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Co-platforming of products and assembly systems

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ABSTRACT

In an era characterized by diversity in customer requirements, manufacturing firms strive to cope by introducing variety of products in an attempt to satisfy customers' needs. Product changes and modifications propagate from the design to the manufacturing phase affecting product/machine assignment requiring dynamic scheduling and resources planning and often leading to costly physical changes in the manufacturing system. An integrated methodology for synthesizing assembly systems for customized products through mapping between products platform and the assembly system platform, which is coined "Co-platforming", was introduced. This methodology is applied in three phases: functional synthesis of generic assembly machine candidates, functional synthesis of optimum assembly machine types and their number and finally, physical synthesis of assembly system configuration. A matrix-based formulation and mixed integer linear programming optimization models are utilized. The methodology is applied to a case study for an automotive cylinder head assembly line. The significance of this new methodology lies in establishing strong mapping between products and systems platforms and using it to synthesize assembly systems capable of co-adaptation, which prolongs the system life to be used not only for many product variants but also for many product generations with minimal additional investments. The proposed methodology aids in synthesizing highly customized assembly systems capable of producing different product variants in different production periods.

1. Introduction

Product variety and proliferation has turned into an undeniable reality due to the frequent changes in customers' requirements, market needs, legislation, etc. Frequent changes in customer requirements lead to necessary changes within the product design phase. Modifications within product design phase propagates to the successive product lifecycle phases such as manufacturing [1]. Therefore, it is required to manage the product variety in different lifecycle phases and in particular, the manufacturing phase, which is characterized by high investment cost of equipment, material handling units, controls, etc. Various manufacturing paradigms have evolved over the years in order cope with the frequent changes in product design such as flexible manufacturing system and reconfigurable manufacturing systems [2]. Joint development, co-development or concurrent design of products and manufacturing systems has been a topic of interest for researchers and scholars to simultaneously address the product and manufacturing systems design during the different production periods [3]. In addition, significant cost reduction can be achieved by using the concurrent approach rather than the sequential approach in which product and manufacturing systems are designed separately [4]. Co-evolution of products and systems [5,6] as well as Co-platforming [7–9] are recent research works which address the co-development of products and their corresponding manufacturing system. This paper overviews the co-platforming strategy and models applied in functional synthesis of generic assembly machine candidates, functional synthesis of optimum assembly machine types and their number and physical synthesis of assembly system configuration. It extends previous work [7–9] to assembly systems and highlights assembly-specific relationships, operations, equipment and considerations which are distinct from metal removal applications.

This paper is organized as follows: Section 2 provides several definitions significant to the paper, Section 3 provides the literature survey for manufacturing systems synthesis and identifies the gaps, Section 4 highlights the scope of the paper and the assumptions involved in the formulation of the model, Section 5 provides an overview for the proposed integrated assembly products and system co-platforming methodology, Sections 6–8 are concerned with the detailed development of the co-platforming strategy and models, Section 8 introduces the case study used to implement the model, Section 9 presents the results and discussion, and finally Section 10 provides conclusions.

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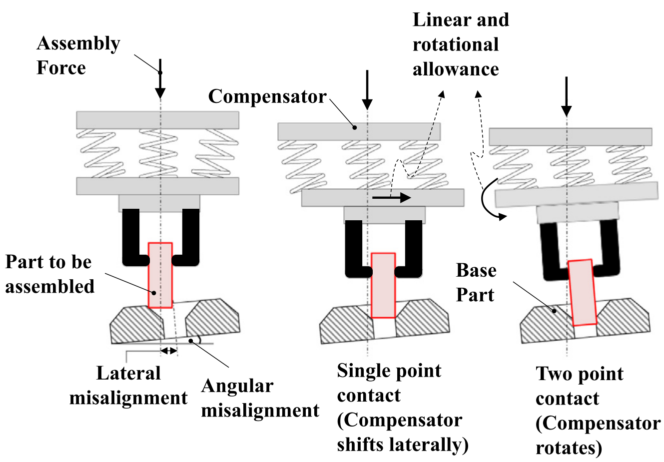

Fig. 1. Example of assembly compliance in automated assembly.

2. Definitions

This section provides several definitions which assists in understanding the paper. *Product platform* is defined as the group of features, component, modules and subassemblies that are shared between all product variants within a product family [10]. *Product family* is defined as a set of related products that share common components, modules or subassemblies [11]. A stage in a manufacturing system consists of one or multiple identical machines or assembly stations, which perform a group of operations as part of the total processing steps. Stages are connected by material handling system (gantry, conveyor, Automated Guided Vehicle…etc.) [12]

Manufacturing system platform or *platform machines* is defined as the group of machines used to process product platform features and components [8]. *Co-platforming* is defined as the synthesis of manufacturing system through mapping product platform features and components to platform machines on one side, and non-platform product features and components to non-platform machines on the other side [7–9]. According to [7], manufacturing systems synthesized through co-platforming experience less investment cost compared to systems synthesized with system platform. *Functional synthesis* is defined as the determination of machine types and the number of each machine type required within a manufacturing system [7].

An important feature in automated assembly is *Compliance*, which permits flexibility within the end effector relative to the tool or robot end-effector mounting plate in order to compensate for angular and positional errors resulting from misalignment between mating parts. In addition, a compliance device is used when the tolerance of an assembled part is less than the repeatability or accuracy of a robot [13]. Fig. 1 illustrates the passive compliance device in which springs are used as flexible elements. *Accuracy* refers to the deviation between the achieved point and command point [14]. *Repeatability* refers to the ability of end effector to reach a command point [14]. Degrees of freedom (DOF) are defined as the number of independent axes available within an assembly machine or industrial robot [13]. Assembly axis refers to "*the axis passing from the centre of the base of the first component to the centre of the top of the final component in the assembly*" [15].

3. Literature survey

Various papers exist within manufacturing system synthesis. ElMaraghy and Abbas [8] proposed a methodology known as co-platforming in which product feature platform is mapped to manufacturing system platform based on matrix formulation and manipulation for manufacturing system synthesis purpose taking into consideration only machining axes and type of cutting tool as machining capabilities. Abbas and ElMaraghy [9] proposed a matrix-based formulation to synthesize manufacturing systems taking into consideration extended machining capabilities such as machining axis, accuracy, cutting power and envelop volume requirements as well as product characteristics such as geometric and dimensional tolerance. Abbas and ElMaraghy [7] proposed a mixed integer linear programming optimization model for the functional synthesis of optimum machine types and their numbers. It is concluded that co-platforming achieves cost savings in terms of total investment cost compared to synthesizing manufacturing systems with no system platform. Hanafy and ElMaraghy [16] proposed a new mathematical model that concurrently synthesizes product family and the corresponding assembly system by considering customization using assembly and disassembly of product components. Bryan et al. [4] formulated a mathematical model for concurrent design of product family and reconfigurable assembly systems. Zhang et al. [17] proposed a method to generate process from product variants and production rules generation for specifying variable parameters according to customer requirements using knowledge discovery of data. Bryan et al. [18] introduced an Assembly System Reconfiguration Planning (ASRP) method that takes into account the product family design evolution over generations and its related assembly system concurrently. AlGeddawy and ElMaraghy [6] proposed a model of co-evolution based on cladistics to track the co-evolution of features of individual products and their manufacturing systems and predict the future development of new products and manufacturing systems in which association is achieved using trees reconciliation. Demoly et al. [19] proposed a framework based on concurrent product design and assembly sequence planning. Gedell et al. [3] proposed a framework for the co-development of products and their associated production systems. They represented the product and the production system as co-equal objects with interactions, interfaces and subsystems. AlGeddawy and ElMaraghy [20] presented a new optimization model based on cladistics to solve and construct the optimum layout of a delayed differentiation single line assembly system for a mix of product variants by optimizing the locations of the products delayed differentiation points. Ozdemir and Ayag [21] proposed an integrated method to solve the assembly line design problem. The Branch and Bound algorithm has been used to find the alternative system configuration and the Analytical Hierarchical Process (AHP) has been used to evaluate each alternative. Koren et al. [22] analyzed several system configurations, namely; serial lines, parallel system, serial lines in parallel and reconfigurable manufacturing systems and compared them according to several criteria such as throughput, quality and investment cost. The study was based on high volume manufacturing systems. Webbink and Hu [23] proposed an automated method which generates the complete set of system configuration as well as assembly sequence. Shabaka and ElMaraghy [24] developed a methodology to synthesize a reconfigurable CNC machine tool which provides the minimum capability required to machine a given product features which can be efficiently altered when the process plan changes. Xu and Liang [25] proposed a mathematical model which concurrently solves the problem of product variant module type selection and assembly line design. De Lit et al. [26] discussed the concept of functional entities and its effect on product family design as well as synthesizing the corresponding assembly system design in which the assembly system is generated for the product family.

Most of the literature considered the manufacturing system synthesis from investment and operation costs point of view and focused on relating individual product features and machines capabilities without considering the notion of mapping platforms

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