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Design, modelling, simulation and integration of cyber physical systems: Methods and applications

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ABSTRACT

The main drivers for the development and evolution of Cyber Physical Systems (CPS) are the reduction of development costs and time along with the enhancement of the designed products. The aim of this survey paper is to provide an overview of different types of system and the associated transition process from mechatronics to CPS and cloud-based (IoT) systems. It will further consider the requirement that methodologies for CPS-design should be part of a multi-disciplinary development process within which designers should focus not only on the separate physical and computational components, but also on their integration and interaction. Challenges related to CPS-design are therefore considered in the paper from the perspectives of the physical processes, computation and integration respectively. Illustrative case studies are selected from different system levels starting with the description of the overlaying concept of Cyber Physical Production Systems (CPPSs). The analysis and evaluation of the specific properties of a sub-system using a condition monitoring system, important for the maintenance purposes, is then given for a wind turbine.

1. Introduction

The main drivers for the development and evolution of Cyber Physical Systems (CPS) are the reduction of development costs and time along with the enhancement of the designed products. This involves the virtualization of the product to improve its design, to support verification and validation and enhance its production and operation. Overall, virtualization enables more flexibility at lower cost across the different stages of development. The interaction between the designed product and the production systems plays an important role in the development of the Industry 4.0 (also called Advanced Manufacturing, Smart Manufacturing and Cyber Physical Production Systems) concept. Future trends, methods and models for the systems design process also have to be considered in relation to their role as enablers of transformation of traditional system paradigms, such as mechatronics, embedded intelligence, and automation systems, into Cyber Physical Systems or the global integration associated with the Internet of Things (IoT).

The concept of automation, an evolved concept of mechanisation, began to develop in the mid-1950s as the increasing ability to apply developments in instrumentation and computer technology to the control of systems suggested a shift towards an environment in which computers would become increasing responsible for the operation of a range of processes [58,15]. The initial concepts of automation were generally associated with manufacturing processes, and the ability to remove people from many of those processes, resulting in what was envisioned as a safer environment producing products with greater efficiency and consistency. As for instance the replacement of electronic systems by processors such as the PDP-8 and PDP-11series from the mid-1960s onwards.

Since the development of the original concepts of manufacturing automation, computers have increasingly been adopted throughout the whole of industry for tasks covering the entirety of the design, development and manufacturing processes, as well as for associated tasks such as financial control, marketing and logistics. Further, the role of industrial computing has extended beyond its original area of manufacturing into fields such as

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healthcare where the ability to collect and manage large volumes of data has been assessed as having a potential value of billions of dollars [45]. However, in many cases the expected results perhaps have not as yet materialised.

In considering the growth of computers as applied to industrial environments, there are a number of factors and issues that need to be taken into account in relation to next generation systems. In particular:

1. A shift from product based to information or knowledge based economies integrated with system level developments such as Cyber Physical Systems and the Internet of Things. In such economies, the ability to access, transfer and share relevant knowledge on the basis of both context and need is likely to redefine the nature of systems, particularly when associated with "*manufacture on demand*" technologies such as 3D printing (additive manufacturing).
2. A refocusing on, and perhaps a redefinition of, the role of the user in a wide range of industry based activities in which the task differentiation takes better account of the associative and collaborative nature of activities. For instance, there is accumulating evidence to suggest that placing humans, with their short attention spans, into an environment dominated and controlled by computers results in a skills loss and reduced decision making capacity as well as in the ability to innovate.
3. A redefinition of the design processes to take account of increasing levels of system complexity and the inability of individuals, or even groups of individuals, to properly comprehend the nature of the system, or its potential failure modes [53].

Over recent years, significant effort has been put in to understanding the relationship of the individual with the physical environment, for instance through design concepts such as Design for All. Perhaps what is now needed is a similar design approach relating individuals to their information environment, and the ways in which the physical and information environments can be more effectively integrated at the level of the individual.

In looking at the role of computers in industry it is suggested that it is necessary to take a wider view of their roles as other than simply as device controllers as their use increasingly permeates all aspects of industrial systems. Most importantly perhaps, it could be argued that the relative roles of, and relationships between, humans and computers needs to be reassessed.

This survey article focuses on "*Methods and Applications for the Design, Modelling, Simulation and Integration of Cyber Physical Systems*" and is organized as follows:

- Section 1 gives a brief description of the current state and the motivation.
- Section 2 introduces the characteristics of different types of system (e.g. mechatronic systems, Cyber Physical Systems, Systems of systems, Internet of Things).
- Section 3 then provides an illustration of methods in the design processes of Cyber Physical Systems.
- Section 4 then presents a presents a range of case studies from system level view to a component level view.
- Conclusions and future prospects are given in Section 5.

2. The evolution of cyber physical systems

This chapter provides an overview different types of system and the transition process from mechatronics to CPS and cloud-based (IoT) systems. Mechatronics can be considered an interdisciplinary field of engineering science which aims to integrate and interconnect mechanical engineering, electrical engineering/electronics, control engineering and computer science (also often called information technology) such that their interactions form the basis for the design of a range of products and product types

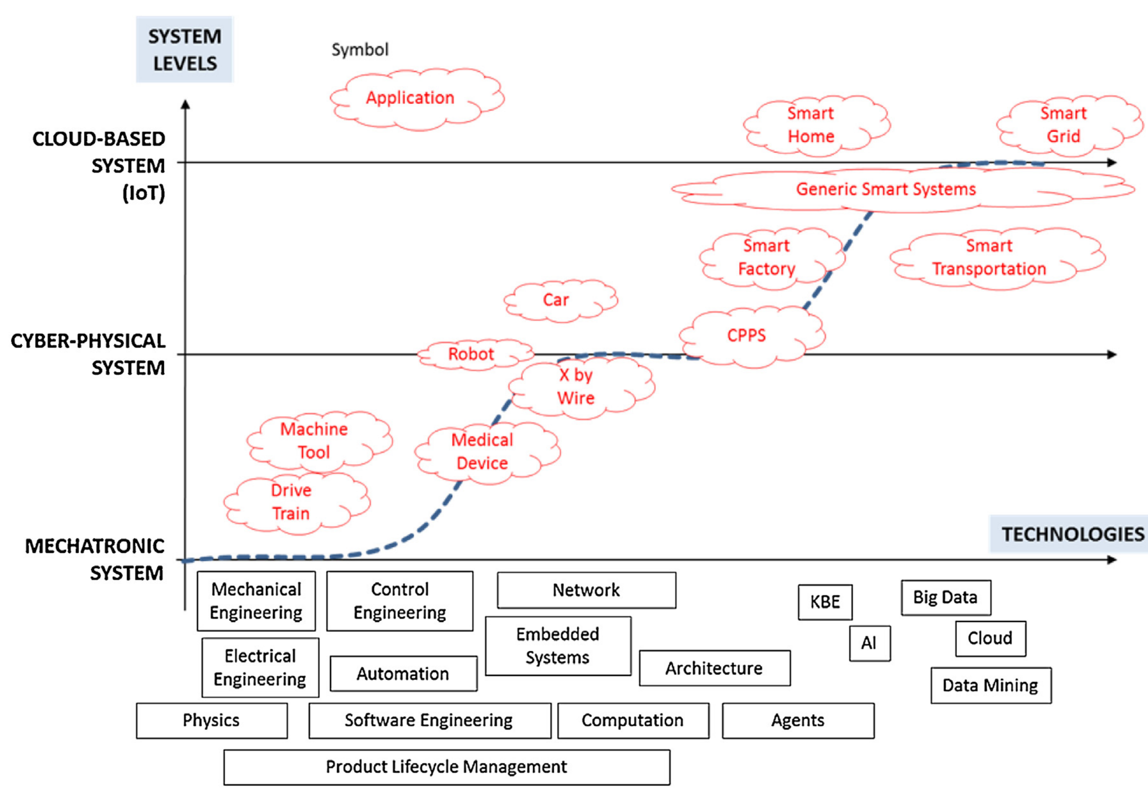

Fig. 1. Transition process from Mechatronics to CPS to Internet of Things.