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TRENDS IN AUTONOMOUS FLEXIBLE SYSTEMS FOR ASSEMBLY PROCESSES BASED ON ARTIFICIAL LEARNING AND UNDERSTANDING OF THE ENVIRONMENT

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ABSTRACT
The application of numeric control machines, robotic systems and computer integrated elements in manufacturing processes has been widely covered and it is accepted as a natural fact in a global industrial environment. However, the increasing claim for mass customisation of products has raised the interest for the materialisation of assembly systems that combine a high level of automation and autonomy with an outstanding degree of flexibility. In order to meet the requirements of the present and to be able to face successfully major challenges to come in the future, flexible manufacturing systems have to evolve to autonomous systems based on artificial learning that understand and take into consideration the evolvable situations in its environment. In accordance to this, the present work reviews over 20 years of studies and materialisations of intelligent assembly systems, agile manufacturing and Artificial Intelligence tools applied to highly reconfigurable assembly systems. The study goes over the birth of the concept of Agile Manufacturing, explores the key issues of rapid configuration systems, and unveils the trends on the development of highly autonomous flexible systems for assembly processes.
Keywords: agile manufacturing, autonomous systems, knowledge based systems, flexible manufacturing systems.

1. INTRODUCTION
Agile or rapid reconfiguration systems are systems in which the duties are planned in a high abstraction level; that is to say, systems in which the specifications to be carried out by the user are the least possible ones. An agile assembly workcell has to be able to assemble parts working with non deterministic conditions and will also be able to switch from the assembly of one kind of product to another only with minimum reconfigurations: Agility implies fast reconfiguration. An agile and universal workcell has to aspire to assemble any part requiring the operations that it has been designed for.
The concept of manufacturing by using agile systems is as easy as to try to emulate the most flexible and reconfigurable resource known: the people. The aim is to implement systems versatile enough to effectuate operations with the least necessary information and to be autonomous enough as to work without supervision; in an unmanned way. The development of agile production systems is therefore, a very complex duty, that involves multidisciplinary issues of different fields that interact one with the others such as computer aided vision, parts subjection and manipulation, automation, planning and programming.

2. BIRTH OF THE AGILE MANUFACTURING CONCEPT
The production technologies based on rapid configuration systems are, from a historical point of view, relatively young. In fact, as it was appointed by Kidd[1], the first mention to the "Agile

manufacturing" concept was in a book published in the US in 1991 by the then recently founded Iacocca Institute[2]. As stated by this institute, a production system is considered agile if '*it is able to adapt itself to the changes of its environment*'. In other words, the agile systems are good in approaching unforeseeable situations and can work without problem in not deterministic circumstances. The Agile Manufacturing systems are able to work with not completely defined conditions and they also have the capability to react to unexpected changes.

Many authors, such as Kidd[1] or Gould[3] (1997), explain the 'agile' movement of the US as a response with commercial and defence interests. Their explanation is that after the Cold War, the US Defence Department recognized that the companies dedicated to the production of goods with military purposes had to change their positioning and to start producing general interest consumer goods. However, the Government asked to these companies to maintain certain flexibility, in order to be able to return to their former activities in case of conflict. Nevertheless, the first 'Agile Manufacturing' definitions were applied eminently to management issues. This idea, served also as the Dove[4] approach (1994): *'To be agile means to be proficient in change and to enable the organisation to do whatever it wants when it desires it'*.

3. CHARACTERISTICS OF RAPID RECONFIGURATION SYSTEMS

The characteristics of the agile manufacturing systems have been studied and specified by many authors. Concerning this review, the features requested to agile systems can be postulated as it follows:

- **Rapid Response –**the ability to start working quickly; once it is decided to launch the production of a new product, the system has to start functioning in the shortest period of time possible.
- **Modularity** – the approaches rely in distributed modules (building blocks) that are combined to deliver a certain functionality.
- **Autonomy** – the modules are created independently of each other and provide self-contained functionalities, working has black boxes for the remaining system.
- **Interaction/Cooperation** – the modules must interact according to certain rules or agreements to deliver a functionality that is a combination of individual contributions. The principle underlying it is that the whole exhibits a functionality that is bigger than the sum of the parts.
- **Structure** – all the modules play a certain role in the system. The definition of a structure supports the progressive encapsulation of complexity.
- **Dynamics** – the systems addressed are not static entities. Most of the approaches support the idea of evolution, either by introducing changes in the environment or learning.
- **Robustness –**it must not be blocked by the uncertainty.
- **Heterogeneity** – the systems targeted by these paradigms are heterogeneous requiring a careful interface definition between entities in the environment.

4. AGILE MANUFACTURING R&D TECHNICAL STUDIES

Many different groups that have worked in the R&D of agile manufacturing systems; some of them only addressing a single subsystem such as parts feeding, subjection, the internal transport, etc.- but some others trying to design completely new systems –like *Workcells* or *Architectures for Agile Assembly*: *AAA*'s-.

On the one hand, the groups that have been dedicated to design subsystems are groups normally not only dedicated to the R&D in the fields of production technologies. Usually, these groups are computer and robotics laboratories placed within University facilities around the world and that are involved in projects belonging to other different lines than manufacturing. Examples of these groups that have been dedicated to study subsystems are the Canadian ERL (1996[5] and 1997[6]) that researched internal transport systems and conveyors, the University of Toronto (2000[7]) that worked on control systems or the Kobe University (2000[8]) that characterized the global management of the production of arrays of separate workcells.

On the other hand, some groups that fixed *Agile Manufacturing* as an own research line, have reached very consistent productive structures; the *Case Western Reserve University*[9] and the *Robotics*

Institute from the *Carnegie Mellon University* in Pittsburgh[10], has been undertaking research in the fields relating to the *AAA*'s for more than ten years already and it is constantly rising the pertinent state of the art with new minifactories proposals. The minifactories are a combination of a set of standardised subsystems that are used for parts feeding, subjection, internal transport and modular structures that are used to implement a productive process. These subsystems are combined in the appropriate way and sometimes it is difficult to discern where a workcell ends and where the following starts. For this reason, the progress in the minifactories represents not only a goal in itself but also a cluster of milestones for every subsystem implemented.

5. TRENDS IN DEVELOPMENT OF HIGHLY AUTONOMOUS FLEXIBLE SYSTEMS

To meet the agility requisites several approaches have emerged: Bionic Manufacturing Systems (BMS) [11], Holonic Manufacturing Systems (HMS) [12,13], Reconfigurable Manufacturing Systems (RMS) [14,15], Evolvable Assembly Systems (EAS) [16,17], Evolvable Production Systems (EPS) [18,19,20], etc.

The BMS [11] are inspired by the functioning of natural organs. Organs are composed of cells and through harmonious interaction with other organs support different organisms. This approach denotes the idea of a hierarchical system where information flows bottom up and top down along the chain. The basic modeling entity is the modelon which can in turn be composed of other modelons forming a hierarchy. The system heavily relies on self-organization, passing from layer to layer DNA-type information, to gather sub-modelons that will be involved in the execution of a given task. A similar approach relies on the concept holon inspired in the work of Arthur Koestler [21]. In this context, holon is a combination of the greek word "holos" (whole) and the suffix on (part). The HMS emerged in the intelligent manufacturing systems (IMS) community as a response to the continuously changing requirements and demands posed to modern enterprises. In HMS the holons must accomplish a certain task using: coordination, communication, cooperation and negotiation while being immerse in a holarchy (a society of holons where each component behaves simultaneously as a part and a whole).

The Reconfigurable Manufacturing Systems (RMS) [15] emerged, as a response to the socio-economic pressures faced by modern and future enterprises and to fulfill a gap between Dedicated Manufacturing Lines (DML) and the not so successful Flexible Manufacturing Systems (FMS). RMS sustain a holistic view over manufacturing systems, at hardware and the correspondent control software entities, focusing in: Modularity, Integrability, Customization, Convertebility and Diagnosability. Similarly to HMS and RMS, EPS [18,19,20] and EAS [16,17,18] rely in the modularization of hardware. Nevertheless EAS/EPS consider a finer granularity level. In this sense, the concept of module is within grippers, robots, sensor, actuators, etc; rather that cells and stations. Additionally EAS/EPS focus on production "change-overs" relying in biologically inspired concepts such as adaptability and evolvability. EAS/EPS modules are defined and optimized to be process specific. Eventually these modules can be aggregated in dynamic coalitions to quickly respond to specific production requirements. EAS/EPS denote a close link with Artificial Life where intelligence is considered a case of embodiment.

6. CONCLUSIONS

Current industrial control approaches are on the edge of becoming obsolete. Globalization has opened wide the door for a worldwide market, however, it has additionally boosted competition. In this context business opportunities are short-termed and of volatile nature challenging enterprises' flexibility and agility. This scenario clearly introduces a dramatic shift in the production environment as the control system can no longer be a static, centralized, immutable and perpetual entity. Equipment re-usage and seamless system reconfiguration and integration are mandatory to stimulate enterprises' competitiveness and ensure survival in a globalized market.

Modern paradigms to industrial control recognize modularity as a key aspect to attain flexibility and agility; as well as intelligent sensoring, autonomous embodied learning devices and agent collaborative decentralized control.

Despite the advances in control architectures some very important issues are still poorly covered in the literature, namely: the link between local intelligence and the physical parts being controlled[22], the role of self-organization and emergence as a response to functional requirements and disturbances and the social laws that guideline collaboration, learning and interaction in and out of the system. The self-organizing technical system autonomy is still considered through the static presumptions.

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