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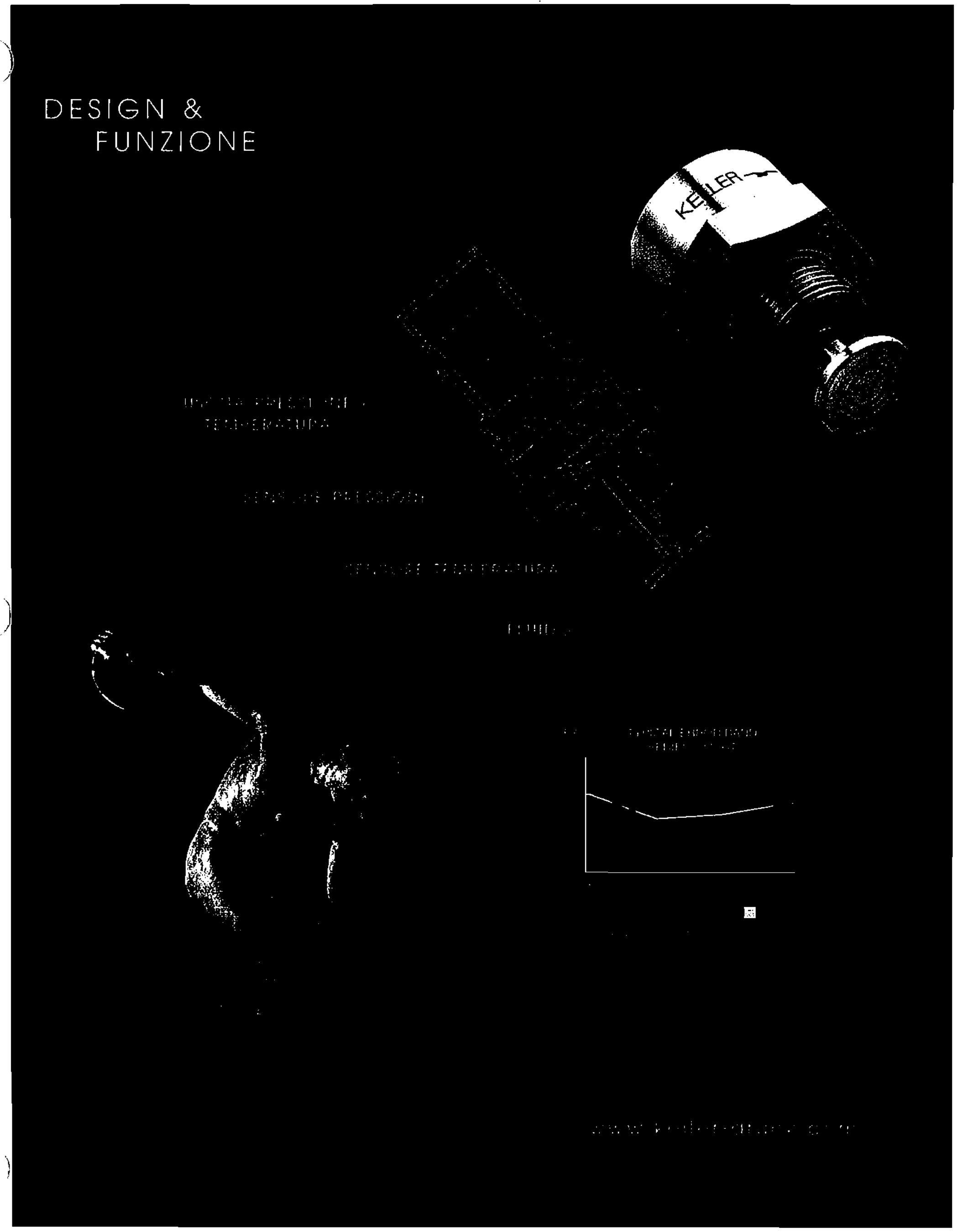

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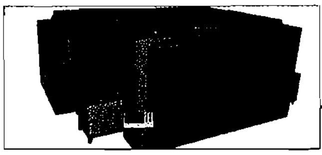

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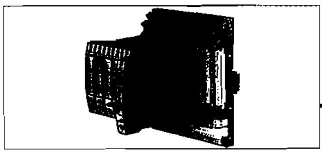

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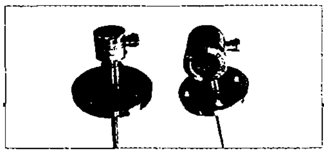

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Agents on RFID tags
A chance to increase flexibility in automation

Albert Treytl, Gerhard Pratl, Basit A. Khan

RFIDs (Radio Frequency Identification) are used for identification of products in manifold areas including industrial automation. Their ability to identify products tremendously supports keeping control over the products in a plant and to set the basis for decisions to optimize the production process. Agent systems, on the other hand, offer a possibility to handle production in a plant in a flexible way, allowing easy reconfiguration and control of the order almost until the final point of production. A combination of both technologies seems reasonable. This article investigates the possibilities of fine-grained order control by software agents hosted on RFIDs. Although this requires advanced types of RFIDs it allows greater flexibility in production. Especially for individual products and small-series production of complex products this technology can offer advantages.

With the trend in industrial production towards more personalized and individual products also the flexibility of production itself must be increased. Distributed Control Systems (DCS) already provide solutions that shift decision making from a central planning unit to distributed middle layers.

RFID (Radio Frequency Identification) is currently used to solve the often crucial issue of product and part identification inside a plant. This identification is the base for all further decisions.

Software agents (software entities autonomously achieving a set of goals or tasks) can be used to introduce flexibility on the shop floor level. Examples using agent-based solutions are Pabadis [1] or Methamorph [2]. Aside of increased flexibility on the shop floor by, e.g., better reaction to machine breakdowns or better usage of machinery, agent-based systems also allow for more flexible control from super-ordinate layers such as ERP (Enterprise Resource Planning). This flexibility can be comprised by the new paradigm "The Order is the Application".

If the RFID identifying the product and the agent managing the manufacturing of the product are (physically) bound together, advanced solutions for practical problems can be found.

RFID in distributed control systems

RFID covers a wide range of devices using wireless communication for identification, including low-cost solutions such as passive labelling tags as used to substitute barcodes as well as advanced embedded system which contain a user interface, cryptographic functions, and considerable computational power.

In practical usage the following classification criteria allow to select the RFID technology best suited for the actual application:

Frequency - the (carrier) frequency of the RFID mainly influences the maximum distance up to which the tag can be operated. Standardized bands are available at 125 kHz, 134 kHz, 8.2 MHz and 13.56 MHz (LF-HF systems), at 433 MHz, (VHF systems), and at 868 MHz, 915 MHz, 2.45 GHz, and 5.6 GHz (UHF systems). While RFIDs in the lower frequency bands reach communication distances only in the centimetre range up to a few meters, the RFID using higher frequency bands can cover distances up to 100 meters but require a direct line of sight between reader and RFID tag.

Energy supply can be divided into passive systems extracting the energy from the field set up by the reader and active systems, which have their own energy supply, mostly a battery or a gold cap. The main effect on the application will be that the computational power of a passive RFID is limited according to the limited energy available from the electro-magnetic field of the reader.

Information storage and processing - RFIDs implement manifold technologies like back-scatter systems storing a bit up to a few bytes, EEPROM and micro-processor based with some kbyte of data, or full microcontrollers including systems offering cryptographic functions and Mbytes of RAM and Flash memory.

For DCS (Distributed Control Systems), RFIDs offer the following advantages:

- In comparison to printed labels (e.g., barcodes) RFIDs offer non-static data that can be changed frequently. This is especially important during production and in cases where production data beyond an ID are stored [3]. Storage volumes

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of kbyte to Mbyte offer enough space for a wide range of automation tasks.
- Ubiquitous electronic reading: Data from (multiple) RFIDs can be read electronically at once without singling. Such solutions also include placement of RFIDs inside animals or tools (ISO 14223) or even in fully metallic carriers.
- Resistance to environmental conditions such as oil, acids, humidity, dirt, scratches, etc.

The table gives a comparison of the major properties of active and passive RFIDs. An important property of passive RFIDs is that they can only be operated in a master/slave way, meaning that the reader must initiate communication and therefore no event notification from the RFID is possible.

Function	Passive	Active
Size and weight	Small	Large
Cost	0.1€ to 1€	3€ to 80€
Life time	Virtually unlimited	3 to 7 years
Communication range	up to1 m (30 m ideal)	up to 30 m (some km ideal)
Reliability	Excellent	Good
Sensor control	No	Yes
Emission of continuous signal	No	Yes
Multi-tag reading	Limited	Excellent, even some thousand
Data record and storage	Low (kbit)	High (Mbit)
Low power signal	No	Yes
Signal security and process security	Limited	Excellent
Event indication	No	Yes

Table - Comparison active and passive RFID[1]

RFID-based software agents

RFID technology covers a wide spectrum of devices, starting at passive tags, which contain an identification number that can be read out up to full-fledged embedded systems containing a microprocessor, volatile and non-volatile memory.

The concepts, which are described here, list the possibilities how agent technology can be combined with RFID: software agents are entities, which autonomously fulfil a given task. They operate in a multi-agent system (MAS) and exchange information between each other.

The role of RFID in such a distributed control system goes beyond product identification and localization: by integration of agent technology and RFID the relation between a product, its location and the attached agent becomes very tight and is represented as one logical unit. The capabilities of different RFID tags allow for different possibilities in the implementation of agents in the system.

If the RFID tag only stores the ID of the agent and all product information, the agent code must be stored externally, that is, physically separated from the item in production. The advantage of such a tag is its cost effectiveness; it is typically used when the RFID is discarded after the production [3]. This type of RFID is not discussed here.

To achieve better integration between product and attached information, the RFID has to be able to store data directly on the tag, so that it travels together with the product. This is especially important when a product leaves a plant and gets transported to another facility. Storing data on an RFID tag requires the tag to be able to read and write data and to be equipped with non-volatile memory. This way the data and the product stay physically attached to each other, while any kind of processing needs to be done on a remote platform. Storing data on the tag also requires at least a memory controller that ensures consistent reading and writing of data into the non-volatile memory. Typical sizes of non-volatile memory of such tags (e.g., in engine production) are around 2 kbyte.

Storing not only the data related to the product, but also the code of the agent able to process the data on the RFID ensures that data and code are treated as one entity (Agent Code on Tag). The code is always an image of the agent that is assigned to the product, requiring that the code and the runtime status is serializable. The disadvantage is that, whenever necessary, the code for the agent must be loaded into an appropriate platform and executed there. After execution it is uploaded to the RFID tag again. Figure 1 describes such a scenario. On the one hand there is an extended need of data transfer - assuming that code size is considerably bigger than data size - and on the other hand the agent is inactive during transfer (step 2, 6, and 4). This is a drawback since the agent cannot communicate with other agents and pursue its goals. Usually such periods can be very long such as in a stock storage or on a conveyer belt. Hence also in Figure 1 an additional agent host is included to guarantee availability during transportation on the conveyer.

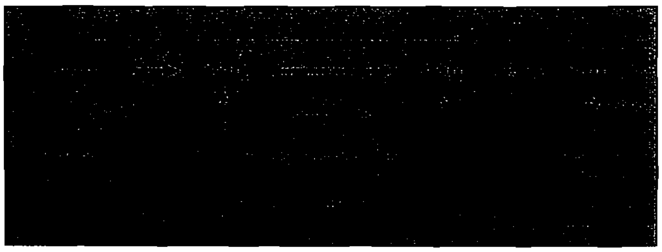

Figure 1 - Agent Code on Tag

The most advanced solution is an RFID tag that can execute code and communicate with other entities in the MAS. This requires an RFID tag that is equipped with a processor and a reasonable amount of memory (see section: *Requirement to RFID*). Only this solution really integrates the agent directly into the product and executes it directly on the RFID tag. The tag then stores the data relevant for a product and runs the agent code that is needed to integrate the product into the overall manufacturing process. Beside the increased computational power the communication coverage is now an impor-

[1]This analysis was part of the requirements analysis done within Pabadis Promise. The work was done by Identec Solutions AG

tant requirement. Especially passive RFIDs (powered by the reader) can hardly achieve the wide communication coverage and the high computational power in a cost effective way. Hence active RFIDs are a good choice since they offer high communication ranges. Because the costs for such a tag are considerably higher than for a passive RFID tag, the usage has to be adapted accordingly: after production the tag is reused and attached to the next product. The agent which operates on the RFID tag has permanent access to all data that are related to the product and can exchange information with other agents whenever necessary (e.g., for scheduling reservation of a resource).

Requirements to RFID

This section analyses the requirements agents imply on RFIDs. Since the size of agents varies in broad ranges according to the data they have to carry, we will concentrate on the minimum requirements implied by the FIPA specification [4, 5], which is the most common standard for industrial agent systems. Our ongoing work also includes activities to implement agents on contact-less smart cards and to analyse the possibilities to port the Jade Leap agent platform (Java Agent Development Environment Lightweight Extensible Agent Platform) [6] to RFIDs.
A basic requirement of the FIPA specification is the ability of an agent to communicate. Hence the agent must be able to interpret and create proper ACL (Agent Communication Language) messages [4] and have a proper transport layer for exchanging these messages in the agent society. Although FIPA defines many optional fields the minimum set of ACL is performative, sender and receiver consuming 50 bytes. Even in ISO14443 contactless smart cards - a kind of advanced RFID - that limit the message length to 254 bytes, a reasonable content length can be transmitted in an ACL message.
For actual message transport FIPA makes no recommendation but explicitly mentions the Internet Inter-Orb Protocol (IIOP), Hypertext Transfer Protocol (HTTP), and the Simple Mail Transfer Protocol (SMTP) as possible transport protocols. Our experience showed that HTTP is the preferred protocol since IIOP would require a noticeable overhead in implementation due to its complexity. SMTP, which was originally designed for email communication, also suffers from non-efficient handling of agent communication. Additionally, the trend in agent (platform) implementations is towards IIOP and HTTP. Technical reasons for the usage of HTTP are: simple structure, state-less operation, wide availability of HTTP servers on embedded systems. Advantageous for resource-limited RFIDs, FIPA only demands a subset of the HTTP/1.1 to be implemented for agent-communication. Namely, the POST request, URI resource identification, and simple Mime support are required.
With these prerequisites it is possible to implement an agent on a RFID. Additionally, a FIPA compliant Agent-Directory-Service has to be implemented externally to publish information about the agent and its services. Nevertheless, such a simple implementation lacks the possibility of code mobility and life cycle management, which a complete agent platform offers. For usage in flexible distributed control systems these features nonetheless would be of advantage to initialize and hence reuse RFIDs and to easily transfer changed order data to the RFIDs.
Within the Pabadis Promise project (see section: *Application within Pabadis Promise architecture*) the authors are working on using the Jade Leap platform on UHF RFIDs. Since Jade Leap is also available for Java 2 Micro Edition (J2ME) the RFID needs to offer 220 kbyte of non-volatile and 72 kbyte of volatile memory and at least a 25 MHz 16 bit processor for the J2ME environment. Jade Leap then additionally requires 450 kbyte of non-volatile memory and - depending on the kind of the agent execution environment (Jade container) - 100 to 700 kbyte of memory. The size of agent code running on a device varies, however the normal size of agent is between 10 and some kbyte. These requirements demand for an active RFID.

Application within Pabadis Promise architecture

The Pabadis Promise architecture [7] is offering a complete distributed control system architecture comprising all three levels from ERP, Manufacturing Execution Systems (MES), and the field level. The core of the architecture is a multi-agent system (MAS, see figure 2) that distributes the tactical planning of the production process throughout the MES level. On the top side the ERP system initiate generation of product agents (PA) within the Agent Manager. The MAS then autonomously process the single orders given by the cus-

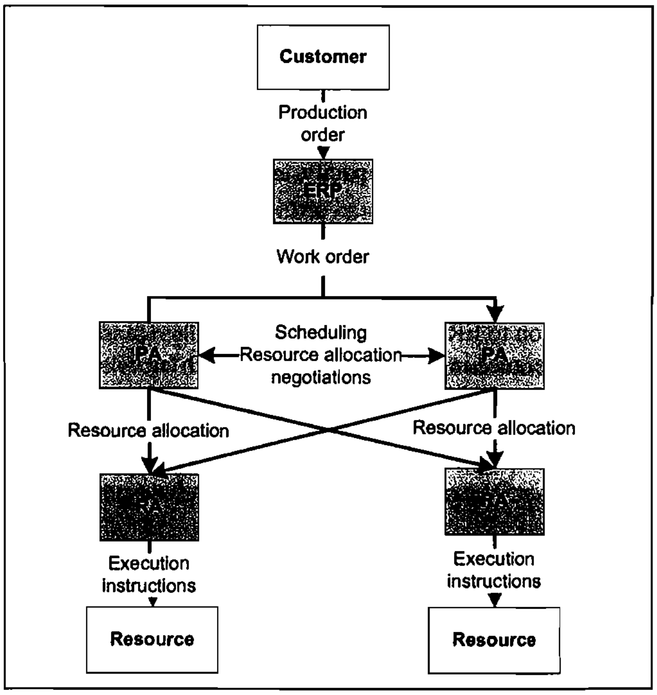

Figure 2 - Pabadis Promise System Architecture (grey areas indicated the Multi Agent System)

tomer. On the bottom side the production capabilities of the field level are represented by permanent stationary agents called resource agents (RA). PAs search for RAs (Resource Agents representing machines) that offer the capabilities needed for the production steps that are listed in the manufacturing order. Negotiations take place between PA and RAs as well as other PAs to acquire the needed resources to start actual production.

Within Pabadis Promise the agent execution on the tag approach (see section: *RFID-Based software agents*) is pursued to match different application requirements. For high-value, highly individualized products hosting agents or migrating the agent code on RFID offers the following advantages:

- For real-time applications the well-defined environment and the close relation between product, agent, and machines will avoid the necessity for real-time network protocols since control commands relevant for the processing task are no longer sent via the network.
- Robustness due to resource distribution; single points of failure are avoided. Additionally, the computational load is distributed (no central resource intensive agent hosts is required) and the network is relieved since communication is mainly done locally.
- Physical synchronization of production flow and information flow. This is of special interest if human workers are included in the production process.
- Migration of agents between different IT systems: direct transport on RFID avoids problems with interoperability and security barriers such as firewalls or transit over public networks.
- The local control can perform a basic plausibility check of the agent before it is executed.

Nevertheless, this approach also requires additional technological effort:

- Additional security has to be provided for hosts as well as for mobile agents
- The implementation is technologically more complex. In particular, active, high-capacity, and fast RFIDs are a significant cost factor
- In case of a RFID-based migration the agent is "offline" during the migration phase. This leads to an availability problem for cooperation of agents in the MAS and the communication to ERP
- Fault tolerance in case of a loss of a RFID-tag

Since the above advantages will only pay off in certain application areas, Pabadis Promise also introduces a "virtual agent" model where RFIDs only contain the ID of the agent and the actual execution of the agents is done on a central agent host.

Application areas where the combined RFID-agent scenario is feasible are identified to be: Semi-conductor industry, car manufacturing, furniture production, airplane assembly and production or stock management. The first two areas already employ active RFIDs with user interface and local computational power, although they do not include the flexibility of agent technology so far.

Conclusion and outlook

Migration and execution of agents on RFID give a valuable amendment to distributed control systems. The approach to physically connect product and agent not only introduce simplicity to the system concept by easing reconfiguration and maintenance of the production process. It also helps to solve real-time issues, and to circumvent barriers when migrating between different systems like in the case of products being assembled in different plants (e.g., car manufacturing).

Nonetheless, the research done so far also indicated that the "agent on RFID" approach is not applicable to all application scenarios. Especially for low-value products and mass production it is not feasible and also linking to standard ERP systems at the moment favours the approach of having pure product identification.

Future work will especially concentrate on the profitable integration of software agents and in particular Jade and FIPA compliant agents on active RFIDs. The goals are to reduce resource consumption and to seamlessly integrate real-time systems.

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