by assembly planners using different authoring software tools. Especially the assembly sequence and process parameters, such as screwing torque, etc., have to be specified by an experienced planner.
- **System Engineer**: A system engineer is needed to setup different technical systems, e.g. authoring-software, postprocessors and further technical elements of DAS. This role is not directly involved in the above illustrated data-driven reconfiguration concept, but has to operate in the background as soon as new DAS are implemented or repaired.

In order to ensure an efficient workflow for reconfiguring DAS, it is important to train the operator to properly apply and maintain the implemented solution. We, therefore, propose a learning design that focusses on the described roles of an information author and a system engineer.

In the past years, several initiatives have been realized at the Vienna University of Technology (TU Wien) to enable interdisciplinary and practice oriented teaching of smart factory topics. In 2011, a Learning Factory (LF) has been established with an objective to enhance self directed student experimentation and exploration [25]. Using a specific product (a racing slot car), students learn the whole product emergence process, from virtual product development through manufacturing of different parts up to final manual assembly processes [25]. To extend this course with modern smart factory elements, the LF is merged with the TU Wien Pilot Factory Industry 4.0. Paper based work instructions describing final assembly processes are replaced by DAS. As a result, students should learn how to configure these systems in an efficient way by using the proposed data-driven reconfiguration concept. In this way, the course should be divided into three phases, which include Bloom's taxonomy of learning objectives [26]:

- **Phase 1 – Theory (Knowledge, Comprehension)**: Students are taught basic knowledge about DAS, cyber-physical assembly environments, industrial engineering and reconfigurable assembly systems. This phase is designed as lecture combined with several short online assessments. Study materials are provided online through a university specific e-learning platform, TUWEL [27], and as printed handouts.
- **Phase 2 – Practice (Application, Analysis, Synthesis)**: Students get separated in groups of four and have to solve a specific task by applying the learnt knowledge of phase 1 (Theory). They use the presented data-driven reconfiguration concept to generate suitable assembly information. The students can choose one out of three existing DAS to reconfigure with the before generated information. Finally, the assembly of the racing slot car should be done while using the chosen assistance system.
- **Phase 3 – Reflection (Evaluation)**: The time required for reconfiguring the assistance system as well as the time required for the assembly process itself is measured. The students are doing a critical review as well as a quantitative and qualitative evaluation on how the task has been accomplished.

5. Conclusions and Outlook

DAS support assembly operators during task execution especially in high variant and complex assembly environments. The generation of suitable assembly information and uploading this information to a database of individual assistance systems is a time consuming task. This paper presents a concept for automated data-driven reconfiguration of assistance systems in a system independent, standardized, and economically feasible way. In future, the proposed concept will be implemented, tested and evaluated in the TU Wien Pilot Factory Industry 4.0 as well as in industrial use cases. This ultimately enables a dynamic reconfiguration of a various number of DAS with lot size one.

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