AN AMBIENT INTELLIGENCE INFORMATION INFRASTRUCTURE FOR PRODUCTION-TO-MAINTENANCE PROCESSES

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Abstract: Specific informational problems are predominant in Process-to-Maintenance (P2M) processes of machine and plant construction industries. An integrated information infrastructure is required to reduce these deficits. Ambient technologies such as active IT-elements and software agents offer the opportunity to design and realize a flexible information infrastructure that is used to coordinate all process phases. Potential benefits of the architecture are discussed in detail and further research to develop an Ambient Intelligence Information Infrastructure (AIII) for P2M-processes is justified.

Keywords: Agents, autonomous control, communication systems, distributed artificial intelligence, process automation, business process management.

1. INTRODUCTION

Primary value-adding processes in production and deployment of machines and plant construction exhibit informational problems that reduce effectiveness and efficiency of these processes. A detailed analysis clarifies deficits to promote a solution to the problems (section 2). In this paper the applicability of Ambient Technologies to this specific area of automation in process control is analyzed. Technologies both on the hardware side such as active IT-elements and on the software side (e.g. software agents) are considered for solving the problems (section 3). Practical application constraints are considered in the development of a general architecture of an information infrastructure which is based on Ambient Technologies (section 4). It enables flexible and distributed control in all process phases. The consequences of such an architecture for the domain specific processes are discussed to allow assessing potential benefits of developing an *Ambient Intelligence Information Infrastructure AIII* (section 5). Concluding, related future research topics are defined in section 6.

2. APPLICATION DOMAIN

Mechanical engineering of large machines and plant construction defines the relevant application domain for this paper. A specific set of processes in this domain is considered since similar deficits identified within these processes call for development of an information infrastructure based on Ambient Technologies.

2.1 Production-to-Maintenance Process

Four process types are differentiated that reflect main value-adding activities in the domain: (1) production of machines or plant modules, (2) transportation of these products to a final destination, (3) installation of machines and plants and (4) maintenance activities during machine or plant utilization. This sequence of sub-processes is termed the *Production-to-Maintenance (P2M)* process.

2.2 Current Deficits

Deficits exist in the supply of information needed for operational fulfilment of each of the P2M-subprocesses identified above.

Typical information problems in production result from centralization of data on products and processes that are stored physically disjoint from parts and products produced. Examples are product data, data on already conducted production activities and scheduled future activities. Since this information is regularly not available at the location of a physical good but only in centralized data bases, handbooks or separate documents, a flexible reaction to disruptive events which depends on such information is in most cases impossible. Any reaction is further complicated by inflexible batch-oriented planning and scheduling applications typical for production domains. Consequently, reduced production quality, prolonged cycle times, reduced productivity and increased costs characterize current production situations in P2M-processes.

Transportation of machines and parts depends on a varying number of specialized carriers. Information regarding destination, route and means of transport is provided in carrier specific formats. Most of this data is stored in servers managed by carriers. Simple barcodes tagged to the goods refer to this information. Coordination of transportation processes relies on centralized planning and routing systems which prohibit flexible process coordination in the face of operational problems, deviations from plans and unanticipated environmental conditions. Decision supporting information is not available at the location where local actors have to react to unforeseen transportation situations.

Installation of machines and plants is an important part of the P2M-process that consists of many different activities. Often detailed instructions are required that are provided by separate means (e.g. installation plans, handbooks, project management tools). Distribution of this information is an obstacle to a continuous installation process that is able to incorporate situations such as missing material or personnel and late deliveries of a plant's parts. An integrated information infrastructure that can provide an immediate overview on the status of installation and related instructions is missing. Increased cost for personnel due to inflexible project management and prolonged installation cycle times are main consequences.

During utilization of a machine or a plant the operating company relies on preventive maintenance to ensure high availability of its resources. Maintenance on the machine-level is often realized on a simple time-based schedule regardless of actual wear. Information on parts built into a machine and historical replacement dates of wearing parts is not located in the physical proximity of a machine but is again distributed to many sources such as written reports or maintenance planning systems. Important data both for scheduling maintenance based on actual usage and for streamlining maintenance activities through enhanced background information on a machine is not available from one integrated information infrastructure.

Summarizing, a flexible information infrastructure that provides both up-to-date information on important aspects of a machine or parts of a plant is not available within P2M-processes. Consequently, neither flexible rescheduling on a local level of each process step nor data integration spanning all P2M-subrocesses is existing. The use of Ambient Intelligence technologies such as active IT-elements and software agents promises to develop an integrated information infrastructure that can minimize the deficits in the P2M-process identified above.

3. AMBIENT INTELLIGENCE TECHNOLOGIES

An overview on ambient technology hardware and software relevant to the P2M-Process is presented in fig. 1. Where possible, a separate assessment is provided for each P2M-subprocess.

	Production	Transportation	Installation	Maintenance
Active / passive IT-elements	• Communication technologies: GPRS, GSM, WLAN, WMAN, WiMAX, Bluetooth, Zigbee • Active and passive RFID technologies • Embedded systems			
	• Active & passive IT-elements e.g. in automotive industry → data collection and process control	• Identification of containers and goods with RFID (→ EPC Global) • Tracking and tracing with RFID • Package routing with RFID data	• Identification of parts with RFID • Link to multi-media data on installation instructions	• Collection of sensor data to control wear of critical parts • Embedded systems with IP-connection
	Important market players: • Passive IT-elements: IBM, Siemens, Texas Instruments • Active IT-elements : EMS, Identec Solutions			
	Market forecast: • European Union in 2008: 2.5 billion Euro sales volume (Soreon) • World-wide in 2010: 11.6 billion Dollar sales volume (Frost&Sullivan)			
Software agents	• Agent systems for inter-organizational proactive event management (SCEM)			
	• Planning and scheduling in production (often negotiation-based) • Process planning • Productivity control	• Routing • Vehicle scheduling • Order tracking	• *No applications identified*	• Sensor control • Sensor networks based on mobile agents
	Important market players: • Agent-based process management: Acklin, Whitestein • Integration agents and RFID: Vizional			
	Market forecast: • World-wide in 2010: 250 billion Dollar sales volume (Gartner Group)			

Fig. 1. Relevant Ambient Intelligence technologies

3.1 Active IT-elements

Active IT-elements as required for an information infrastructure for the P2M-process consist of: (1) one or more sensors and effectors (active transmitter), (2) data management and storage capacities, (3) computing logic and (4) internal energy supply. Relevant communication technologies are e.g. GPRS, GSM, WLAN, Wireless Metropolitan Area Networks

(WMAN) and short-distance technologies such as Bluetooth and Zigbee components.

For data storage, management and computing logic, reuse of existing embedded systems within machines is a viable alternative besides using smart active labels (Furness 2004) or similar concepts based on radio frequency identification (RFID) technology. Development of active IT-elements is promoted by the Smart Active Labels Consortium (SAL-C 2004). In addition to active IT-elements, simple passive IT-elements are of use in an integrated information infrastructure. Passive RFID technology is predominant regarding realization of passive IT-elements. For a technology overview on passive RFID technologies we refer to (IDTechex 2004) and (Finkenzeller 2002).

Current research is focused on development of basic Ambient Intelligence infrastructures that provide security mechanisms, context awareness and mobile communication channels (Ambient Networks 2004). Main industrial players are IBM, Siemens and Texas Instruments prevalent in passive RFID technologies and specialized vendors such as Escort Memory Systems (EMS 2004) that provide active IT-elements for the automotive industry. Market outlook is very optimistic for active and passive IT-elements forecasting a global market size of nearly 12bn $ in 2010 (Frost&Sullivan 2003).

3.2 Software Agents

Agent software is at the brink of providing full-fledged industrial applications which is underlined by large prototypes for production scheduling in an automotive plant (Bussmann et al. 2000) and solutions for automated markets where agents trade on behalf of users (e.g. Whitestein 2004). An overview on the current state-of-the-art in agent technology and future developments is provided in a roadmap of the AgentLink consortium (Luck et al. 2003).

Relevant to the field of supply chain management, in which the P2M-process and its optimization are a subfield, numerous concepts and prototypical realizations of systems have been proposed. An important area covers scheduling problems in production and transportation domains that are often solved based on negotiation mechanisms (e.g. Wagner et al. 2002). Specialized on machine control are concepts of Holonic Manufacturing Systems (HMS) that have been extensively studied in many research projects (e.g. Van Brussel et al. 1998). Such concepts can offer important input to the development of an information infrastructure for the P2M process since they support flexible coordination of processes in a distributed environment (compare section 2.2).

An important aspect for the execution of operational processes is the ability to monitor activities and alert actors in case of unexpected deviations from plans. Supply Chain Event Management (SCEM) systems can solve these tasks. An innovative concept has been developed based on agent technology (Bodendorf et al. 2004).

A current focus in agent-related research is on adjustment of agent autonomy to increase acceptance of agent systems (Hexmoore et al. 2003, Chalupsky et al. 2001). Practical relevance is attributed to security and robustness aspects of agent systems that are influenced by data base management mechanisms such as transaction security (Nimis et al 2004) and cryptographic techniques (e.g. Hannotin et al. 2001). In physically distributed and mobile environments, as are common in P2M-processes, aspects of agent mobility and related security aspects are important constraints for a practical solution (Bryce 2000).
Market forecasts for agent technology are extremely positive for the mid-term future: sales-volume is predicted to reach approximately 250bn $ in 2010 (SAP 2004).

3.3 Limitations

Basic technology both for hardware infrastructure (active IT-elements) and software solutions (agent technology) are available but an integrated approach designed to meet the requirements and solve the information problems in the P2M-processes is not available. For isolated sub-processes such as the maintenance management of machines innovative solutions such as ePS-Network-Services® (Siemens 2004) are available. However, a flexible active information infrastructure based on Ambient Technologies that can cope with the different aspects of the P2M-process is not available.

4. AN AMBIENT INTELLIGENCE INFORMATION INFRASTRUCTURE (AIII)

The basic approach for providing proactive process support based on an *Ambient Intelligence Information Infrastructure (AIII)* is as follows: on the hardware side, the concept relies on a number of passive and active IT-elements. The active IT-elements serve as a basis for an agent-based software layer which provides an active communication interface to operational processes and corresponding process control systems (see fig 2).

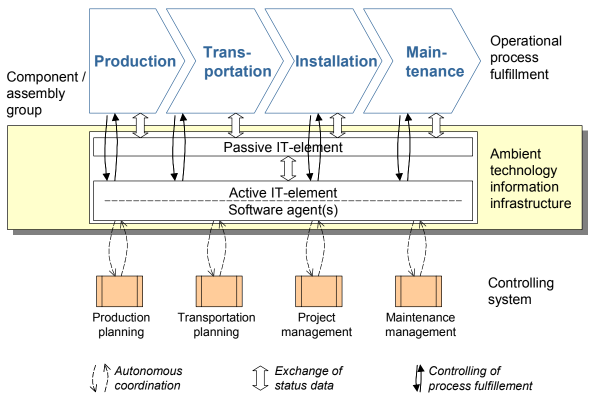

Fig. 2. Architecture overview

4.1 Technical Infrastructure

Passive IT-elements Simple, small, and inexpensive components or subgroups of machines and plants are equipped with passive IT-elements. These IT-elements are able to store basic component-related data such as part-identification, install date or super-ordinated group. This information can be read and possibly be modified by actors in operational processes and by active IT-elements (see below). This function can be realized with a basic communication infrastructure. However, passive IT-elements do not exhibit individual behaviour.

Passive RFID tags provide a suitable technology to achieve this functionality, as they are cheap and do not rely on external nor internal power supply. Using passive tags, it is possible to implement tasks such as identification and presence detection. More elaborate passive tags provide additional sensors to enable measurement of e.g. pressure or temperature (Finkenzeller 2002, p. 313). Low cost and ease of integration of miniature transponders into existing IT-infrastructures allow equipping almost any component of an industrial site with an electronic tag (see fig. 3).

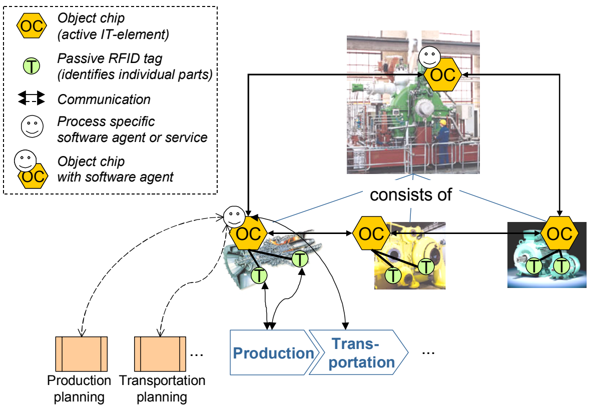

Fig. 3. Integration of passive and active elements

Active IT-elements Complex, expensive modules and components that consist of multiple subgroups, are equipped with an active IT-element which in the following is referred to as an *Object Chip (OC)* (see also fig. 3). It provides the following characteristics:

- Multiple sensors with data management and storage capacities
- Data processing capabilities (e.g. running applications)
- Autonomous power supply
- Multiple effectors (e.g., active transmitters via Bluetooth, GPRS or GSM)

It is assumed that *Object Chips* are often used to extend existing IT-infrastructures which were originally designed for performing control tasks during operation of a machine or a plant (e.g. embedded systems). This way, existing infrastructure can be enhanced to satisfy the above-listed characteristics. Requirements on an *Object Chip* will soon be covered by higher-range active RFID tags and the emerging Zigbee standard is likely to be a candidate for providing a low-energy ad-hoc communication infrastructure.

4.2 Integrated Software Agents

Object Chips (OC) provide the basis for a software agent runtime platform (see fig. 2). Based on wireless communication facilities of an *OC*, mechanisms are integrated that enable spontaneous establishment of local communication networks. Beyond communication with control systems and actors in operational processes, this also provides the technological basis for a spontaneous interconnection of components and assembly groups of machines (see fig. 3). This further extends the functionality of the *Ambient Intelligence Information Infrastructure (AIII)*: located directly in a component or subsystem of a machine, software agents can realize proactive monitoring, control and coordination of individual sub-processes within the overall P2M-process.

A software agent in the context of the *AIII* is considered to be a set of services, business rules, context knowledge and communication abilities integrated in an autonomous execution mechanism. Services are provided to external actors or systems (e.g. reception/retrieval of status data for a component). Business rules code behaviour and plans which an agent needs to fulfil its goals. Goals, knowledge about capabilities as well as environmental models and related facts are part of the agent's context knowledge. Communication abilities use the sensors and effectors provided by an active IT-element to establish communication with other IT-elements and their agents, external IT-systems or human actors.

The fact that agents are physically residing on an *OC* which may reside on a component that changes its location during P2M-processes' execution, provides an indirect form of physical mobility to the agent. In addition, agent mobility is provided by several existing agent platforms which allow agents to migrate across different runtime platforms.

It is proposed to use the communication infrastructure provided by *OCs* to migrate process-specific agents to and across *OCs* during different phases of the P2M-process. This phase-related transition and change between different types of agents allows a flexible and efficient utilisation of the scarce computational resources available on an *OC*. However, since an agent is composed of services, business rules and context knowledge a phase specific exchange of parts of an agent is introduced to redefine the duties and abilities of an agent without replacing its code completely. In consequence, a "partial" migration of an agent through reconfiguration is achieved which improves flexibility of the information infrastructure *AIII* and reduces data communication compared to migration of whole agents.

A key issue to be considered in setting up this infrastructure is security and robustness of data management, communication and software migration. This is of specific importance in an autonomous process coordination scenario to secure the P2M-process from technical failure or intentional manipulation of the information infrastructure *AIII*.

5. APPLICABILITY OF AIII FOR P2M-PROCESSES

The above-described information infrastructure *AIII* is used in the individual P2M-sub-processes as follows: During production of a component, a process-specific production assistant agent resides on the component's *Object Chip*. The agent locally monitors and controls the manufacturing process and is able to provide context-specific information to other actors.

Upon change to the next sub-process (transportation), the specific knowledge and capabilities of the production assistant agent are no longer required. The corresponding agent code is exchanged with logistics-specific code. The reconfigured agent is able to monitor and coordinate transportation processes. Business rules employed by this agent can e.g. be configured dynamically for a specific logistics service provider. A similar exchange of business rules also occurs in the following P2M-sub-processes of installation and maintenance.

Thus, at each point in time only one process-specific agent resides on an *Object Chip*. Information that is relevant during multiple process steps is passed on from one phase to the next using the information infrastructure *AIII*. A semantically correct transformation of data from a previous phase and of basic data required for all process phases is required. This ensures that each reconfigured agent can work autonomously with the information obtained from preceding process phases.

5.1 Production

The information infrastructure illustrated in fig. 2 provides the following advantages during production: the agent on the *OC* aggregates information regarding all sub-systems in its scope which are equipped with multiple *OCs* and/or passive IT-elements. Thus, the current status of production of a component is assessed and managed directly related to the physical product. All data is available at the product's location at any point in time. The agent monitors completeness and correctness of the production process by comparing its local stored state with a plan description. The agent's local description is incrementally extended on the *OC* by additional status information such as e.g. location, date and responsibility for performed activities. For parts equipped with writable passive tags, corresponding status information can be stored on these. Thus, it is possible to provide e.g. information for a future phase such as information on installation details for a machine due to specific parts installed during production. Another example is provision of delivery address and planned delivery date on individual passive IT-elements whose information can be reused during transportation. This enables applications and actors to access and use this information even if no server connection is possible during transportation.

5.2 Transportation

Throughout delivery, the agent uses the sensory capabilities of the *Object Chip,* e.g. to recognize transportation damage. In addition, due to information stored in the production phase, no part can disappear or fall off unnoticed. Passive tags equipped with a strain sensor can recognize e.g. bending due to improper handling during loading or transport. Delivery information stored in passive IT-elements and in the *OCs* are used for optimal routing as well as early recognition of shipment errors and delays. In this case, the software agent residing on the *OC* can contact a transportation planning system and request a change in the delivery plan.

5.3 Installation

The main added value of the information infrastructure *AIII* in this phase is improved support for human actors, such as mechanics. Detail information, e.g. the size of assembly fittings or required hinge moment, can be accessed locally during assembly from the *AIII*. This enables development of applications that greatly ease the assembly process and decrease error rates. In addition, the process-specific agent connects to a project management system (or: is accessed by it). Information available on the *OC* is used to improve assembly coordination (e.g. dynamic assignment of mechanics or coordination of delivery and assembly schedules). In case a machine is disassembled for transportation, the *OC* can check completeness of sub-components after delivery. This is realized by checking available information on passive tags within reach of the *OC*. It allows the process-specific agent to plan a partial assembly, e.g. if some components have not yet arrived due to delays during transportation.

5.4 Maintenance

Within this phase, monitoring of individual components is improved by aggregating information from previous phases as well as history of maintenance activities. Thus, the age and expected lifetime of a component can be calculated more precisely. History information is also used to identify / classify components or assembly groups as wearing parts. This enables a specific, more efficient use of maintenance capabilities even in the absence of specific sensory systems.

Finally, availability of an *Ambient Intelligence Information Infrastructure (AIII)* provides new business models for automation and plant construction vendors: infrastructure, components and information contained in the infrastructure can be sold or leased to customers for individual usage. Hence, customers can use the infrastructure to place custom software agents on the *Object Chips* of a new system and thus embed the system into a flexible production system controlled via distributed coordination.

5. CONCLUSION AND OUTLOOK

In this paper a solution to a set of similar deficits identified in all P2M-sub-processes is proposed. It is based on the use of various types of Ambient Technologies that are combined in a flexible information infrastructure. Its main components are passive and active IT-elements that provide a hardware environment for software agents. Within the various sub-processes (production, transportation, installation and maintenance) phase-specific agents enable flexible monitoring and coordination of the processes. Proximity of the IT-elements to the physical products and components offer new ways of interacting with actors in all process phases and provide opportunity for fast and flexible reactions to unanticipated problems during execution of the P2M-process. Concluding, analysis of potential benefits in each of the sub-processes justifies further research directed at developing the *Ambient Intelligence Information Infrastructure AIII*. Important future tasks within the roadmap are:

- Definition of required functions and associated roles in all sub-processes to design the scope of agents' capabilities.
- Analysis of required data and design of ontologies and transformation mechanisms for the various sub-processes.
- Identification of current technical constraints regarding the combination of IT-elements, software agents and their integration with products (machines, plants) relevant to P2M-processes.
- Design and implementation of prototypes that realize basic functions of the *AIII*.
- Evaluation of results acquired from prototypes and comparison to empirical data gathered from real-life P2M-processes to assess the true potential of the *AIII*.

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