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An automated assembly process planning system

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Abstract

The generation of assembly process plans of complex products is a challenging task. An assembly processing planning system reducing the human intervention and the computational effort is discussed. The method utilizes the information stored into the CAD model of the assembly for the extraction of the part precedence information which is then complemented with technological priorities. Results are demonstrated in an industrial case study from the optoelectronics industry.

Keywords: CAPP; process planning; assembly planning; assembly sequence generation; optoelectronics;

1. Introduction

A product's assembly plan affects both the assembly process efficiency and the assembly line's design. Planning and using efficient assembly processes can actively contribute to the reduction of a product's manufacturing cost. Assembly Planning includes the determination of a feasible method and layout, in order for a product to be assembled from its components.

Mechanical products often have multiple assembly sequence plans, due to the complexity and the multiplicity of their components. Therefore, some assembly sequence plans are more efficient than others and the selection of the appropriate one requires a high level of expertise and experience from the planner's side. Assembly process planning is a time-consuming procedure and, as a result, the automation of this procedure is necessary. The goal of the current study is the proposition of a method that can contribute to the reduction in time and effort on process planning generation.

To demonstrate the functionalities and the innovation potential an industrial pilot case was selected. The pilot case involves robotic assembly of solar panel cells, which can be produced in different variants (power output, shape, size etc.) in order to demonstrate the adaptability of the process planning method.

2. Current practices

2.1. Process planning

The Robotic equipment has found great application to a broad range of automatic assembly systems, specifically in the assembly lines of automotive industry, electronics, rubber/plastics and metal/machinery industrial sectors. The robots' intrinsic characteristics, such as high accuracy, speed, repeatability, strength and reliability, have enabled production firms to invest in large scale installations that can work around the clock with minimal human intervention [1]. Nevertheless, technological limitations impose the contribution of human operators on the process, by providing support to the system [2].

The development of such complex systems and the variation of production conditions bring about new problems [3]. A plethora of such problems have been extensively analyzed by researchers [4][5][6][7][8], and include conflicts between process planning and scheduling, unbalanced resources in the production line and the problem of selecting suitable resources with respect to the given conditions. From

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an optimization point of view, several computational methods have been proposed in order to address these issues. A novel approach is presented by Papakostas et al [9][10][11], which includes a data model along with a set of rules for realizing the knowledge-enabled structuring of assembly process information, taking into account 3D specifications of both robotic manipulators and parts. Xinyu Li [5] experimentally investigated into the impact of multi agent modelling on Integrated Process Planning and Scheduling (IPPS) optimization. A further study was also performed, integrating game theory in order for multi-objective manufacturing problems, similar to assembly scheduling problems to be addressed [6]. In the same context, the Particle Swarm Optimization (PSO) algorithms were used by Guo et al. [6][13][14] to search the optimum solution for both scheduling and process planning. A PSO-based algorithm was also proposed by Papakostas et al [14], where both time and cost parameters were considered for the generation of alternative sequences. For the facilitation of the integration and optimization of process planning and scheduling, an annealing-based simulation was proposed by Li et al. [15], combined with a unified representation model. Heuristics is another approach to solving such problems. Pierre de Lit et al. [16] provided an original Ordering Genetic Algorithm (OGA), enabling the automatic generation and evaluation of assembly product trees. Similar practices were followed in a further study by Carmelo Del Valle et al. [17], where their solution was based on and/or diagrams. A more applied approach of genetic models to assembly was made by X.F. Zha et al. [18], who proposed and implemented an algorithm in standard modelling language EXPRESS/EXPRESS-G. A more sophisticated version of the aforementioned algorithm was also proposed by Greg C. Smith et al.[19], who presented a modified automatic generation of initial assembly sequence population. The performance of Artificial Immune System (AIS), Iterated Greedy algorithm (IG) and (AIS-IG) algorithms was investigated into the makespan flow shop scheduling problem in [20]. Mohapatra et al.[21] evaluated the performance of different process plans in terms of minimizing the makespan, machining cost and idle time of machines. JR Li et al. [22][23] presented a study, matching the advantages of the Tabu search algorithm and the enhanced genetic algorithm for assembly. C.W. Leung et al. [24] presented a study by combining an agent based model and the ant colony optimization algorithms.

However, the aforementioned studies seldom accommodate a rescheduling mechanism and take into consideration the fluctuation of the real production line conditions [8].To this effect, Abumaizar and Svestka proposed an algorithm for rescheduling in job shops [25]. The experimental/simulation assessment of an online scheduling approach is demonstrated by Chih-Chiang Hsu et al. [26] for multiple mixed-parallel workflows in grid environments. A more recent research done by Elisabeth Gunther et al. [27] proposes the online computation of close to best completive ratio solutions, using competitive-ratio approximation schemes. Meanwhile, Michalos et al. [1] presented a more applied method through using the hierarchical and decision making algorithms to obtain rotation alternative schedules and evaluate them, according to several criteria. With similar ethos, Michalos et al. [28] provided a web-based platform combined with intelligent search algorithms to generate job rotation schedules. Viera et al. [29]; Aytug et al. [30] and Potts and Strusevich [31] provided a comprehensive review of research studies on various types of rescheduling problems.

2.2. Assembly planning

The Assembly Planning aims to identify and evaluate the different ways of constructing a mechanical object from its components. *"Given a geometrical and technological description of a product, find an assembly sequence that satisfies the precedence relations between operations and meets certain optimization criteria."*[9]. In the last decade, several approaches have been proposed to automatically generate assembly sequences. Summarizing, the existing approaches for the generation of assembly plans, can be roughly classified into three main approaches [9][10][11]:

- human-interaction,
- geometry-based reasoning and
- knowledge-based reasoning.

The automatic generation of assembly sequences, which is the key topic of computer aided assembly process planning (CAPP), has been an object of research for the past 30 years [33]. The assembly sequence generation is a part of the wider problem of Assembly Planning (ASP), especially when a large number of potential assembly sequences exist, as in the case of complex assemblies. Therefore, there is a growing need for the generation of assembly sequences to be systematized and computerized. Thus, many research activities have focused on various aspects of assembly sequence planning, such as assembly modelling, assembly sequence representation and assembly sequence generation algorithms. However, these methods and algorithms are less interactive and require more space to store the representation of assembly sequences and process time for complex problems [14].

Directed graph methods have been widely used to represent the ASP problem [11], [14]. A directed graph D = (P, C) can describe the assembly, where each vertex (P) represents a component, and each edge (C) represents a relationship between two components. In some cases, the contact-base feature is employed to represent the precedence relationships of the product, consequently, the directed graph is also called precedence diagram. However, the contact-base precedence diagram cannot effectively express the complexity of the assigned assembly relations [32].

A summary of the aforementioned methodologies, including their advantages and disadvantages can be found in Table 1. However, these approaches are often purely academic, without providing an implemented tool for the end user to enable automated process planning, based on the CAD file of the product.