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Digital manufacturing and flexible assembly technologies for reconfigurable aerospace production systems

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Abstract

Reconfigurability is an important aspect of modern manufacturing systems as it facilitates the seamless introduction of new products to production and the adaptation to demand volatility. Advanced manufacturing technologies broadly used in automotive industry have limited application for typical UK aerospace manufacturing, as they require production volume and repetition of operations to deliver value. This paper discusses a framework of key technologies ranging from digital manufacturing concepts to flexible fixturing that enable reconfigurability in aerospace manufacturing systems. Initially, the overall architecture of the framework is presented illustrating the key components such as a cloud based data storage mechanism, an intelligent multi-product assembly station, kitting boxes embedded with sensors, a manufacturing network management portal and a decision support tool that combines data analytics and discrete event simulation. Afterwards, the main functionalities and technologies of the components are described and finally an industrial application scenario for the proposed framework is presented.

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1. Introduction

Today's manufacturing companies strive to improve their performance in a globalised, interconnected and volatile market environment [1]. Traditional approaches of dedicated production lines, although still in use/practice, cannot deal with changes related to the market such as; increases in product demand, product changes, such as the introduction of a new product in the line, and system failures, such as a machine breakdown, in a cost effective or timely manner.

In high volume manufacturing, such as automotive, the introduction of automation and information and communication technologies (ICT) on the shop floor, supported by digital manufacturing tools, has led to more flexible production systems which are capable of dealing with the volatile market demands and having a mixed product flow. In the aerospace sector, and in particular in manufacturing firms belonging first layer of the supply chain and below, the scale of product volume does not allow for the introduction of automation, such as robotics. In addition, the high complexity of aerospace products requires operations with high dexterity that make automation even more challenging and require operators of high skills and both technical and practical knowledge.

The concept of reconfigurable manufacturing systems has been introduced [2] as a new class of production system that lies between dedicated lines and flexible manufacturing systems, introduced in the mid-nineties [3]. The concepts of machine and system modifiability and the modularity of key operational functions and components are key elements of a reconfigurable manufacturing system and both of them are prerequisite for product and volume flexibility.

A modular and modifiable manufacturing system that is able to deal with an increased number of product varieties, high performance operations, flexible machines and reconfigurable systems structures is expected to be characterised with high complexity as well [4]. To handle this complexity, an integrated framework of data models, digital manufacturing tools and sensor network, is required to represent simulate, optimize, monitor and control a

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manufacturing system. The integration of such a framework with a manufacturing system would lead to Cyber Physical Production System (CPPS) [5], that following the definition of the Cyber Physical System (CPS), should be understood as "a system of collaborating computational entities which are in constant connection with the surrounding physical world with its on-going processes, providing and using (at the same time) data-accessing and data-processing services available on the internet."

There are three main technologies that could be considered as the main enablers of a CPPS: a) digital manufacturing tools, b) Internet of Things (IoT), and c) Cloud computing. According to the Verein Deutscher Ingenieure, "the digital factory includes models, methods, and tools for the sustainable support of factory planning and factory operations." [6] [7] and in a broader sense can be associated with the concept of the digital enterprise technology (DET) that is the collection of systems and methods for the digital modeling of the global product development and realisation process in the context of life-cycle management [8], [7]. "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction" [9] [10]. IoT comprises network infrastructures such as sensor network, wireless and standard Internet in order to provide a wide range of services in many everyday life aspects. [11].

The application of Cyber Physical Systems approaches and technologies to manufacturing systems is driven by different international initiatives. In the USA it is the advanced manufacturing initiative that encompasses a number of research programmes and organisations covering CPPS amongst other research areas [12] [13]. In Germany, Industrie 4.0 is the research platform responsible for defining the research framework and the guidelines for the Factory of the Future vision [14] [15] and could be considered a continuation of the "smart factory" [16] concept. A number of research programmes and projects focusing on CPPS are funded by EU under Horizon 2020 and in particular Factories of the Future [17] [18]. Finally Innovate UK along with EPSRC and industrial initiatives are fostering research in the areas of high value manufacturing [19].

During the past years a number of different digital platforms and concepts have been proposed for reconfigurable manufacturing systems. PROMISE-PABADIS introduced an agent based architecture in order to overcome the limitations of typical centralized manufacturing execution systems [22]. Another architecture for service oriented process, monitor and control focusing on the next generation of industrial SCADA (Supervisory Control and Data Acquisition) and DCS (Distributed Control Systems) systems has been proposed by the IMC-AESOP project [23]. In the context of the R&D project VFF a digital framework that incorporates a series of digital tools, used during the entire lifecycle of a factory and provides both data and knowledge management functionalities [26]. ARUM project developed agent based planning and scheduling tools employing the service oriented paradigm in order to address disruptions taking place during the ramp up production of aerostructures [24]. In Sense&React a context aware information distribution systems has been developed that collects data from sensors located at the shop-floor in order to increase the visibility of shop floor processes by providing the right information, to the right people, at the right [25].

2. M4 Approach and Architecture

Meggitt PLC, an engineering group specialising in components and sub systems mainly for aerospace, defence and energy markets is exploring technologies under the umbrella of CPPS and introduces intelligent and digital manufacturing approaches to its production facilities around the globe starting from three UK factories.

Meggitt has a diversified product portfolio with numerous different products of high complexity and tends to use dedicated production lines of low flexibility. These products do not lend themselves to automation and in combination with their low volume, the underutilization of lines may often occur. On top of this, even the most sophisticated algorithms cannot unlock the full potential of a factory without considering a company's suppliers. The optimisation of a single factory requires an alignment with the supply network.

M4 "Meggitt Modular Modifiable Manufacturing" aims to address the aforementioned challenges investigating technologies such as digital manufacturing, cloud storage and services, and IoT. In particular M4 envisions the development of a flexible Cyber-Physical Production System interconnected with other factories within the company and with the companies suppliers. Advanced multi-product assembly stations, which will be operated by multi-skilled staff with the support of intuitive information distribution systems, and intelligent, potentially autonomous, product delivery systems will be capable of uploading product, process and operation data to the cloud using an array of embedded sensors. Additionally, expensive capital investment assets, such as state-of-the-art (SOTA) CNC or metal additive manufacturing machines will be connected via the cloud, allowing business units to share assets and facilities across an organisation. Harvested data will be analysed providing full historical traceability and real-time shop floor visibility in terms of KPIs, while predictive analytics algorithms will be applied for short and long term optimisation of shop floor operations, allowing the factory to improve itself over time.

A generic layered architecture has been proposed in order to fit into the manufacturing shop floor requirements that could be applied to different production systems. The architecture is composed of four layers and is illustrated in Figure 1. The first layer is regarding the physical components of the M4 platform and is related to the areas of kitting, internal logistics and assembly along with a plastic additive layer manufacturing machine. Key components on the shop floor are the intelligent workbench, which supports the build process of different types of products, fixturing and the loading/unloading mechanism that will almost eliminate setup time. Sensors of different types and technologies are deployed at the shop floor to ensure required data is captured for traceability and visibility purposes and belong to the second layer of the architecture. Data storage is the third layer and is where data coming from the shop floor sensors is stored either