The IDEAS Project: Plug & Produce at Shop-Floor Level

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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 Assembly Systems (EAS) 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), EAS now tackles its current major challenge (FP7 IDEAS project) in proving that factory responsiveness can be improved using lighter Multi-Agent technology running on EAS 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: Shop-floor Plug & Produce, Evolvable Assembly 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 at the point of inception, which we fix for the entire product lifespan, with little or no possibility to change the system should our predictions prove to be inadequate or even catastrophically wrong. 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] and the results exhibited at international fairs, Hannover 2008, fig.1).

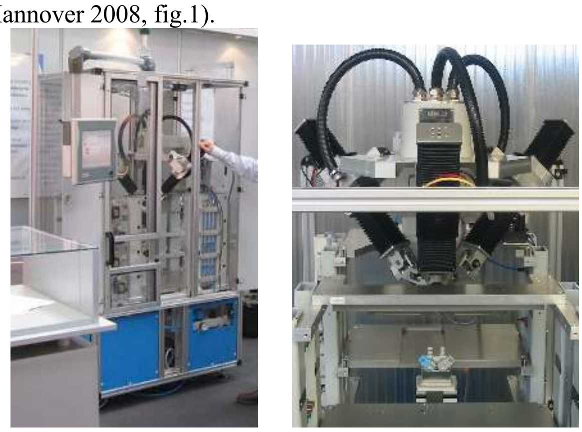

Figure 1. *First EAS/EUPASS system, Hanover Fair 2008*

In January 2011, the EAS approach was finally proven to work within an *industrial* setting at the FESTO premises in Germany. Do note that EAS systems have been running as prototypes at the UNINOVA lab since the mid-2000's as well. This latest industrial FESTO assembly system was re-configurable and exhibited basic self-organisation. This system has, since then, been active. Developed in the IDEAS FP7 project, the details will be given herewith.

1.1. Industrial view

European industry is struggling to balance its globalized presence and production on the one hand with the need to retain and protect its core knowledge on the other. Europe industry has experienced substantial outsourcing to countries outside Europe, in some cases moving from one low wage country to the next. Today the recognition is clearly growing that this mechanism may have been profitable in the past but is now approaches the point where different models have to be found. A natural question is whether "innovative" technology can help to improve. The answer, when looking at technology as a solution on its own, is a simple and sobering: NO. Only if technology is employed in the right context, e.g. considering the condition under which financial decisions are taken, the mid and long term strategic perspective of organisations, and legacy technology and practices currently embed in the enterprises, can it is seen how new ways can be found and exploited. From a technology, economic, and social point of view, adaptive machinery as described in this article has a chance to solve some of the pressing challenges by increasing the economic flexibility of automated while allowing rapid technological innovation, highest levels of labour utilisation, reducing the factory footprints, and allowing to react to fast changing product generations.

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 which take the fundamental requirements of plugability of components into account. This includes the ability to dynamic add /remove components without the need for reprogramming 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 and are not known in advance. This is a challenge that needs a completely new approach . Hence, in the context of EAS, a solution based on the multiagent paradigm, new solutions based on concepts inspired by Complexity Theory and Artificial Life are being developed [7], [9].

Hence, the control approach to be developed in the context of EAS wants to go back to the basics, that is to say relying strictly on the original idea of considering each component as distributed intelligent units (mechatronic agent in the sense that each of these units are being agentified) which may be aggregated to create complex systems. In this context, concepts such as emergence and self-organisation become more and more important to be incorporated into the next generation of control solutions. However, true implementations of these new concepts on the shop floor are still very few. In this context, a mechatronic agent is a production device (gripper, robot, …) that embeds a computer board within which an agent is running.

Considering what was stated above, one may view Evolvable Assembly Systems (EAS) 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 EAS achieves fine granularity. Granularity defines the functional complexity of the components which 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 three fundamental aspects are:

1. New control paradigm based on distributed control and build in self-organisation principles.
2. An agent based control architecture that considers manufacturing components as mechatronic agents that can be plugged or unplugged to create systems, **without reprogramming**.
3. Mechatronic devices/equipment with their own embedded control capability.

These points lead to the need to develop small and cheap controllers to use when embedding agents in modules and, furthermore, a methodology that allows the user to define modules at fine granularity level, from a control-point-of-view.
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. The aim of the project is to develop a new EAS industrial suitable distributed control approach and supporting engineering tools which will be demonstrated for three industrial customers- FESTO, 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.

This is a major innovation since most of the agent based manufacturing is not focused on agentified manufacturing components. In fact the IDEAS major innovation is to have proved that highly responsive and adaptable reconfigurable production systems can be created based on agentified production devices with fine granularity. Another important innovation that must be considered within IDEAS is the development of the industrial controller board able to run agents. In fact, one of the major limitations concerning the adoption of agent based manufacturing at device level has been the inexistence of low cost boards able to support agents. Within IDEAS a major step has been done in this directions thanks to the boards being developed by ELREST

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 and UNINOVA.

The project's first objective was to prove the validity of the approach by running a medical assembly system at the FESTO facilities (see Figure 2).

Figure 2. *The FESTO MiniProd System*

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The system shown above ran the following processes:

- Glueing unit:
  Dispensing glue for assemly of small components
- Pick & Place unit
  Pick and place handling system
- Electrical testing unit
  Testing unit for qualitiy/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 below.

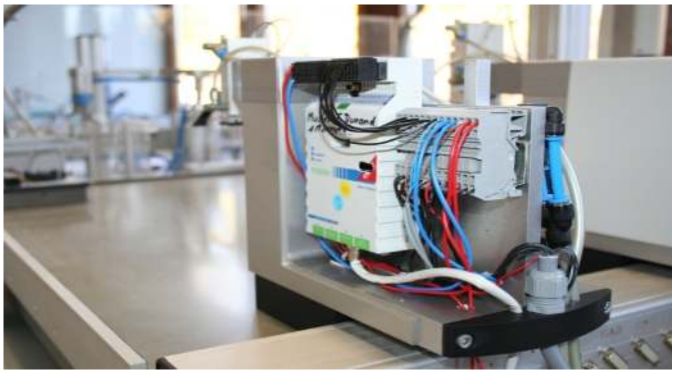

Figure 3. *Combo211 (Elrest) applied within a module*

As this could probably be viewed as the first time an assembly system actaully 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, and that commercial control equipment can be used. Do note that plug & produce has been shown to work before, partly by Service-Oriented Architecture approaches (SoA[15]) and in industry (see Daimler-Banz case[16]). The novelty in IDEAS is that the self-configuration and reconfigurability are *entirely* at shopfloor level: the system demonstrated exploited ONLY multi-agent control and NO supervisory control was used at any instance. That is to say that the control was at the actual machine control level using embedded intelligent devices, as opposed to high level organisation and co-ordination of systems mainly focused on the material flow and routing decisions. This type of system control is unique and requires zero re-programming efforts, all the while allowing extremely fast system deployments (towards zero integration time).

4. The IDEAS Drivers

In order to attain this success, IDEAS has relied on many years research [7], [8], [13], [14] (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

4.1. The Mechatronic Architecture

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 Mechatronic agent concept proposed by the EAS paradigm, targets the reduction of the initial build and subsequent reconfiguration effort through the use of modular equipment with standardised interfaces and build-in control capabilities which allow modules (Mechatronic Agents) to be rapidly connected together and dynamically configured to achieve a wide range of assembly processes [17]. The Mechatronic Agent concept hence goes beyond the mere plug-ability of hardware building blocks, such as one would find in a LEGO system. The idea is to not only have the physical equipment modularity, but also create modules of the functional capabilities needed to execute an assembly process. These functional capabilities need to be directly related to the physical building blocks of the system.

Hence when a Mechatronic Agent is plugged into the system is comes with its own process capabilities. These capabilities are the so called Skills.

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, MRA
- ❖ Coalition Leader Agent, CLA
- ❖ Transportation System Agent, TSA
- ❖ Human Machine Interface Agent

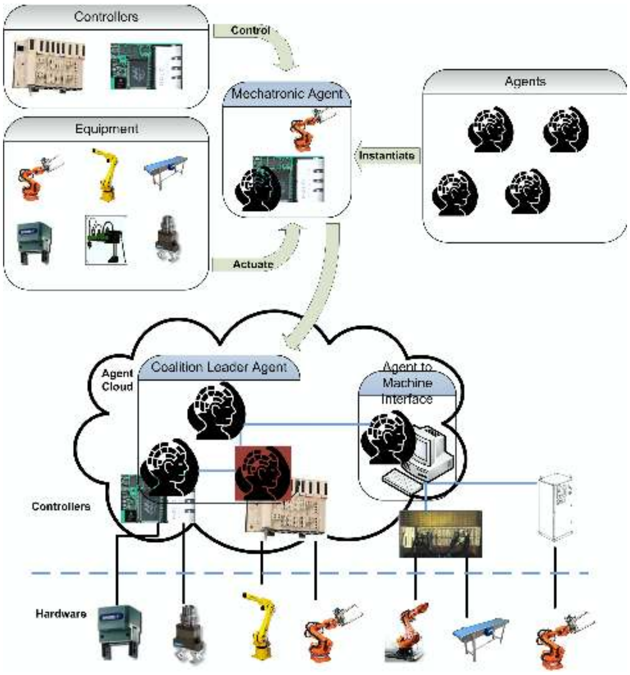

Figure 4. Conceptual view on the MAS framework

Figure 4 illustrates the conceptual view on the MAS framework.

A Mechatronic Agent in a general sense is a composition of an agent, a controller and a specific equipment. This set of entities, which can then be further specified and,combined to support different processes and integrate different systems.

The **Mechatronic Agent (MA)** is an abstract concept that gathers the main descriptive attributes of all agents in the system. In this context it provides the adequate support to ensure generic semantic interoperability between the agents. Fundamental aspects covered by the MA concept include:

- Skill - Agents offer their functionalities encoded as skills. A skill encloses the necessary information for public interfacing as well as the dynamic links with the system's low level libraries (specific of each mechatronic entity).
- Yellow Pages Service Interaction - the MA provides the data representation (object) that describes each agent in respect to the hosted and publicly available functionalities (or skills).
- Messaging - the MA abstracts and extends the JADE native communication system (including FIPA interaction protocols) making the compliant with the skill execution logic.
- OMAC state - the MA harmonizes the agent state with the OMAC state machine.

The **Machine Resource Agent (MRA)** extends the functionalities conceptualized in the MA. Its main purpose is to abstract mechatronic modules that can be plugged and unplugged from the system and that host a set of executable skills. The MRA implements the server side communication supporting the execution of its skills and ensures the dynamic invocation of specific system libraries that implement the advertised skills. Additionally the MRA implements a generic interaction with the Transportation System Agents to inform changes in its positioning that may affect the execution of its skills.

The **Coalition Leader Agent (CLA)** is a construct that enables the composition and execution of skills. A CLA supports the execution logic of processes which are designed by the user based on the available skills in the system. The CLA is able to react to changes in the system that compromise the composed functionality. In this context any removal or fault in the modules used in a coalition forces the CLA to negotiate a valid replacement to maintain the functionality level..

Product Agents (PA) are a special case of Coalition Leaders. Their internal structure and behaviours are similar. The main difference is conceptual. A Product Agent is the system response to the emerging production requirements. In this context the Product Agent executes the skills that match process requirements. Products Agents are in this context in the highest level of the functional hierarchy of Mechatronic Agents. There is no composition beyond Products which also means that they cannot be used as building blocks to derive new skills on the system. The PA ensure a one to one identity between the agent abstraction and an instance of a product being produced. They are therefore fundamental in maximizing the decoupled nature of the system promoting robustness and process fault tolerance.

The **Transportation System Agent (TSA)** abstracts components of the transportation system. It provides localization, transport and positioning functionalities. Each TSA keeps track of its own position in the system which is typically associated with the position of an MRA or CLA on the system as well.

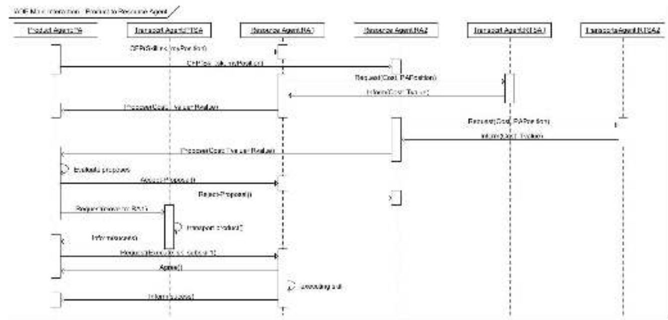

Figure 5. Product Agent to Resource Interaction

Figure 5 shows how a product agent may interact with different resources. The product agents and coalition leaders carry their own process plans. As detailed D3.2 PA is a particular case of CLA that does not respond to skill execution requests. In both cases however their skills can be pre-instantiated (i.e. another Mechatronic Agents is assigned as the owner of a specific subskill). In this case the CLA or PA will not attempt to negotiate and will require its associated transport agent an immediate transport to the desired agent. If there is no owner assignment the PA is free to decide in runtime the best location to have the skill executed. It does so by issuing a call for proposals (CFP) to all the agents in the system that call fulfil the desired skill. Each resource agent or coalition leader computes the cost of hosting that operation including the transportation cost which it gets by querying the associated TSA. The product agent decides on the best location based on the cost metric and requires a transport to the specific location. When the PA arrives at the specified location it directly contacts the MRA or CLA to handle the execution.

The addition of an MRA does not imply any reprogramming since the only consequence to the architecture is that the system has new skills (abilities) that were announced by the mechatronic agent (MRA) that was just added. As soon as these skills are announced the transport agent knows where the MRA is located and any subsequents requests by any product agent can be handled. If the MRA is removed the consequence is that the system does not have the skills that belonged to the removed module, and consequently the transport agent is not able to handle any requests from the product agent involving those skills.

Another advantage of this mechatronic architecture is the possibility to naturally handle different product variations within the system. The only limitation is that the system must possess all the skills required to implement the different product variations. In fact, since each product agent can carry its own process plan, that lists the process sequence, and the product agents only runs this process sequence, as long as there are available MRAs able to do the requested process (skill), adding a product variation does not have any impact in the system.

In order to implement this, the project developed several tools. The actual agent development environment, called IADE (IDEAS Agent Development Environment 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).

4.2. The Control Boards

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

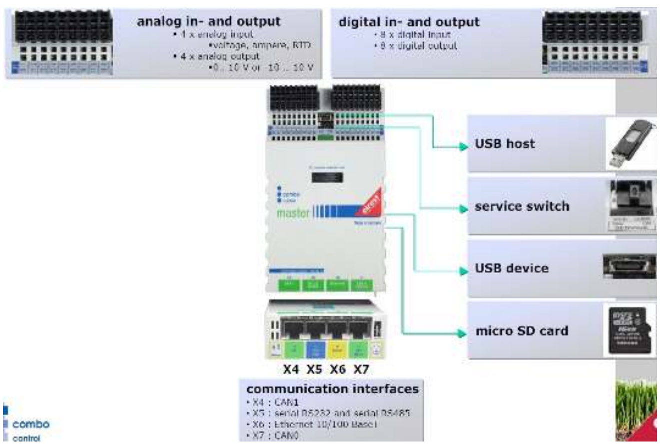

Figure 4. Overview of the Combo 211 utilised

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).

This version of the Combo 200 runs CodeSys V3, which is of some importance at mechatronic level.In fact it was found necessary to separate the mechatronic functionality requirements from the "intelligent" agent functionalities. The agent functionalities are implemented in JAVA/JADE, while the mechatronic ones in CoDeSys IEC 1131-3. Other development work includes the implementation of different drivers (CAN, Ethernet, RS232/RS485), implementation of I/O's and stepper-frequency count in FPGA and software.

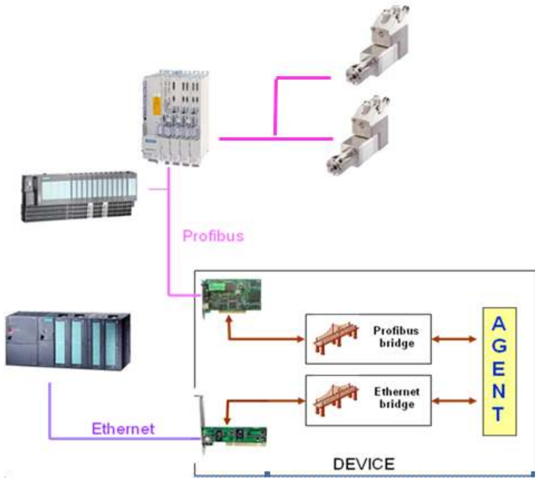

Figure 5. Connecting Legacy Equipment

Finally, it was deemed very profitable to attempt to simulate the behaviour prior to downloading the software. Therefore an OPCconnection was created between the Combo 200 and I/O driven simulation via a dedicated "socket".

Do note that this also includes the development of software that enables the user to integrate legacy equipment to this distributed control system, even at communication level.

4.2. The Configuration Tools

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 brough 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

The concept of evolvable assembly systems focuses on system adaptability. This adaptability will require an overall approach for the system lifecycle definition, which identifies fundamental concepts, their interrelationships and core characteristics. Very simplistically, the lifecycle of any assembly system can be divided into its design, its build and ramp-up, its operation, and its decommissioning phase. This basic lifecycle model is often extended by enabling a system to be reconfigured once its operational requirements change substantially enough to justify the required effort. EAS defines modularity as both physical and logical, thus establishing assembly processes as a basic logical block, the "skill", which represents a capability.

Therefore, the Skill concept is central to the Assembly Process centred Configuration Method [14], [18]. Skills define the process capabilities offered by the Agents (equipment units) to complete the required assembly process steps. Process skills take a similar role as methods in programming or services in SOA systems. Those Skill capabilities will be used to select and configure a new or re-configured assembly system. From a configuration and design point of view this implies that the available skill capabilities will be compared to a set of process/skill requirements. A similar match process would have to take place if a control system wants to support real time resource (skill) allocation. This makes it evident that a process model will need to include a Skill and Skill Requirement concepts.

Furthermore, one of the key advantages of the Mechatronic Agent concept is that modules can be developed in parallel by different module providers. Consequently it will be necessary to control the definition of Skills and Skill Requirements to ensure interoperability. One mechanism to achieve the consistency of the definitions is the use of predefined templates. If the same set of templates is used to define both the Skills and the Skill Requirements, they can be directly compared and matched. Those templates will need to be linked to predefined types of skills and parameters.

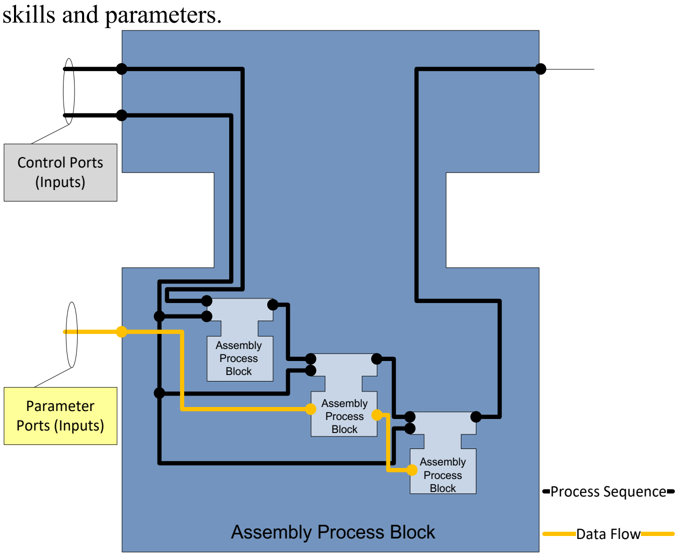

Figure 6. Overview of Composite Skill Concept

Finally, it is expected that Skills will have some parameters which can be set either fixed for the operation of an assembly system or dynamically based on the outputs from other skills. Hence it will be necessary to define which parameter settings a Skill should be executed with to achieve the desired result either in advance or during run-time with. These settings can be defined in the form of a Skill Recipe concept which should prescribe how a Skill Requirement can be achieved by a Skill. The agents will possess the definition of the skills, which enables it to provide information on its capabilities has well as having the recipe for their execution. Figure 6 provides a schematic overview of this concept using IEC 61499 notations. Note the possibility to aggregate simple skills into complex ones.

The concept of Skill Requirements has two functions. One is as discussed above for the definition of composite skills to bridge between different levels of granularity. The other one is for the specification of the assembly system requirements, which provide the product work flow. A detailed description of the configuration methodology is quite complex, and is given in [18]. Figure 7 provides a three stage overview of the configuration process.

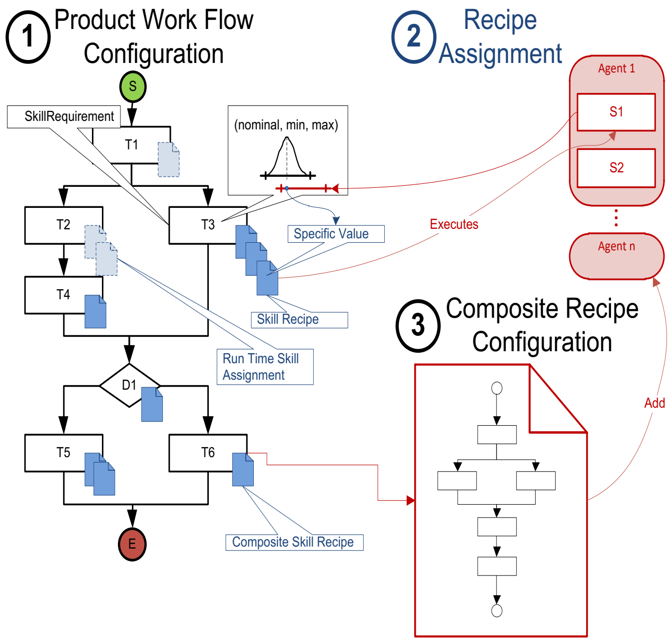

Figure 7. Conceptual Overview of Configuration Process

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).

4.2. The Industrial Element

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 figures below illustrate the schematic layouts.

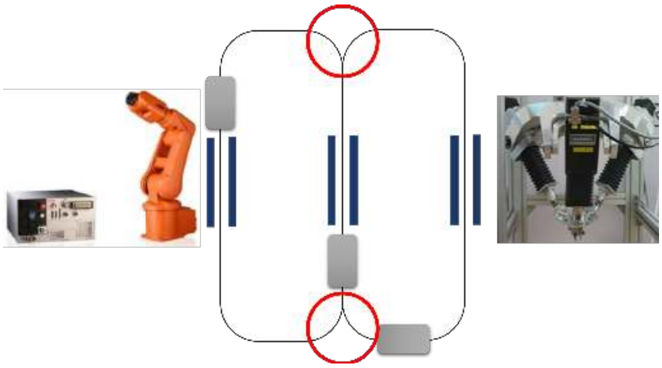

Figure 8. *The Washing Machine Components Assembly System* (KTH)

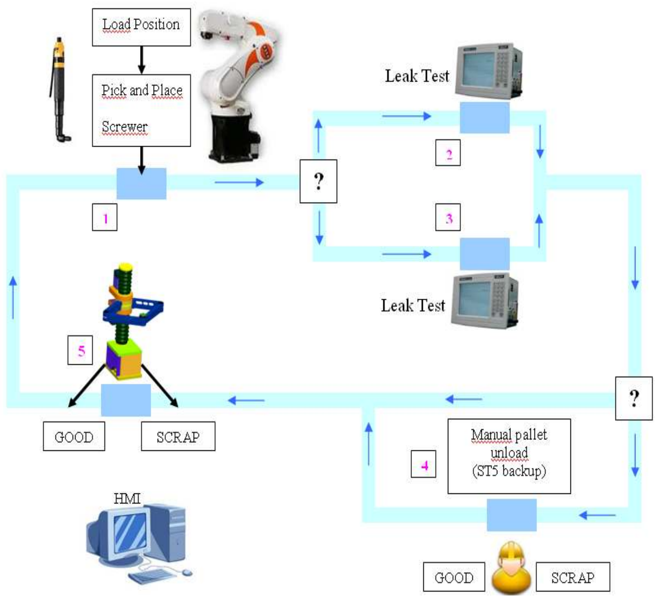

Figure 9. *The ECU Assembly System(MASMEC)*

Both solutions will be thoroughly validate and Life-Cycle Analyses performed. Finally, both a new Business Model has just begun to be developed [19] in support of the more strategic decisions that will be encountered, as well as a completely revised approach to planning & scheduling of such systems (Demand-responsive planning, [20]).

A new way of implementing automation equipment, industrially, will take time. It is linked to the long life cycle times of such equipment. Therefore the changing process will not be fast. But the argument for the new technology that is described here is very convincing. Systems can be adapted to new tasks in shorter time and to lower cost, equipment can be remodelled and reused. Ramp up times decrease by several factors and thus, in the overall consideration,one may expect a clear economic benefit. At the same time it is admitted that new software is required, a changed mindset for the system integrator is a prerequisite and running the production with such kind of equipment is different from what it was before. The latter fact hints at the circumstance that this process will take time. Also more scientific work is needed.

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.

6.1. Critical Mass vs Academic Focus

The industrial partners in IDEAS confirm that the way automation is carried out will change. Software and smaller controllers allow a higher degree of function integration every year. Humans are once again back into focus as they still are (and will remain for many years to come) the real heart of a factory. Taking the sum of these ingredients leads one to recognize that evolvable modules based on agent technology can be a very effective help in promoting new solutions needed badly for European industry. The IDEAS partners admit that this will not be the only possible answer but they claim that this research gives an important contribution to addressing some of the pressing questions involved. European research focussing on this area - and the number of actors and researchers is clearly visible - shows that this overall research will lead to solutions very interesting for European industry.

In summary one may say that 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 between all parties 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.

7. Acknowledgements

The authors wish to thank the European Commision for the funding and, in particular, their Project Officer Jan Ramboer.

The IDEAS partners have shown incredible commitment and worked well beyond the budget limits and normal working hours, therefore our deepest thanks go to:
Johannes Hoos (FESTO), Friedrich Durand (ELREST), Piero Larizza (MASMEC), Roland Krain (TEKS), Pandelli Borodani (Centro Ricerche FIAT), Pedro Ferreira (Univ. of Nottingham), Andreas Hofmann (Karlsruhe Inst. Of Tech.), Luis Ribeiro (UNINOVA) and Alessandro Mazzon (Electrolux Italia).
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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