Smart Factory – Mobile Computing in Production Environments

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ABSTRACT

Companies want to provide their customers with highly individualized products so as to gain sustainable advantages over their competitors. The high degree of individualization has also deep effects on the production: it demands a vast amount of highly specialized tools for certain steps in the production process and a frequent changing of machinery settings and tools. As a result, the management of production resources and their coordination become quite dynamic and complex, so that existing resource management systems are too static to handle them.

This paper shows how the use of pervasive and mobile computing can help companies to address the resulting problems. It derives the requirements and identifies resulting research challenges, especially pertaining to the mobility and dynamic state of the tools. Finally, the Nexus platform is presented and it is shown how some of the identified challenges are addressed.

Categories and Subject Descriptors

C.2.4 [**Distributed Systems**]: Client/Server, Distributed Applications, Distributed Databases, H.2.4 [**Systems**]: Distributed Databases, Query Processing, Relational Databases, H.3.3 [**Information Search and Retrieval**]: Query Formulation, Selection Process, J.1 [**Administrative Data Processing**]: Manufacturing

General Terms

Management, Economics, Human Factors

Keywords

Smart Factory, Production Environment, Mobile Computing, Context-aware Applications

1. INTRODUCTION: THE CURRENT SITUATION IN PRODUCTION ENVIRONMENTS

While the manufacturing processes of *consumer goods* like in the automotive and electronic engineering industries are dominated by standardized products and defined components, the character of *capital goods* manufacturing such as in machine tools and manufacturing systems industries is stamped by a high percentage of custom-made solutions, by high numbers of product varieties with simultaneously low batch sizes. This high degree of individualization, which is very typical for capital goods, often affords a vast amount of highly specialized tools for certain steps in the production process and a frequent changing of the machinery settings and tools. This puts stress on present reactive planning systems, making the process intransparent and difficult to control. Our studies show that the development of the ratio of mobile resources to machines almost doubled over the last 20 years. Therefore a more transparent, optimized production resource management system is needed that can handle the highly dynamic information and thus enables a better synchronization of the resource use. Active planning based on current and exact information is a central element of success for factories with high demands in productivity and flexibility.

Reports of company representatives often criticize an unsatisfying supply of mobile manufacturing resources: Equipment or material is missing when the manufacturing should start, the wrong resources have been fetched or resource deliveries are unpunctual which leads to production delays. Often tools are still ordered from the stock even though the production has already been cancelled. Furthermore, amount, location and state of tools in use, e.g. mechanical wear of a cutter, are often unknown. Tool inventories are not exactly known by number and kind: tool reservoirs are either scaled too large encouraged by flexible production programs and changing responsibilities throughout the tool life cycle (cost inefficient) or too small (production delays).

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2. A SCENARIO FOR THE PRODUCTION OF PRINTING MACHINES

As a realistic scenario imagine a medium sized production company for printing machines and supplies. The company holds 400 machines (milling, drilling, etc.) and about 200,000 mobile resources (tools, fixtures, measurement equipment etc.). While 92% of the tools are in store, approximately 8% are going through the different phases of their life cycle at any time. Information about the production are still brought to the worker using field bus systems or paper sheets and work plans that are attached to the material showing the needed work steps. Most problems concern the management of highly mobile manufacturing resources such as tools, e.g. cutters that enter the system, constantly change their state and at a certain point leave the company. These tools are subjected to *closed, complex life cycles* consisting of storage, measurement and presetting, transport to the point of use and partial consumption, reprocessing, repair and transport back to storage or recycling. These cycles must be exactly timed and coordinated with the ongoing production process so as to avoid stops due to missing, wrong or worn tools. Late innovations in production engineering like high performance cutting lead to an even stronger speeding up of the tool cycles: since modern processing centers constitute high investments, an economical use of the machines calls for a high load and throughput and thus for high cutting speeds. A faster wear of the tools and therefore an earlier need for corrective maintenance e.g. reprocessing of the cutters, are deliberately accepted

During the life cycle the dynamic state of tools has to be captured and communicated to the parties involved: the production planning system for direct resource planning in production; the stock & tool management system for positioning of tools and state analysis; the quality control for quality assurance of the process; supply chain management for material flow analysis and effects on the supply chain; production controlling for information on the effectiveness of the company and optimization potential. As shown, different objects of the production system are interested in the information using different views of the information. This is even more challenging taking into account that the tools run through different zones of responsibility. The goal is to optimize the production towards time (faster supply of needed resources, shorter planning time), quality (higher production quality by continuous surveillance of tool state and work results) and costs (lower tool stock size and lower fixed capital using efficient information flow).

3. REQUIREMENTS AND CHALLENGES

In order to reach the goals described in the scenario, dynamic information has to be provided to the smart resource management system. In the following we discuss the requirements that have to be fulfilled and identify the challenges that have to be met on the way.

Gathering Dynamic Information

Depending on the kind of tool, it has to be equipped with sensors and/or identification tags. Smaller and simpler tools may only have identification tags, so that their current location can be determined by the storage, the transport cart or the machine that is using it. Larger and more complex tools, as well as machines and transport equipment can be equipped with sensors, and possibly a limited amount of processing power, storage and communication facilities, so that they can provide information about their current state.

Challenge 1: Suitable identification tags, sensors, sensor readers and communication facilities have to be found with a small form factor and limited power consumption that work in a factory environment (e.g. RFIDs that work in an environment with a lot of metal and interfering electromagnetic fields of other production machines, high resistance against chemical, mechanical and thermal influences).

To determine the position of the tools a positioning system is needed that provides accurate position information.

Challenge 2: A positioning system is needed that provides accuracies in the range of 15cm that can be employed on a large scale and that works in a factory environment (e.g. accurate systems based on ultrasound have a problem with interfering noise in the factory).

Updating Smart Resource Management Systems

The current state and the location of the tools have to be communicated to the smart resource management system. For the tools that are currently in use, the information should be updated every 10 to 30 seconds to always have accurate information about the current situation in the factory. As there are 200,000 tools of which 8% are in use, an update rate of at least 2000 updates per seconds for both the location and the state of the tool has to be supported. The information about the tools in stock only needs to be updated every 3 minutes, so this leads to an update rate of 1000 updates per second.

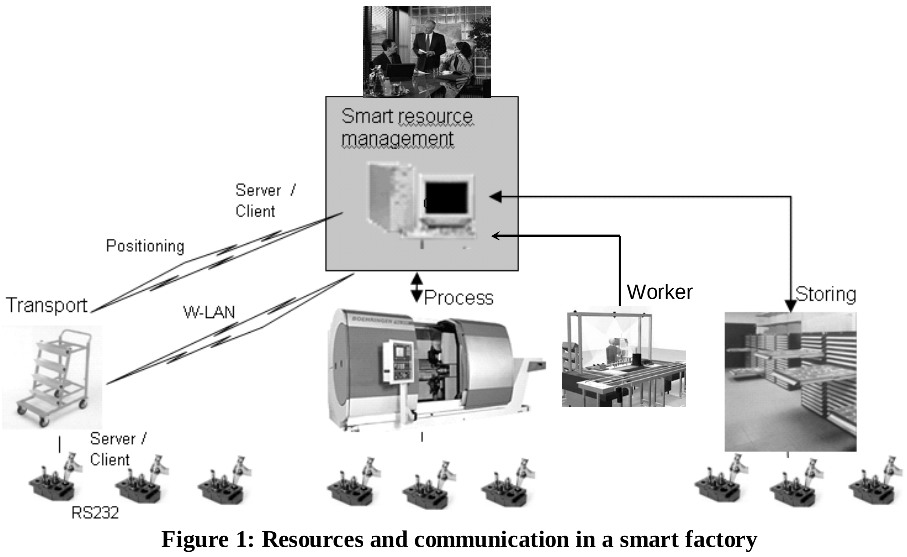

Figure 1: Resources and communication in a smart factory

Challenge 3: The resource management system has to handle high update rates with about 3000 location updates and the same number of state updates per second.

Supporting Different Types of Queries

The smart resource management system has to efficiently support different kinds of queries. We can differentiate between object-based queries and location-based/spatial queries.

Challenge 4: The resource management system has to provide efficient support for spatial queries, which is especially challenging with respect to highly dynamic mobile objects. For an efficient support of such queries a spatial index is necessary and this index is constantly changing as the objects are moving.

Integration of Different Information

In order to answer queries different kinds of data has to be integrated, e.g. potentially large static information about a certain tool together with its current dynamic state. The static information may already be available in the current production planning systems.

Challenge 5: The smart resource management system has to be integrated with current production planning systems (PPS) and enterprise resource planning systems (ERP) such as SAP R3.

Queries over and Handovers between Different Organizational Units

The tools are handled by different organizational units, e.g. storage, transportation, production and recycling. These organizational units may have separate information systems.

Challenge 6: It must be possible to make queries over information from different organizational units and to allow seamless handovers of the data between different organizational units when tools cross organizational boundaries.

If we broaden the picture and look at multiple factories or a whole supply-chain, this challenge becomes even more important.

Whereas Challenge 1 and Challenge 2 are mainly engineering challenges, Challenge 3 to Challenge 6 fall into the area of mobile computing and networking. In the following section we will present the Nexus platform and how it addresses some of these challenges.

4. NEXUS: ON THE WAY TOWARDS A SOLUTION

The Nexus project at the University of Stuttgart is funded by the German Research Foundation (DFG) as a center of excellence with more than 30 researchers. The goal is to develop a platform to support mobile, context-aware applications based on spatial world models. One application area that is investigated in this context is the “smart factory”.

The Nexus platform aims at world-wide scalability. It is unrealistic that there will be one homogenous model of the real world. Instead there will be multiple different (partial) models at different levels of detail and each of these models is stored on a context server. However, the application should not have to deal with the heterogeneity and distribution of the model. As shown in Figure 2, applications query a federation component. The federation then queries the servers that have the data to answer the query, integrates the replies and provides the application with a homogenized result.

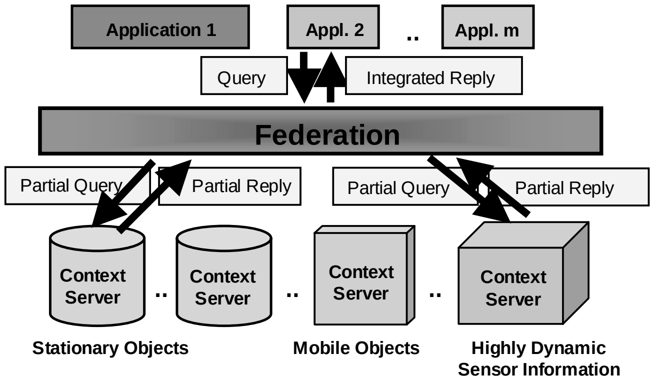

Figure 2: Nexus Platform

A smart resource management system for a single factory has a smaller scale, but as we have seen in Challenge 6 there are different organizational units that possibly have separate information systems. To integrate them, the federation concept seems to be a suitable approach that also scales to whole supply chains involving multiple companies.

For the Nexus platforms, we envision different kinds of context servers, depending on the dynamics and mobility of the objects. Currently two types of servers exist, spatial model servers that handle the data of stationary objects and location servers that handle the position information of highly mobile object. We plan to add specialized servers for highly dynamic sensor information in the near future. With these specialized servers, Challenge 3 and Challenge 4 can be addressed. Currently a single, main-memory-based location server can handle about 2000 position updates per second, allowing the efficient processing of spatial queries through a spatial index. Current databases with spatial extensions can only handle around 100 position updates per second. Federating multiple location servers provides the scalability that is necessary for the smart factory.

Within the Nexus project, we are going to build a prototype system in order to show the feasibility of the approach.

5. CONCLUSION AND OUTLOOK

As shown, the ideas of mobile and ubiquitous computing not only have a potential for improving our everyday life but also for optimizing production systems and the challenges of industrial systems. On the way, there are a number of challenges, some of which we have identified in this paper, especially regarding the management of highly mobile resources with dynamic state. The Nexus platform may provide the basis to address some of them. In addition to the technical challenges, there are a number of soft issues like safety and security (industrial spying and sabotage), or the effects and influences on the persons working in a smart factory (loss of competences and their compensation, growing numbers of staff away sick due to bad job satisfaction or stress and thus growing costs for the company etc.) that have to be investigated as well. This more holistic approach of technology assessment avoids disciplinary blinders and requires interdisciplinary research, which we conduct in our center of excellence.