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Modular design for increasing assembly automation

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ABSTRACT

Modular design can address the need for a high number of product variants and further allow a higher degree of automation in the assembly line. A framework is developed for the simultaneous modular product design and the design of automated manufacturing system. Product designs are optimized for automation using Design Structure Matrix and Modular Function Deployment. Alternative production systems are designed and accessed based on the analysis of assembly steps hierarchically. The implementation of the framework on the design of a production system for furniture assembly, able to handle multiple variants with a large number of components, is demonstrated.

1. Introduction

Modular architectures allow for higher variability of products, a key requirement for mass customization [1]. By replacing, adding or eliminating modules a high degree in customization can be achieved. Modularity has been a hot topic for the CIRP community over the last few years. At least 10 papers have been presented in the last 5 years covering a number of different aspects of modularity.

Modularity has been employed in the automotive industry with a great success [1]. However, automotive industry is characterized by products that stay in production for at least two years and with production rates that basically impose automation. In the present paper the focus is on industrial sectors where the majority of companies are small to medium sized, with medium production rates and a large number of products, which results in their design being altered every few months. A typical example is the furniture manufacturing sector where almost all assembly operations are manual. Modularity has not been used in such industrial sectors, however it sounds ideal due to the fact that it can satisfy diverse customer requirements and allow for continuous product renewal. Additionally, introducing modularity concepts in the design can allow the implementation of carry-over modules between products, and thus allow at least for partial automation.

The objectives of the present study are thus to test the feasibility of modularization and identify the steps towards automation in such industrial sectors. Two complementary methods of investigation were carried out covering two areas of engineering: product engineering and production system engineering. The first method of study integrated and extended an innovative use of proven design methodologies to analyze product portfolios. The second method of study extended the use of a proven technique for analysing a product and its manufacture in order to automate it. The case study used for proving the approach is from the furniture industry, which produces more than 300 different types of sofas, to designs that are renewed at least once per year.

2. The proposed framework

To complete both objectives, the framework needs to be split in two main tasks: modularization and automation. The first consists of analysing the current portfolio of products in order to identify product families and suitable products to be modularized. This decision needs to be based not only on the commonality between variants, but also on the amount of sales per variant in order to gain maximum benefit. The key task is to define the modules. This definition can be based on geometric and functional requirements. Additionally, each module must be assessed and characterized as a common (or carry-over) module and a differentiator. The differentiator modules are the ones that differentiate each variant and serve as the strong marketing points. For an industrial sector with frequent product updates, these modules are the ones to be redesigned. The common modules are the ones to be shared from all variants in the product family and ideally between families as well. These are basically the modules whose production could be automated. For the automation to take place, standardization of the design and of the joining interfaces is required. In Fig. 1, this procedure is schematically presented. The tools to be used for each step are to be described for the pilot case in the following sections.

The second task focuses on identifying the steps towards automation. Studies suggest that automation is the natural consequence of modularization. When designing a product, the functional requirements are the number one priority in order to satisfy prospective customers. However, certain specifications need to be met for fitting the manufacturing process within the company. Typical methods to be used in this case include “design for manufacturing” and “design for assembly”. The solution

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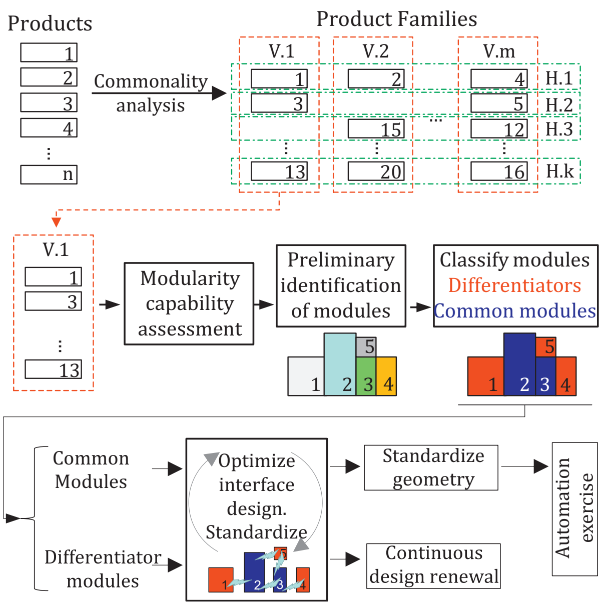

Fig. 1. Modularization approach proposed.

proposed in the present paper is based on the use of standardized designs for setting a constant internal demand and justify automation. This standardization is reflected in the introduction of common modules and the design of simple joining methods for the interfaces of the modules.

3. The case study

The furniture industry comprises mainly of small and medium size companies. The plants of these companies usually have a different section for each manufacturing process. Typical sections include machining, assembling, painting, finishing and packaging. These sections usually consist of single or various lines, characterized by linear flow. Each of these lines is made of different stations, containing single or multiple machines, which can be manual or automatic. All the different stations are usually connected with rolling conveyors or lift trucks. The degree of automation in the assembly lines usually is very low.

The commonality analysis of the product portfolio was performed qualitatively. Fig. 2 indicates one of the product families identified, composed of two-seated sofas of similar seat length. However, as pointed out in Fig. 1 commonality should be examined from a number of different perspectives, indicating that the same variant can be part of multiple families and all interactions need to be considered.

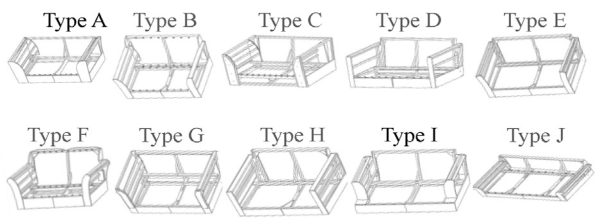

Fig. 2. Product variants for the case study.

4. Modular design

4.1. Introduction

Caridi et al. defined modularity as the strategy for efficiently organizing complex processes and products [2]. The possibility of manufacturing a product quickly allows a company to respond to changes in the demand and meet the customers' requirements.

Depending on how they are manufactured, products can be classified into modular or integrated designs [3]. The main differences between these two product architectures are the way in which the functions are divided and how the interfaces are distributed [4]. A modular system may be composed of different elements matched with simple interactions [2], which have been designed previously, following a standard pattern.

4.2. Modularization methods

All modularization methods are based on three steps: decomposition, decoupling of interfaces and recombination of parts. In the decoupling phase, the product complexity is decreased as the capacity increases due to the ability to produce in parallel. Thus each module can be analyzed, produced and tested independently from each other, reducing the time required for the production of the whole item. Common modules can be standardized in order to achieve economies of scale.

Holmqvist and Persson [5] analyzed a number of modularization methods. They identified six methods that can be used for dealing with the complexity of the product modularity, namely Fractal Product Design (FPD), Modular Product Development (MPD), Modelling Product Modularity (MPM), Modular Function Deployment (MFD), Design Structure Matrix (DSM) and Axiomatic Design (AD).

The selection of the most applicable method(s) depends on the characteristics of the product under consideration. All methods were assessed, revealing that DSM and MFD methods are more suitable because of their analysis of the customers' requirement and the step-by-step design of the final modules. The first thread of study thus integrated and extended the use of these two proven methodologies to analyze product portfolios.

4.3. Design Structure Matrix (DSM)

The assessment on whether modularity is an option on a product design is performed using the DSM. This method starts by decomposing products in functional/physical elements, then analysing and documenting the interactions between these elements and concludes by clustering the components. Recently a clustering method improving this method for the automated module characterization was presented [6]. Applying DSM starts with decomposing all product components; characterizing them by unique names and analysing their function in order to study similarities and differences. The core of the DSM is the matrix revealing the interactions between the different components of the products. Typically these are presented in the form of parts/parts matrixes, clustered per identified module (Fig. 3). The clustering is performed in this case with regards their function since there the structural aspects of the design are very rigid. This analysis suggested splitting the sofas into four modules: seat and back, left arm and right arm.

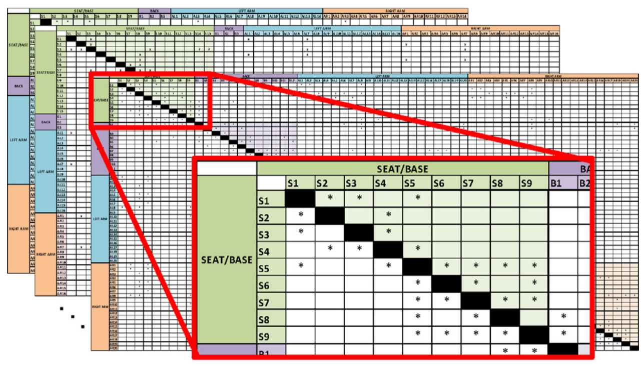

Fig. 3. DSM analysis of case study.