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Novel approach for the automated assessment of the »fitness for automation« of an assembly based on a neutral product model

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Abstract

Companies involved in product assembly from high-wage countries face several challenges due to a shortage of skilled workers, rising cost pressures, and an increasing number of variants. To remain competitive in the market, companies must select an appropriate level of automation for their assembly. Currently, automation decisions are typically made by individual experts, whose decision-making processes may not always follow a structured methodology and, therefore, cannot be reproduced. While there are methods for evaluating the automation potential of existing assembly workstations, there are currently no automated approaches for evaluating the automation potential of assembly processes even before a workstation is designed. As the manual and individual analysis of possible automation approaches for assembly tasks also ties up skilled workers, this approach is time-consuming and cost-intensive. This research paper presents an approach to automatically evaluate the »fitness for automation« of an assembly based on a neutral product model using neutral data formats. The »Fitness for Automation« (FfA) is a dimension of the automation potential besides the »savings potential«. The FfA reflects how easily individual assembly sequences and ultimately an assembly can be automated or, equally, how great the implementation risk of automation is, and where design changes could be performed.

Keywords: automation potential; fitness for automation; assembly planning; STEP AP214

1. Introduction

Companies involved in the assembly of industrially manufactured goods face various challenges. Companies from high-wage countries are particularly affected. The reason for this is the competitive pressure from low-wage countries [1]. Automating assembly can enhance cost efficiency and thus prevent relocating production abroad. However, it has been known for many years that automating all integrated steps in the assembly process does not necessarily lead to savings. [2] [3]

Even today, full automation can significantly increase costs, primarily due to the high expense of acquiring necessary technologies [4]. Additionally, automation often reduces production flexibility and complicates the introduction of new products and variants. This is especially challenging given the increasingly diverse product range, smaller production runs, and frequent changes in products or variants, which require flexible adaptation of the assembly process. [2] [5]

For this reason, it is essential to assess whether and to what extent the automation of individual work steps or the entire assembly of a product, including the associated costs are worthwhile. To evaluate this, the question arises as to

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what effort is involved in implementing automation [1]. In this context, the "Fitness for Automation" (FfA) of the product to be assembled is determined, which evaluates the technical feasibility of automation. The FfA can later be used along with the potential savings to assess the automation potential. In this way, a decision can then be made as to whether assembly should be automated or manual. [6]

The assessment of the FfA and the resulting decision on what to automate is, however, influenced by the companies' own know-how and the personal feelings of the employees. Often, the necessary expert knowledge for a comprehensive and accurate assessment is lacking. [7]

To support the determination of the FfA, a decision support tool is required for correct assessment. To expedite the decision-making process due to the mentioned product or variant changes, this should also occur in an automated manner. [5]

Individual applications for assessing the automation of existing manual workstations are already known [6]. However, to evaluate products prior to the design of the workstation, the assessment must be feasible based on the product model. To ensure comprehensive application, it is essential to conduct this using a neutral data format to avoid any proprietary constraints. Additionally, an assessment of the level of automation should be made for optimal evaluation [8]. This aims to prevent inappropriate resource usage and unprofitable investments.

In the further course of this work, various methods that are relevant for determining the FfA are evaluated. For this purpose, they are compared with the requirements listed in Table 1. Subsequently, a new method for determining the FfA is presented based on the results of the conducted evaluation.

Table 1. Requirements for method evaluation

Requirement	Relevance
R1	Automated process
R2	Applicable based on the product model
R3	Analytical
R4	Objective
R5	Based on a neutral data format
R6	Assessment of automation level
R7	Generally applicable for assembly

2. Methods for determining the automation potential

First, various methods that serve to investigate the automation potential of the assembly of a component will be analyzed. This will begin with a collection of methods focusing on different themes. Subsequently, it should be assessed whether one of the identified methods for determining the FfA is applicable, taking into account the previously established requirements (R1-R7 in Table 1).

Nomenclature

FfA	Fitness for Automation
APA	Automation Potential Analysis
APP	Assembly Planning Procedures
DFAA	Design for Automated Assembly
LoA	Level of Automation

2.1. Description of the methods considered

Existing methods for determining the automation potential of an assembly can be categorized into different groups [9]. The individual groups differ in that they focus on different aspects in the evaluation. The following groups of methods have been examined:

Automation **P**otential **A**nalysis (APA)
The potential savings associated with the automation of an assembly task are analysed. The assessment includes both the FfA of the component and the cost reductions relative to a manual workstation. [6]

Assembly **P**lanning **P**rocedures (APP)
All systematic steps for planning and organizing assembly processes are examined. The main focus here is on the efficiency and effectiveness of the required workflows and resources. [10]

Design for **A**utomated **A**ssembly (DfAA)
The evaluation of the automation potential focuses on product design. The suitability of the design of individual components and the overall product for automated assembly is analysed. [11]

Level **o**f **A**utomation (LoA)
These methods focus on determining the appropriate level of automation for assembly. The level of automation represents the ratio of the individual work steps between human and technological efforts. [1]

Table 2 lists the methods evaluated in the course of this work and assigns them to the described groups. The assignment is not always distinctly separable and is based on the classification of the methods themselves, the classification of existing works, or an assessment of the procedures described in the approach.

2.2. Review of the evaluated methods

To determine whether any of the examined methods are suitable for assessing the FfA, they are compared against the requirements (R1-R7 in Table 1) during the analysis. The extent to which the considered methods meet these requirements is outlined in Table 2. It is evident that none of the methods fully satisfy all requirements.

The approach of the individual methods is analytical in most cases (R3). This is because the automation potential is determined based on defined evaluation criteria through several iterative stages. However, nearly none of the methods explain how the necessary information for assessing the individual criteria is gathered, provided, or utilized. Consequently, this information is often perceived subjectively by the user, which contradicts requirement R4.

The requirement R5 of whether the FfA can be assessed using neutral data formats is also not addressed by most methods. Approaches that describe which data format is used to provide information often use partially or exclusively proprietary data formats and therefore do not fulfil requirement R5.

In some methods, such as Deutschländer's approach, the automation potential is determined by using evaluation tables that must be filled out for each application case [12]. Individual methods, such as those presented by Neb et al., are capable of autonomously extracting information from the provided dataset and automating the determination of the FfA as required in R1 [7]. However, these are proprietary data formats, which contrasts with requirement R5.

Determining the FfA exclusively based on the product model is feasible with the majority of the examined DfAA methods, as indicated in R2. Fahlström et al. utilize a CAD file format for information provision [13]. However, this also constitutes a proprietary data format that includes additional information alongside geometric data. As indicated in the descriptions from chapter 2.1, LoA, APA, and APP methods require additional knowledge about potential automation cells or the existing manual workstation, thus necessitating information beyond the product model.

With few exceptions, most methods are generally applicable to the field of assembly (R7). If this is not the case, it may be attributed to the fact that some methods, such as those by Madappillya et al. [14], focus on industry-specific requirements (e.g., the maritime industry), or, as in the case of Trommnau et al. [15], on specific component properties (e.g., limp components).

2.3. Conclusion on the design of a new method

As previously mentioned, the analysis of the methods shows that none of the approaches fully meet the defined requirements (R1-R7 in Table 1). In particular, the objective (R4) and automated (R1) evaluation based on neutral data formats (R5) is a challenge that is hardly addressed by any of the methods. However, the analysis also makes it clear that individual requirements can usually be fulfilled by various methods. This indicates that a combination of several approaches can result in a method capable of determining the FfA in accordance with the defined requirements. For this reason, the following chapter describes how such a method was developed.

Table 2. Qualitative analysis of the identified methods with regard to the various requirements, sorted by group assignment.

Autor	Reference	Group	R1	R2	R3	R4	R5	R6	R7
Spingler et. al.	[6]	APA	○	○	●	○	N/A	N/A	●
Neb et. al.	[7]	APA	N/A	◑	N/A	●	○	◑	●
Ross	[10]	APP	N/A	○	●	○	N/A	●	●
Deutschländer	[12]	APP	◑	◑	●	○	N/A	◑	●
Samy et. al.	[16]	APP	○	○	●	○	N/A	◑	●
Roulet-Dubonneta et. al.	[11]	DFAA	○	●	●	○	N/A	○	◑
Fahlström et. al.	[13]	DFAA	●	◑	●	◑	○	●	○
Madappillya et. al.	[14]	DFAA	○	●	●	○	N/A	○	○
Trommnau et. al.	[15]	DFAA	N/A	◑	●	○	N/A	◑	○
Eskilander	[17]	DFAA	○	●	●	◑	N/A	○	●
Ezpeleta et. al.	[18]	DFAA	○	◑	◑	●	N/A	○	●
ElMaraghy et.al	[19]	DFAA	N/A	○	●	○	◑	N/A	●
Salmi et. al.	[1]	LoA	N/A	○	●	◑	N/A	●	●
Reifur	[5]	LoA	◑	◑	●	○	N/A	◑	●
Malek et. al.	[8]	LoA	○	○	●	◑	N/A	●	●
Keiser et. al.	[20]	LoA	N/A	◑	◑	○	N/A	●	●

N/A = not applicable; ○ = not realized; ◑ = partially realized; ● = realized

3. Design of the automated FfA assessment approach

A new method is developed to determine the FfA with requirements R1-R7. It combines optimal approaches from previously analyzed methods, addressing deficiencies with elements from others.

3.1. Structure of the automated FfA assessment approach

Most methods use established evaluation criteria to determine the automation potential of assembly tasks in iterative stages. These criteria are consolidated, as discussed in chapter 3.2. The linkage of the individual evaluation criteria and the final determination of the automation potential based on these criteria varies among the different methods.

One of the most widely used DfAA method is the DFA2 by Eskilander from 2001 [17]. This method evaluates the suitability of the product design for automated assembly. The utilized evaluation criteria are not all consolidated under a single value. Instead, the design is assessed on two different levels. A distinction is made between the product level and the part level. At the product level, the automation potential of the product design of the cohesive assembly and the relationship between the individual components is evaluated. At the part level, the construction of the individual components is examined, determining the automation capability of each part independently. Roulet-Dubonneta et al. [11] and Madappillya et al. [14] adopt this approach and expand it with a sector-specific focus on the electronics and maritime industries. In contrast, evaluation criteria from methods that focus on other aspects, such as the APA presented by Spingler et al., tend to evaluate the automation of the handling process or the assembly task rather than the product design [6].

The evaluation criteria for determining the FfA in the method presented here are divided into multiple levels, similar to Eskilander's DFA2 [17], and are shown in Fig. 1. However, to accommodate other methods, the FfA is determined not only for the product and part level as in Eskilander [17], but also for the assembly level. This aims to specifically assess the automation effort of the assembly process. The specification of the FfA across different levels provides insight into where the challenges lie when implementing automation and which parts are particularly easy to automate.

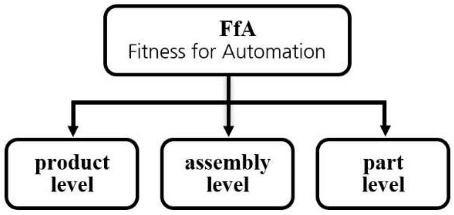

Fig. 1. Representation of the FfA on different levels.

Determining the FfA across different levels is intended to assist in the assessment of the LoA. The information on how efficiently each individual assembly task can be automated enables the identification of which tasks should be automated and which should be performed manually. In this way, the LoA can be defined [20]. In addition, it can be determined how the implementation effort of automation can be minimized through targeted manual preparation (e.g. the organized provision of components prior to automated assembly).

Determining the FfA across different levels results in a series of output values rather than a single value. Not only is one of the three levels created for each assembly group, but a separate level is formed for each existing element to which the respective level refers. An assembly with ten components consists of one product and ten parts that are assembled in nine assembly steps. Therefore, in this example, FfA values are determined for one product level, nine assembly levels, and ten part levels.

3.2. Structure of the evaluation criteria

Most of the analysed methods determine the automation potential of an assembly task based on established evaluation criteria. In order to ensure that the FfA is as meaningful as possible, as many of these criteria as possible should be included in the determination. For this purpose, the individual evaluation criteria are collected and assigned to the levels described in the previous chapter. They are assigned to the level to which the respective evaluation criterion applies. It may occur that individual criteria relate to several of the three levels and contribute to the assessment of their FfA. These are then assigned to all levels where they can be applied.

When assigning the individual evaluation criteria, various points must be considered. Some methods do not exclusively rely on the product model of the item to be assembled when determining the automation potential. Samy et al. also consider the automation potential in relation to different assembly systems for material handling, material provision, and the execution of the assembly task, which are part of the workplace setup [16]. Ezpeleta et al. analyses whether the automation of the assembly task is worthwhile by comparing the necessary assembly times of the manual workstation with those of an automated workstation [18]. To calculate these times, they use information about the workplace setup, which allows for determining the time based on the distances of the material provision locations. For these reasons, it is crucial to ensure that the assigned automation criteria exclusively refer to the product model or are adjusted to be applicable to the model. Criteria that do not relate to the product model or cannot be evaluated accordingly will not be considered.

The same applies to criteria that evaluate characteristics beyond the product's assemblability. In his DFA2 method, Eskilander assesses not only assemblability but also maintainability and the associated disassemblability of the product [17]. The FfA is merely an assessment of the implementation effort for automated assembly. Therefore, evaluation criteria that extend beyond the evaluation of assemblability are not further considered.

The same applies to the subsequent evaluation of individual criteria. Some of the identified criteria require a subjective assessment for their evaluation. Spingler et al. formulate different criteria for assessing the FfA in their APA method [6]. However, no clear evaluation scheme is provided regarding which information and reference values are used to evaluate the criterion. Instead, it requires a subjective assessment by the user, who is expected to possess a certain level of expertise. For example, when asking whether one of the parts is a flexible component, no further clarification is provided regarding what this entails and what conditions must be met for this criterion to be satisfied. In contrast, Ross clearly states in his developed method how the respective criterion can be evaluated objectively [10]. For instance, it is specified how the bending stiffness of a component can be determined and what conclusions can be drawn regarding its shape stability. Therefore, when consolidating the criteria, it is essential to consider whether and how the individual criteria can be objectively derived from a neutral dataset.

The following tables present the evaluation criteria from the method analysis and their allocation to the respective levels: Table 3 for product level, Table 4 for assembly level, and Table 5 for part level. Additionally, the basis for the evaluation is briefly outlined for each criterion.

Table 3. FfA criteria on product level

Criteria	Description
base object	Initial part for assembling all other parts
design basis object	Stable positioning of the base part Sufficient clamping possibilities
number of parts	Number of parts to be assembled
unique parts	Ratio of unique parts to the total quantity
assembly directions	Number of different assembly directions Assembly directions feasible in a single setup
chain of tolerance	Assembly of parts into mounted components Assembly of multiple parts in a single step Simultaneous assembly of a part into multiple joints
parallelization	Parallel assembly via subassemblies integration
total dimension	Length, width, and height of the assembled product
tool rating	Use of standard tools Required number of tools and tool changes

Table 4. FfA criteria on assembly level

Criteria	Description
orientability	Positioning support via end face chamfers Fixed or variable position of the joining location Number of degrees of freedom to be aligned
assembly task	Type of assembly task Required force / torque during assembly
tolerance	Tolerance of the joining location position
accessibility	Free accessibility of the joining location
tool clearance	Sufficient space for tool movement
assembly motion	Type of joining motion
centre of gravity	Support of joining motion by gravitational direction Holding of assembled but not fixed parts
check and adjust	Verifiability of correct positioning
influencing parts	Necessity to fix or remove other parts for assembly

Table 5. FfA criteria on part level

Criteria	Description
dimension	Size of the part for reasonable handling
weight	Weight of the part for reasonable handling
form stability	Bending stability considering stiffness
sensitivity	Brittleness of the part Surface sensitivity
tolerance	Component tolerance for reliable gripping
hooking	Risk of entanglement with other, identical parts (consideration between volume and volume)
alignability	Alignment of the part during gripping Part is symmetrically designed around the grip area Number of degrees of freedom to be aligned
assembly support	Presence of joining aids
tangibility	Gripping surfaces close enough or part is magnetic Need for a special gripper Centre of gravity aligned with the gripping point
relevance	Verification of the necessity of the part
provision	Distinction between single parts and bulk materials Sufficient possibility for separation

3.3. Design of the data foundation

The design of the data foundation on which the FfA is to be evaluated is crucial for meeting specific method requirements. It is essential that it only provides information about the product model (R2), relies on neutral data formats (R5), and that the information is automatically retrievable (R1). Methods that enable automated assessment of assembly task automation use a 3D geometry data format of the product as a basis. When selecting the appropriate data format, various aspects must be considered, such as the ability to separate the geometry information of individual parts from the entire assembly. Additionally, the model must offer an exact 1:1 representation of the product without simplifications or incorrect scales in geometric properties.

Neb et al. utilize a SolidWorks API for this purpose [7]. The advantage of this data format lies in the ability to make user-defined settings to specify the information to be transmitted. However, as previously mentioned, it is a proprietary data format and therefore cannot be used. The same applies to the method presented by Fahlström et al. [13].

For evaluating a Co-Platforming methodology, ElMaraghy et al. use a neutral STEP file [19]. This data format provides a 1:1 representation of the product geometry and separates the geometric information of individual parts from the assembly. Due to its general applicability, a STEP AP214 is used for the method developed. A drawback of this data format is that it transmits limited information beyond the product geometry. To compensate this, additional information describing the product model is provided via a JSON file. This machine-readable, neutral data format conveys objective information extracted from an ERP system or other product information.

4. Conclusion and future prospect

Based on an analytic literature review, this paper presents a new approach for determining the Fitness for Automation (FfA) of assembly tasks, incorporating requirements R1-R7. It integrates optimal elements from existing methods while addressing their shortcomings. The approach consolidates evaluation criteria across multiple levels – product, part, and assembly – allowing for a nuanced assessment of the FfA, and thus the identification of elements that may hinder automation. The evaluation consists of a comprehensive set of criteria, ensuring that the FfA reflects the complexities of the assembly process while relying on neutral data formats for automated assessment. Consequently, the determination of the FfA can be conducted in an automated (R1), product model-based (R2), analytical (R3), objective (R4) manner, using neutral data formats (R5) within the general application field of assembly (R7), while also providing insights into an appropriate level of automation (R6).

For the targeted application, future research must focus on implementing the listed automation criteria in an algorithm. This includes the reading and interpreting of neutral product models in STEP files as boundary represenations, and the output of the resulting FfA via a clearly structured user interface. In addition, the integration of an automated generation of the assembly sequence and corresponding assembly tasks according to Beck et al. [21] is necessary. These tasks are subject of further investigations. Furthermore, implementing an automated grasp point detection within the program workflow is required to evaluate individual criteria.

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