The PABADIS’PROMISE architecture – a new approach for flexible manufacturing systems

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Abstract

PABADIS’PROMISE (PABADIS based Product Oriented Manufacturing Systems for Re-Configurable Enterprises) is a new European research project aiming at the improvement of the flexibility of manufacturing systems by extending the applicability of distributed intelligence at all levels of control. This paper introduces the basis ideas of the concept and describes details of the technological and conceptual approach. After a short comparison of the state-of-the-art and former research projects in the field of flexible manufacturing systems the general architecture and functionality of a PABADIS’PROMISE will be described. The targeted enhancements will be discussed in comparison with existing systems with a special focus on the usage of mobile agent systems and RFID-technologies on the field control level. Finally, the expected benefits resulting from the implementation of a PABADIS’PROMISE system will be summarized.

1. Introduction

Future manufacturing systems will have to face new requirements to react on upcoming dramatic changes in technological, environmental, economic, and social terms as described in an EC evaluation study for the developments within the next 20 years [1]. European manufacturing will be more and more driven by a turbulent industrial environment which is characterized by an aggressive economic competition on a global scale, more educated and demanding customers, and a rapid pace of change in process technology. Thus, future manufacturing will require high flexibility/adaptability and speed with respect to organization of production and supply-chain management and require an increasing amount of services and inter-company collaboration. These requirements especially concern control and networking of embedded control systems of manufacturing enterprises at ERP (office), MES (factory control) and production level. In the last years several approaches for future manufacturing systems such as HMS and PABADIS [2] were developed, making remarkable advances in enhancing the flexibility of production systems by using distributed and agent based systems. Nevertheless, the industrial application of these concepts is still in the fledgling stages due to the required comprehensive paradigm change on all levels of a manufacturing systems and problems of more practical nature with respect to an economic reasonable use of technologies such as agent systems. To overcome these problems and make the next steps towards a wide industrial usage, future projects have to face up the ongoing technological development in the information technologies and increase the applicability of the basic concepts under real industrial conditions.

Taking these requirements into account and building on top of the PABADIS architecture, the PABADIS’PROMISE project extends the idea of distributed control to an innovative architecture which incorporates both resource and product.

2. Starting point for the development

Current automation architectures are characterized by hierarchical and monolithic structures as shown in the left part of figure 1. As they are control device centered with application design prior to system use, the structure is inflexible and inefficient with respect to re-design/re-usability.

The nowadays Enterprise Resource Planning (ERP) Systems have a monolithic architecture with a high abstraction of data and company management and cost accounting oriented view enabling only limited access to field control by abstract order handling. First approaches for distributing ERP systems are mainly oriented at distributing high-level functionalities without considering the needs of distributed factory planning or distributed field control.

On the MES level several mainly proprietary planning technologies either focusing on ERP system cooperation or dedicated to efficiently interact with field control devices.

Devices on the automation level are mostly proprietary using vendor dependent control device technologies with interfaces for communication system
and sensor/actor level access. The interaction of control devices with MES/ERP-level systems is characterized by distinct technology disruption.

To overcome the resulting drawbacks of limited flexibility and interoperability, within a number of research activities new architectures were developed. Some of these concepts such as PABADIS [3,4,5] break the monolithic architecture on the MES layer by using agent and plug-and-participate technologies, other introduce a distributed control architecture on the field level by collaborating function block systems (in approaches like CORFU [6,7], TORERO[8,9,10]) or cover both areas such as HMS [11,12,13].

The main results reached by these approaches shall be exemplary described for the PABADIS-approach:

- distributed, resource centered control architecture with order related application parameterization on demand
- flexible net-working of manufacturing resources by plug-and-participate structures
- integration of interface to field control for improved data exchange
- advanced devices with standard interfaces for integration in distributed control systems, platform independent programming, and control code reuse
- advanced concepts for distributed order management based on agent systems neglecting Real-Time and embedding aspects by focusing on PC based systems
- Concepts for description and comparison of products and production processes related to special industrial areas based on description parameter systems and formatted text documents

These systems shows in principle the applicability of agent based distributed architectures in flexible manufacturing systems. Nevertheless there are still open problems in terms of a practical application and industrial acceptance. Implementations have to be costly tailored to the specific needs of implemented demonstration systems and even the generic PABADIS-architecture has limitations especially with respect to the interaction between MES and control level. The application of agents on the field level is still cost intensive with respect required resources and here especially the mobility of product related agents is problematic in terms of networking capabilities of devices and system reliability. The generic approach enables the integration of a wide range of control devices following different concepts, but also limits the interaction with the control application to a simple parameterization.

Therefore the PABADIS’PROMISE architecture will carry this distribution trend beyond current boards by including distributed manufacturing sites with border crossing ERP interaction, stringent connection of order data and material, and an improved field control flexibility by on-the-fly and on demand order related control application design. The incorporation of new technologies such as RFIDs and agent systems tailored to the specific needs of field control systems will enable reasonable implementations of these new concepts.

3. PABADIS’PROMISE Architecture

To meet the described challenges the PABADIS’PROMISE project introduce a new control architecture and control design concept which will maximize product and process related flexibility, enable order related manufacturing, improve design and application efficiency, and consider cross-company value chains. These developments can be summarized in the vision “The Order is the Application”. The core points of these concept are:

- resource and order centered control application with on-the-fly order related control application design
- the flexible application of manufacturing resources and advanced resource and order management
- the integration of detailed manufacturing related management functionalities and structures within the ERP, enabling a detailed order and resource management at field control level

![Figure 1 From current automation to PABADIS’PROMISE](image)
• most advanced devices with integrated manufacturing resource control functionalities, standard interfaces for embedded agent technology, function block oriented high level programming, and automatic networking
• the incorporation of Real-Time and embedding aspects into agent technology by improvement of deterministic behavior, predictable interaction, and footprint reduction
• an ontology based most general description and comparison technology overlapping industrial areas and dedicated to manufacturing information and control application management
• the integration of new technologies such as enhanced RFIDs with high data transport capacity and integrated functionalities with respect to data use and management

The basic architecture of a PABADIS’PROMISE system is shown in figure 2 and will consist of the entities described in the following.

3.1. ERP interface building blocks
ERP systems will cover the overall management of company wide work flows integrating information, costumer relations, labour, material, and resources enabling an efficient economical process of a company. The integration in a PABADIS’PROMISE system will lead to some new requirements for an ERP. These changes can be characterized on the one hand by the increasing flexibility of the MES-level resulting form the usage of distributed approaches and on the other side by the new possibilities of information exchange with the control level. As the control system provides the possibility for a direct interaction between ERP and Shop Floor to enable an order oriented shop floor control, the ERP-systems has to support and handle all relevant information in an appropriate level of detail. Both investigations will result in additional building blocks for ERP systems necessary to enable the efficient application of advance concepts and structures at shop floor control level. Since ERP systems have more functionalities than managing the production system with respect to an efficient order fulfillment the mentioned new distributed ERP system building blocks have to be integrated in the existing ERP system architectures. Thereby centralized as well as decentralized parts are expected depending on the overall requirements and company relevance of the different ERP system functionalities.

3.2. Multi agent system
The functionality of a distributed manufacturing system is mainly realized by a multi agent system. In PABADIS’PROMISE this system consists of order agents responsible for the processing of a dedicated product, stationary agents representing the resources of the production system toward the agent world and enabling the access to the control level and a communication and transportation infrastructure enabling the mobility of agents. An agent system for factory control has to meet the specific requirements of this application domain such as limited resources on target devices and Real-Time constrains. These features either can be realized on top of an existing agent system or by generating a new agent system. Compared to available agent technologies this new system will realize a new quality of agent systems for application in the industrial control area by enabling a direct execution on relevant devices, a possible integration in the control system by provision of Real-Time features and a close connection to products by using the RFID-technology for physical migration of agents. Therefore, the RFID system is necessary to enable the transport of all relevant data including agent source code and state data, order related management data, order related product and production process description data, and order related control code. In addition, the RFID system has to enable the automatic re-launch and execution of the agents.
transported on the RFID in an arbitrary control device directly after its arrival at a RFID reader.

3.3. Next generation control devices

On the other side of the system is the shop-floor level represented by control devices or generic interfaces to system resources. The main characteristic of the PABADIS’PROMISE architecture with respect to control applications is the usage of fine grained functions encapsulating the control code that will be finally combined in an automation application following the requirements of the issued order. The fine grained functions are as generic as possible with respect to the underlying control devices. A basic principle of PABADIS’PROMISE is the application of on the fly design of order related control applications based on predefined building blocks encapsulated in control agents. Therefore appropriate interaction mechanisms between these agents and the basic control functions of a device have to be specified. This includes all steps of execution of a control application such as selection of (fine grained) sub-functions, aggregation and configuration of the application. Furthermore aspects enabling the dynamic integration of control application components and the safe execution on the control system have to be taken into account. The basic functionality of devices on the field control level is represented by Stationary Software Agents, representing the physical possible production process by fine grained control building blocks which are permanently located on the resource control devices. They will behave as drivers for the physics of the specific resources. To enable the execution of product dependent control applications dynamically created in collaboration of mobile and stationary agents a generic interface of the stationary agent to the low level functions of the control device is needed. This interface has to support an event driven communication approach to enable (if necessary) a decoupling of agent and control application execution environment and should not depend on the application of specific protocols to enable the integration of a wide range of devices from powerful industrial PCs down to limited devices such as intelligent sensors or I/O-devices.

4. Integration of the Agent system

As one of the core ideas of the PABADIS’PROMISE concept the integration of control functions, agent systems and RFID-technology shall be described more in detail. First the specific needs resulting from the close connection of agents to products and resources on the field control level are summarized as several constraints have to be taken into account. The requirements to the agent system are characterized by:

- the possibility to run on limited devices (the typical field control devices are restricted regarding memory and file systems and for RFID-systems these restrictions are even more serious with respect to the resource consumptions of typical agent systems)
- platform independence to run on different devices within the very heterogeneous field level, provision of a Plug-and-Participate functionality (integrated in the agent system or by using an additional PnP-technology such as Jini or UPnP)
- support of an event-oriented interaction mechanism as prerequisite for handling the components of a fine grained control function,
- support of common industrial communication systems (this includes Ethernet based protocols as well as RFID typical communication),
- and support of Real-Time behaviour of control application parts.
Within PABADIS’PROMISE an agent system which fulfils these requirements will be developed and will be one cornerstone for the successful implementation of the concept. Compared to previous architectures the possibility of the physical migration of agents stored in RFID-tags is a new quality in PABADIS’PROMISE. This principle ensures a close connection of agent and product and increases the reliability of an order agent migration. Figure 3 shows the single steps for this migration and the entities involved.

Step1: Upload of order agent to the RFID-tag (including order related data and agent code)
Step2: Physical transport of the product with the attached RFID-tag
Step3: Detection of arrival at the next resource (by reading the RFID tag), download of agent code and order data, re-instantiation of order agent and execution of the next (processing) step

As exemplarily shown with respect to the agent technology PABADIS’PROMISE will improve the behaviour of flexible manufacturing systems also with respect to the other parts of the system such as ERP, MES functionality and control applications.

5. Summary

The ongoing research project PABADIS’PROMISE will develop a new architecture to overcome restrictions and limitations of currently existing approaches for distributed manufacturing systems. This will be reached by introducing new concepts and technologies such as:

- Architecture and methodology for on the fly design of manufacturing control systems based on plug-and-participate of resources and for on the fly design of order related control applications based on predefined resource related control building blocks on the resource side and order related building blocks on the product side; both encapsulated in embedded Real-Time agents.
- A minimum-size, embedded, and Real-Time agent system for factory control, providing access to order data during the whole production process and, thus, the maximum flexibility with regard to additional customer wishes/changes even during manufacturing.
- New generation of control devices enabling the definition, design and control of sets of fine grained basic control functions running on it to control the machinery as such, the communication paths, the security mechanisms and so on as resource related control building blocks – without any relation to the products produced and enabling the integration of this control function blocks on-the-fly in order related control applications during the runtime of the device and the underlying manufacturing resource.
- RFID tags for order and product data transmission - attached to the products, enabling the migration of embedded Real-Time agents.
- Building blocks for a new generation of Enterprise Resource Planning Systems dedicated to handle most flexible manufacturing systems with direct access to the filed control level will be developed.
- An ontology based product and process description language for the complete integrated data flow of the overall control system.

The intended results of PABADIS’PROMISE will enable a most flexible, adaptable, and efficient control of manufacturing systems covering the necessities of future manufacturing. The results can be used as a whole but also independent of each other to improve future European manufacturing systems.

The new control design architecture, the products related to this architecture and the new emerging manufacturing ontology will have different impacts.

The impact on manufacturing systems in general can be subsumed by improving production efficiency, improving the ability to integrate customer requirements until its ultimate deadline defined by the realization of production steps and by new emerging products and services. These new products and services will emerge in the fields of control devices, specialized design tools and its application, ERP system add-ons, RFID’s, and services based on the application of building block design strategies.

The complete range of companies within the manufacturing sector and all sectors related to the design, development, and implementation of manufacturing systems will be effected by the PABADIS’PROMISE project. At least one market leader of the effected markets is involved in the project as a participant. Smaller companies and SMEs will be enabled to apply the project results with respect to the mentioned economical effects. Here the integration, application, and finally market of specialized knowledge of SMEs will be improved.

The PABADIS’PROMISE project invites any company or research unit to participate in the Associated Reference Group of the project aiming in enabling an information exchange of the project with external experts.

References


