The IDEAS Plug & Produce System
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ABSTRACT
Current major roadmapping efforts have all clearly underlined that true industrial sustainability will require far higher levels of systems’ autonomy and adaptability. In accordance with these recommendations, the Evolvable Production Systems (EPS) has aimed at developing such technological solutions and support mechanisms. Since its inception in 2002 as a next generation of production systems, the concept is being further developed and tested to emerge as a production system paradigm. The essence of evolvability resides not only in the ability of system components to adapt to the changing conditions of operation, but also to assist in the evolution of these components in time. Characteristically, Evolvable systems have distributed control, and are composed of intelligent modules with embedded control. To assist the development and life cycle, a methodological framework is being developed.

After validating the process-oriented approach (EC FP6 EUPASS project), EPS now tackles its current major challenge (FP7 IDEAS project) in proving that factory responsiveness can be improved using lighter Multi-Agent technology running on EPS modules (modules with embedded control). This article will detail the particular developments within the IDEAS project, which include the first self re-configuring system demonstration and a new mechatronic architecture.

KEYWORDS: Evolvable Production Systems, Modularity, Distributed Control

1. INTRODUCTION

According to the results attained by many roadmaps [1],[2],[3] one of the most important objectives to be met by European industry is sustainability, which is multi-faceted: including economical, social and ecological aspects. The obvious conclusion to this holistic problem is that future manufacturing solutions will have to deal with very complex scenarios. The truly interesting characteristic of this conclusion resides in the word “complex”. Although often used, the basic essence of complexity is that it may not be fully understood and determined in all its ruling parameters; however, we seem to continue to build production systems based on known functionalities and predicted operational scenarios. This, to the authors, remains a rather disturbing factor.
Albeit the enormous efforts made in the 1990’s by Flexible Assembly and Manufacturing Systems, followed by Holonic [4] in the late 1990’s-early 2000s, Reconfigurable Systems [5] and other approaches, the dream of cost-effective, high-variant assembly remains elusive. One of the reasons may lie in the fact that one cannot solve unpredictable scenarios with a focus on predictable functionalities. Nature does not work with predictability. Nature does not propose an evolutionary change based on a single factor, nor does it do so by selecting a single motivating factor. Living organisms evolve by proposing a variety of solutions, but this is done in ways that are not yet fully understood. Yet the adaptation is guaranteed.

Based on this pre-conception that it may be more realistic to assume that a production environment is not fully predictable, and that we should not focus entirely on the required functionalities alone, Evolvable Assembly Systems was proposed in 2002 and has, since then, been developed and tested to emerge as a production system paradigm (see EUPASS, A3 projects [6], as given by [7])

In January 2011, the EPS approach was finally proven to work at the FESTO premises in Germany. The assembly system was re-configurable and exhibited self-organisation. Developed in the IDEAS FP7 project, the details will be given herewith.

2. BACKGROUND

First of all, the solutions proposed by EAS are not intended to be understood as a general panacea for all assembly scenarios. At present they are a potentially cost-effective approach to large variant flora production and/or short product lifecycles. Once the methodology is completed, and the technology matures, EAS could become more generally viable and cost-effective.

EAS may be viewed as a development of reconfigurability and holonic manufacturing principles. It was initially developed in 2002 from the results of a European roadmapping effort (Assembly Net), and was subsequently further developed in a series of European projects (EUPASS, A3, IDEAS). Its objectives have all been drawn from roadmapping conclusions and are well elaborated in earlier publications [8],[9].

As defined in [10]) RMS incorporates principles of modularity, integrability, flexibility, scalability, convertibility, and diagnosability. These principles impose strong requirements to the control solution. In particular, centralized approaches become completely unsuitable due to their intrinsic rigidity. Decentralised solutions must be considered that take into account the fundamental requirements of plugability of components, which includes the aspects related to dynamic addition/removal of components, as well as adaptation in the sense that the system does not need to be reprogrammed whenever a new module is added/removed. This is a fundamental aspect behind any control solution approach to solve the defined requirements. Therefore, the major challenge in the control solution is how to guarantee proper coordination and execution in a system in which both its components and working conditions can be dynamically changed. This is a challenge that needs a completely new approach and this is why in the context of EPS a solution based on concepts inspired from the Complexity Theory and Artificial Life is being developed. The next section covers what concepts from non-traditional manufacturing research domains are being used to create truly dynamic control solutions.

Hence, the control approach to be developed in the context of EPS wants to go back to the basics, that is to say relying stringly on the original idea of considering each component as a distributed intelligent unit that may aggregate in order to create a complex system. In this context, concepts such as emergence and self-organisation become more and more important
to be applied to new generation control solutions. However, true implementations of these new concepts within shop floor are still very few.

Considering what was stated above, one may view Evolvable Production Systems (EPS) as a development of the Holonic Manufacturing Systems (HMS) approach; however, a closer looks reveals that, although there are similarities in the exploitation and implementation phases, the paradigms differ quite substantially in their perspective (or trigger issue), and that only EPS achieves fine granularity. By granularity it is considered the level of complexity of the component that compose a manufacturing system. For instance, when a line is composed of several cells and these cells are modules that can be plugged in and out, this is coarse granularity. If, on the other hand, the components that can be plugged in or out are grippers, sensors, or pneumatic cylinders, this is fine granularity. This issue is in fact a very important one in terms of distinguishing the paradigms. The target for EAS is the shop-floor control, which normally demands programming, re-programming and vast integration work.

This is where EAS plays a decisive role. The two fundamental aspects are:
1. A methodology that allows the user to define modules at fine granularity level, from a control-point-of-view.
2. The development of control boards capable of running the agent software and, simultaneously, be small enough to be embedded in the smaller modules.

The IDEAS project proved this to be viable as a shop-floor solution.

3. IDEAS-THE BASICS

IDEAS stands for Instantly Deployable Evolvable Assembly Systems. This is an FP7 project that started in 2010 and will end in 2013. It is to develop EAS systems for two industrial customers, IVECO and ELECTROLUX.

The project took advantage of several developments that were done during the EUPASS (FP6...) project, such as:
- ontological descriptions of the assembly processes [9],
- equipment modules prepared for embedded control [11],
- data exchange protocols verified, [12],[13],
- basic methodological principles set [14].

IDEAS had as a main objective to implement the agent technology on commercially available control boards. This would enable distributed control at shop-floor level. What is being considered here is not the planning or logistics level but the actual operational level of the assembly system.

To this effect the ELREST company and FESTO research division set out to specify the exact requirements, based on the needs detailed by the industrial customers Electrolux and Centro Ricerche FIAT. MASMEC, Karlsruhe Institute of Technology and FESTO supported the effort by developing system modules, TEKS provided the simulation software, and UNINOVA and KTH developed the agent technology. Finally, the methodological framework upon which the whole project would base its work, was developed by University of Nottingham.

The project’s first objective was to prove the validity of the approach by running a medical assembly system at the FESTO facilities (see Fig.1).
The system shown above ran the following processes:

- **Glueing unit:** Dispensing glue for assembly of small components
- **Pick & Place unit**
  Pick and place handling system
- **Electrical testing unit**
  Testing unit for quality/functional product test
- **Stacker unit**
  Pneumatic/Servopneumatic handling system

This assembly system, called the MiniProd, was finally demonstrated in January 2011. It ran with a multi-agent control setup, could be re-configured on-the-fly, and the modules self-configured. This was achieved thanks to the fact that the agent software could be run on commercial control boards (Combo, ELREST), which are shown in the following Fig.2.

As this could probably be viewed as the first time an assembly system actually operated with a totally distributed control system, and self-configured, it was shown again for the European Commission in November 2011. The system performed flawlessly, confirming that multi-agent control can be used for truly reconfigurable assembly.
4. THE IDEAS DRIVERS

In order to attain this success, IDEAS has relied on many years research (including the work done in RMS, etc.) and the following own developments:

• A simple and effective mechatronic architecture
• Control boards developed for multi-agent applications
• An elaborate and well-structured methodology
• Industrial commitment

The mechatronic architecture is, first of all, an architecture that considers the control demands from an embedded-system point of view. That is, each assembly system module is an entity with its own control, hence the “mechatronic”. The difficulty was in creating an architecture out of which an effective control structure could be instantiated for any assembly system layout. As the demands on assembly are extremely diversified (see conveyor system in MiniProd-free-moving pallets!), this posed challenges. The final Mechatronic Architecture is based on four basic agents:

• Machine Resource Agent
• Coalition Leader Agent
• Transportation System Agent
• Human Machine Interface Agent

In order to implement this, the project developed several tools. The actual agent development environment, called IADE (IDEAS agent devt.env.) is based on an elaboration of JADE. The Java Agent DEvelopment framework is FIPA compliant and also provides basic development tools. The IDEAS project further developed these tools and included others to support the simulation of the agent control prior to its being downloaded into the modules. Experiments made at the simulation level and real module also indicated that the simulated module and real unit actually run the exact same code, rendering the simulation extremely accurate (1:1 relation).

The second main development has been the development of commercial control boards capable of running the multi-agent setup. The ELREST company provided the project with several alternatives, out of which the Combo211 was selected for use. This required quite some developments, amongst which:

• Combo200 series runs on WinCe6
• Implemented CrEme™, a Java Virtual Machine (NSI.com)
• Fits to the needs of the Agents and supports JADE
• Implementation of 24V I/Os, Ethernet, CAN and RS232/RS485 connections

The control boards function very well and have also been thoroughly tested at the other partners labs. The project currently intends to develop three variants of these control boards, depending on the required granularity and number of agents/module (from very small, cheap, to mid-size capable of running more than one agent).

Thirdly, the project would have never succeeded if the tools that are required to engineer such solutions were not specifically designed and integrated within the IDEAS methodology. This work, led by University of Nottingham, has brought together many partners (KTH, MASMEC, KIT, TEKS, ELREST, FESTO): the synchronisation and integration are sensitive aspects. The objectives included:

– Develop Semantic Representations for Devices and Skills
– Create Requirements and Target Specification Language
– Semantic Rules for Integration & Validation of Skills
Develop a rapid System Configuration Environment
- Develop Visualisation and Transparency Tools

Note that this includes skill definition support, Workflow definition support, simulation tools and more.

One of the most interesting outcomes of the work has been the link between simulated system and real system. Using commercial software (Visual Components) coupled to the multi-agent programs made it possible to run the exact run-time code prior to download. That means that the simulations represent exactly what will occur in reality (at control level).

All the developments, from EUPASS to IDEAS and beyond, would be quite superfluous if industry had not provided the critical mass and know-how to achieve such results. Industrial aspects are the key ingredient as the certification procedures, variation of hardware constraints, specific customer needs, market demands, etc., all play a decisive role in the effective deployment of a technology. IDEAS took this a step further as it set as an objective that one of the “missing links” had to be corrected: develop a control board for such applications. This was made possible by the industrial commitment, both at control development and requirements specification.

5. FUTURE STEPS

The project is now consolidating these results and developing them further. The next step will be to build two industrial systems, in order to verify the full-scale utilisation at customer-level. The two systems will be built at KTH (Stockholm) and MASMEC (Bari). The products to be assembled are an ECU (electronic control unit) from a commercial vehicle, and some specific washing-machine components. The figure 4 below illustrates the schematic layout.

Figure 5. The ECU Assembly System(MASMEC)

Both solutions will be thoroughly validate and Life-Cycle Analyses performed. Finally, a new Business Model has just begun to be developed in support of the more strategic decisions that will be encountered.
6. CONCLUSIONS

The article describes the first realistic developments for multi-agent control for assembly applications. The work is extremely valuable but there remains a fair amount of research and development work to be done.

First of all, the human role in such automated systems needs to be studied such that people may become an integrated element in EAS solutions. This includes the development of role models, interfaces and data capture methods. Secondly, the tools mentioned earlier need substantial elaboration, such that a solid and robust development methodology (guidebook and set of tools) can be generated. This is a highly multi-disciplinary requirement as computer specialists will have to collaborate with production and system engineers at detailed level.

Industrially, these solutions seem to generate sufficient interest, especially as these first tests have clearly shown the viability. The show-stopper is, therefore, not particularly at industrial level but, rather, at academic: consensus as to which “paradigm” is chosen as the most promising is not being based on true industrial development results but on theoretical details. This attitude needs to change and closer, more practical collaboration is required in order to truly support industry. As Thomas Kuhn would possibly put it, we must abandon normal science and search for a true industrial breakthrough.

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One of the final demonstrators, to be built at KTH, is also developed with the collaboration of XPRES (eXcellence in Production RESearch), a Swedish national R&D initiative.

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