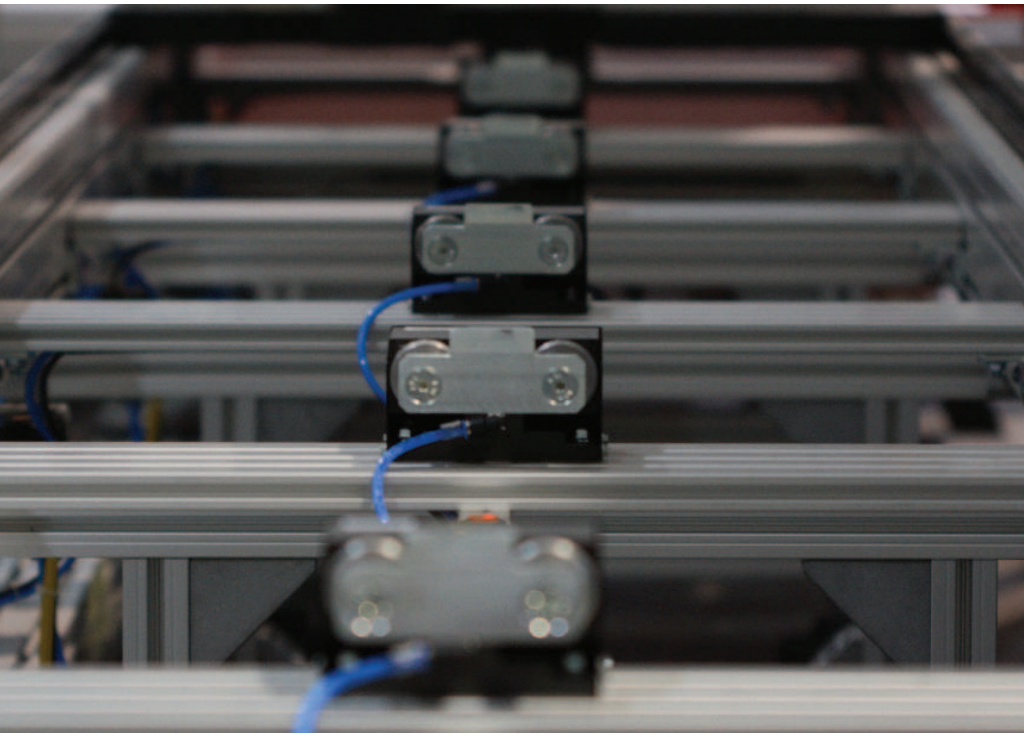
Grace

inteGration of pRocess and quAlity Control using multi-agEnt technology



Grace project

The EU FP7 Grace project aims at **integrating process and quality control within a production line**. This goal is fully in line with the trend to develop modular, intelligent and distributed manufacturing control systems.
The system is based on a collaborative Multi-Agent System (MAS) which operates at all stages of a production line and it is complemented by self-adaptive control schemes developed at the level of process resources and quality control stations as well as at line or factory level. The MAS aims to individually tune parameters of each product taking into account information collected during the whole production process, so to compensate production process variance.
The innovation is the **new vision of the production process which leads to a deep integration of process control with quality control and finally product value**.

MAS

Multi-agent architecture for line production system, integrating process and quality control

The majority of traditional manufacturing control systems are not designed to exhibit the capabilities of responsiveness, flexibility, robustness and re-configurability needed to face evolving requirements of modern manufacturing, since they are built upon centralized and hierarchical control structures.
The distributed nature of the agent-based approaches suggests the definition of distributed control functionalities based on autonomous agents that account for the realization of efficient, flexible and robust overall plant control, differing from the conventional approaches due to its inherent capabilities to adapt to emergence without external intervention.
The Grace system will act at the Distributed Control System (DCS) and Manufacturing Execution System (MES) levels, implementing the sharing of process critical information between and inside the two layers, enforced by the agent technology (Figure 1). This results in a **more efficient management of resources and a higher final product quality**.

Architectural autonomous and cooperative components

The Grace Multi-agent system is **based on a society of distributed, autonomous and cooperative agents** representing the components of the production system. Each individual Grace agent has a partial view of the system and behaves according to a small number of simple rules that constitutes its behavioural repertoire. These agents may represent a physical resource, e.g., processing machines and quality control stations, or a logic activity, e.g. a production order. The whole production process is supervised and controlled through the integrated and coordinated operation of a network of collaborative individual agents.
In such distributed environment, several types of agents are identified according to the process to control and to their specialization (Figure 2): **product type agents** (PTAs), **product agents** (PAs), **resource agents** (RAs) and **independent meta agents** (IMA).
PTAs represent the catalogue of products that can be produced in the

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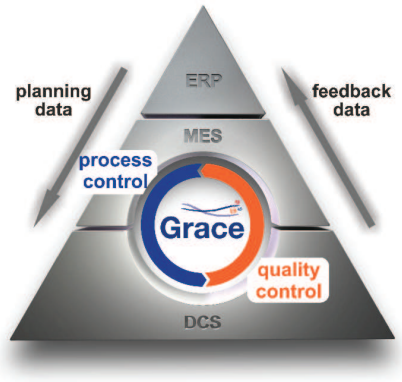

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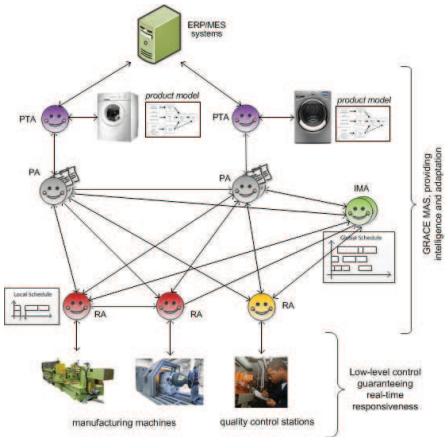

1 DCS-MES focus of Grace project in the automation pyramid

2 Grace multi-agent system architecture

production line (one agent for each product type). Each agent contains the product and process models required to produce the product, being responsible for monitoring the product execution (allowing the traceability of the production) and for adapting/optimizing the process plan according to the feedback of previous executions.

PAs manage the production of product instances in the factory plant, according to a process plan to produce the product. They are responsible for the data collection of the execution of the product, the product process management (including the rerouting of pallets) and the optimization/adaptation of production and quality control programs/parameters.

The RA agents represent the physical resources of the production line, such as machines, robots, quality control stations and operators. They manage the execution of their production/testing/transportation/assembly operations in the production line, namely the dispatching and process control, resource monitoring and optimization/adaptation of the operation parameters. RAs can have different specializations according to the particularities of the resource, namely **Machine Agents** (MAs), **Quality Control Agents** (QCAs), **Transport Agents** (TAs) and **Operator Agents** (OAs). Of particular importance in the Grace MAS are the MA agents that are associated to mechatronic equipment, such as robots and machines that execute production operations (adding value to the product), and the QCA agents that are associated to the quality control stations and manage the execution of testing/quality control operations in production line.

The IMA agent implements the global supervisory control and optimized planning and decision-making mechanisms. It collects and checks data over time (from the other individual agents), performs trend analysis and elaborates suggestions and warnings to improve the process and product execution. In opposite to the PA and RA agents, that are placed at the operational execution level and are mandatory, the IMA agent is positioned in a higher strategic level (without hard real-time constraints) and is not mandatory (i.e. the system can continue working without it, however losing some optimization). The PTA agents are also placed at strategic level, like IMA agent, but are mandatory.

Cooperation to achieve the MAS behaviour

The global behaviour of the Grace MAS system **emerges from the cooperation among the individual agents, each one contributing with its local behaviour**. The interaction between agents requires the understanding of shared knowledge, using interaction protocols, a proper agent communication language and a proper knowledge representation. In particular, the use of a proper ontology is an important piece to formalize the structure of the knowledge related to the existing resources and the product and process models that describe how to produce the catalogue of products, providing a common understanding on the vocabulary used by the intelligent, distributed agents during the exchange and sharing of knowledge.

The interaction among agents is designed to enhance integration and collaboration, opening a sound perspective for:

- **Developing self-adaptability** to desired variations of process set-point and process variables and to unplanned fluctuations of process/product parameters;
- **Developing adaptive procedures and self-learning** for quality control systems at local and global level;
- **Developing supervisory control schemes** at factory level so to maximize production efficiency and product quality;
- **Developing factory-level decision-making strategies** based on data analysis methods exploiting information from all current processes and from historic data base.

Contribution and innovation

The resulting MAS architecture guarantees the achievement of the following innovative aspects:

- **Modularity and flexibility**, i.e. plugging in or out autonomous components/agents;
- **Run-time adaptation**, i.e. applying local self-adaptive and self-organization concepts to adapt the system behaviour according to the unplanned changes;
- **Run-time and on the fly reconfiguration**, i.e. adding, removing or changing components without the need to stop, re-program and re-initialise the other components;
- **Robustness and responsiveness**, i.e. a better response to changes/failures, by using distributed control structures.

Another important contribution of the Grace project is related to the **fully assessment of the multi-agent systems benefits in real industrial environments**. In fact, there is a gap today between theory on development of adaptive multi-agent systems, and their implementation in manufacturing industry. The Grace project seeks to fill this gap, by demonstrating the effective applicability of multi-agent systems in a real world case, considering the case of a factory operating with on-demand production, where some changes of process set-point and of product characteristics can be predictable, and other random unplanned changes of process variables may always occur.

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