Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 50 (2016) 129 – 134

www.elsevier.com/locate/procedia

26th CIRP Design Conference

A framework for automatically realizing assembly sequence changes in a virtual manufacturing environment

Mussawar Ahmad[a]*, Bilal Ahmad[a], Robert Harrison[a], Bugra Alkan[a], Daniel Vera[a], James Meredith[b], Axel Bindel[c]

[a]Automation Systems Group, WMG, University of Warwick, CV4 7AL, Coventry, West Midlands, UK
[b]Mechanical Engineering, University of Sheffield, South Yorkshire, S10 2TN
[c]HSSMI, Queen Elizabeth Park, London, E20 3BS

* Corresponding author. Tel.: +44 (0) 2476 573413. *E-mail address:* Mussawar.Ahmad@warwick.ac.uk

Abstract

Global market pressures and the rapid evolution of technologies and materials force manufacturers to constantly design, develop and produce new and varied products to maintain a competitive edge. Although virtual design and engineering tools have been key to supporting this fast rate of change, there remains a lack of seamless integration between and within tools across the domains of product, process, and resource design - especially to accommodate change. This research examines how changes to designs within these three domains can be captured and evaluated within a component based engineering tool (vueOne, developed by the Automation Systems Group at the University of Warwick). This paper describes how and where data within these tools can be mapped to quickly evaluate change (where typically a tedious process of data entry is required) decreasing lead times and cost and increasing productivity. The approach is tested on a sub-assembly of a hydrogen fuel cell, where an assembly system is modelled and changes are made to the sequence which is translated through to control logic. Although full implementation has not yet been realized, the concept has the potential to radically change the way changes are made and the approach can be extended to supporting other change types provided the appropriate rules and mapping.

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference

Keywords: Assembly sequence; assembly process; virtual engineering; hydrogen fuel cell; control logic

1. Introduction

The mass customization paradigm seeks to provide individualized products at near mass production costs [1]. Product variety can be achieved by making changes at different points during a product's life cycle from the design phase through to the use phase, and is further facilitated by product modularity [2]. With certain high value products, in order to ensure that customer or legislative requirements are met, it is necessary to make changes at the design phase *e.g.* reducing the harmful emissions of a combustion engine. This has the impact of affecting all downstream product realization domains such as process design and manufacturing system design [3]. As a result of this impact, the paradigm of reconfigurable assembly systems (RAS) has been proposed as a means of accommodating such design changes efficiently to reduce costs, in a way that is not possible for traditional dedicated manufacturing lines [4]. There has been a significant amount of work on describing the nature of a RAS [4, 5], but to reach the full potential of such systems, the knowledge capture and translation through the product realization domains must be as agile as the vision for the physical manufacturing system. In industry, the lack of seamless integration through the product, process and resource design domains results in clunky knowledge transfer where miscommunication or an entire lack of communication results in delays and errors. This is further exasperated by the global nature of businesses today whereby such domains may exist across multiple organisations spanning several countries and continents [6]. This has been referred to as the *co-evolution* problem [6, 7] but can more generally be described as the need for engineering concurrency [8]. The use of virtual engineering (VE) tools are becoming ever more

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference
doi:10.1016/j.procir.2016.04.178

prevalent in industry and, within their respective domains, facilitate in change realization more cost effectively than has previously been possible *i.e.* changes can be evaluated in a virtual environment and simulations can be carried out to assess performance without needing to invest in physical materials and resources. However, despite the sophistication of such tools, making a change to a product must still be *manually* translated to a change in the manufacturing system via the process domain to assess: accessibility, fixture design changes, assembly sequence feasibility *etc.*[8]. This research proposes a method for translating product design changes through to automation system control logic for deployment automatically using vueOne (a virtual engineering tool developed by the Automation Systems Group at the University of Warwick.)

2. Review of literature and gap analysis

2.1. Approaches for domain integration

Many researchers have looked at how to integrate the Product, Process and Resource (PPR) domains. The definition of what the product realization domains should be called and how they should be defined *i.e.* what factors should be encompassed within them, varies depending on background and experience. An early example is presented in [9] which describes what should be mapped, but not necessarily how such mapping should be achieved in a practical sense. However, it is clear that in order to attain integration, it is necessary to decompose each of the heavy, complex domains into smaller components to a satisfactory level of simplicity, allowing an identification of where mapping between the domains is appropriate [3].

A component based (CB) system was proposed by Rosenman and Wang that compared five collaborative architectures and described a web-based interface to manage component agents [10]. To address communication issues regarding design changes Chao *et al.* used the agent attributes of proactiveness and autonomy to co-ordinate the design activities of multidisciplinary design teams [11]. Ribeiro *et al.* extended their previous works to demonstrate how agent technology could be used to support "plug and produce" in run time [12]. Process plans were embedded within product agents which coordinated with system resources (conveyors, gates, stations) to route pallets through the system based on product requirements. Wang *et al.* argued that realizing agent-based approaches in real-time is difficult as the decision making process is neither deterministic nor event-driven. Instead, they proposed a process oriented function-block (FB) framework, where each FB represents basic assembly operations with embedded algorithms to describe how to fulfill the operation which in turn communicate directly to control systems or operators in the form of instruction sheets [13]. A method to support integrated product and process design was proposed by Mervyn using manufacturing middleware that synchronized applications [14]. Java and XML facilitated portability, and compatibility was achieved with common data structures.

Alternative integrative approaches include the use of knowledge-based systems within ontologies - enriched and supported by semantics. Numerous examples of this approach can be found in the literature, with each researcher choosing different areas to focus on and differing ontological structures to meet the requirements of their case. Lohse presented the ONTOMAS framework to reduce assembly system design effort using domain ontologies and implementing a function-behavior-structure paradigm to capture the characteristics of modular assembly system equipment [3]. A similar abstraction approach was proposed by Hui *et al.* that used semantic objects to retrieve information from documents of various formats and by inference allowing domain specific tools to become better integrated [15]. Lanz used feature based modelling to capture detailed product knowledge, categorizing features into geometric and non-geometric, to provide knowledge for a holonic manufacturing system [16]. Raza and Harrison described a collaborative production line planning approach supported by knowledge management theory [17]. A service-oriented architecture was proposed and supported by semantic web services that allowed automatic discovery and execution of assembly processes by modelling and mapping assembly processes and systems in [18]. An influential architecture for integrating the PPR domains is the Virtual Factory Framework (VFF) which is a data model that links and stores knowledge to support engineering concurrency in the resource domain [19], but does not have the granularity to model system control logic. More recently, knowledge-based mapping has been used to support in the selection of function blocks for manufacturing resource components [20], and Ramis *et al.* [21] showed how product requirements could be translated directly through to dynamically changing programmable controller logic. Chen *et al.* extended EAST-ADL (a language developed to model automotive electronic systems, see [22]) to model production systems using MetaEdit+ [23]. Mapping within and between the concepts of *Equipment*, *Process* and *Product* were achieved through the EAST-ADL feature links.

2.2. Virtual prototyping manufacturing systems

Virtual prototyping tools (VPTs) for manufacturing systems should provide: 1) a model consistent with real manufacturing systems, 2) effective simulation and prototyping capability and 3) a means for collaborating with key product realization domain stakeholders [24]. These tools facilitate "digital manufacturing" and state-of-the-art examples include: DELMIA Automation by Dassault Systems [25] and Technomatix by Siemens [26]. Both tools provide modules or workstations within common environments to model a large range of mechatronic systems. However, both are "heavyweight" applications requiring high end computing and specialized training, and as they focus on flexible rather than modular, reconfigurable systems, they are not inherently designed to easily identify the impact of making changes [24, 27]. A number of academic groups have also presented VPTs namely: Min *et al.* [28] who integrated real-time machine tool data within a virtual manufacturing environment. Suk-Hwan *et al.* [29] developed Web-based virtual machine tools to interactively operate CNC machine tools, and Dietrich *et al.* [30] presented sample scenarios for how the real and virtual processes could be integrated. While these tools show promise in their respective applications, they do not easily integrate