Smart Factories - Manufacturing Environments and Systems of the Future

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Abstract

In basic research projects the Stuttgart model of adaptive, changeable and virtual enterprises has been formulated. Regarding to this model a new perspective with the usage of ubiquitous computing is discussed, which allows the collection and distribution of information and knowledge at all places of work in manufacturing. The approach is a dynamic system that manages production fluctuations using decentralised communication and information support. Using a meta-model of the smart factory location, sensor integration and communication structures are developed. This provides a decentralized system, which uses intelligent manufacturing equipment in order to accomplish a highly flexible production. As a result a minimum in complexity, costs and time consumption is created. In this paper, the potential and architecture of smart factories based on wireless communication and location technologies will be presented with a focus on management of mobile objects in the production environment.

Keywords:
Ubiquitous computing, manufacturing resource management, smart factory

1 INTRODUCTION

Information about manufacturing resources is a key element of production companies. This paper shows new concepts using the idea of ubiquitous computing in production systems. Decentralized, dynamic structures are designed in order to reduce down time risks. These systems hold the advantages of distributed intelligence and therefore are able to compensate for failures in single cells. At the same time the complexity of the processes are reduced to a minimum which makes the tool management together with a modular build user friendly and easy to customize. First an analysis of production evolution, planning environments, manufacturing systems is given. The Vision of the evolution from the digital towards a smart factories and the resource planning within such a system is discusses and the potential of such a development. Enabling methods and technologies are introduced before a summery ends this paper.

2 SMART FACTORY

2.1 From the digital to a smart factory

A *digital factory* is defined by multiple elements. The first step is a full geometrical, scaleable model of the factory. In this respect the digital factory of today is a tool for ergonomic layout planning. Ideas are brought together easier and changed faster without the limitations of normal paper work. The next step from static models towards a dynamic system is the implementation of simulation modes. The so called *virtual factory* enables planers to optimize production facilities or to evaluate changes by bringing a defined load onto the model. This simulation process allows logistic and process optimisation at different scales. Suppliers and Operators may use the same data base as engineers or consultants. The changes within the factory establish faster because more experts are able to work together and parallel. This in return saves costs and simulation makes it possible to focus momentum onto identified root problems. A known problem for planners is the fact that the manufacturing facilities have a long life, but their configuration changes within months. The third step is the fusion of the virtual and the physical world. In this new type of factory physical models feed virtual models with field data that in return simulate changes or possible options within the production line. Even after the factories are installed, data flows back into simulation models. This makes it possible to learn from the future without manually updating input. These mechanisms will solve the problem of outdated information and data overflow by processing and storing data as close as possible to the resource and only passing relevant information forward. The Consequence is a *smart factory* that optimizes throughout the life cycle of the manufacturing systems by using data collecting and filtering technologies that blend into the environment.

2.2 Present resource management

Short planning horizons put stress on production planning. At the same time manufacturing processes are not limited to a specific work place but a complex cooperation of several periphery systems. Therefore management of manufacturing resources (transport systems, warehouses, machines but also tools clamping fixtures measuring devices, NC-programs etc.) and the synchronisation of their usage is a central element of factories with high demands in productivity and flexibility. Reports in literature and of company representatives often criticize an unsatisfying supply of manufacturing resources. Often equipment is missing before the manufacturing starts or resource deliveries are unpunctual. Tool inventories are not exactly known by number and kind or companies complain that the tool reservoir is too large encouraged by late resource deliveries. An economical or efficiency report of the resource management is not common or sometimes not even possible. The fate and behaviour of some resources within the manufacturing system is unknown and therefore overhead stocks are likely to be existent. For the same process numerous tools are used creating numerous results. Sometimes tools are still ordered when the production of the relevant product is already cancelled. Process specific or sometimes workpiece specific tools raised complexity of the resource management task. Against major trends of decentralised intelligence and distributed communication today's production and automation systems still use centralized structures for resource data management. Production lines and there resources are still organized over a control centre and split into task elements like logistics, production lines, human resources and quality management. The symptoms show that centralized structures however are not able to manage flexible, mobile resources and processes. In order to satisfy the requirement a new approach is necessary. Decentralized intelligent systems are able to react more efficiently to changing requirements.

2.3 Improvement potential of resource management in smart factories

As shown it is necessary to enhance present resource management toward a more flexible, efficient system. The basis problem of present solutions is a inflexible structure that has to handle a complex task without all relevant information. In order to receive reliable information about manufacturing resources, which is the first step towards a reliable management, an environment must be created that collects and delivers information as soon as it is needed, to the location where it is demanded, in the depth asked, without the restrictions of wired communication. This is a challenging task remembering that optimizations of information networks and information streams as well as quickly analysing faults and their roots will have a direct impact on future production systems their financial success. Two sorts of resources are known, immobile and mobile resources. Mobile resources can be subdivided into low and high mobility. Low mobile resources are those that do not change there position frequently but have the ability to do so if necessary. Good examples are NC-machines that are usually put into place for about 5 to 10 years. Highly mobile resources are for example handheld devices or tools. It is obvious that the mobile objects cause planning problems and are the main cause of the symptoms described in the previous chapter.

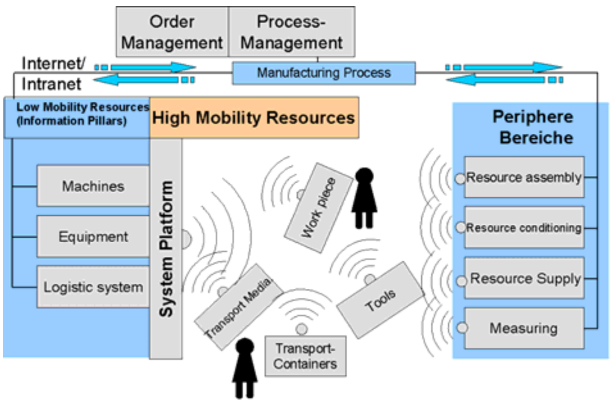

Figure 1: "smart" resource management

They already are an important factor and their importance will rise observing the continuously increasing competition. The question is how can we cut down tool costs and raise efficiency of mobile resources. To buy a new manufacturing resource and to fully integrate it into the process needs several steps in classic productions. A request followed by a resource evaluation. Once a lack of resources is detected theoretically several reactions are possible to deal with the situation. From buying to resource rents different approaches are standard procedures with known advantages and disadvantages. In our case the resources the resource is ordered. Several forms have to be filled out before the request reaches its goal. Once the resource arrives it has to be booked into stock and finally handed out to production. This shows how reactive and linear most processes still are. In order to reach the goal of highly flexible parallel productions the reactivity has to be transformed into an active resource management. This means that data that concerns the resource flow within the company have to be used in order to simulate future demands. At the same time processes like booking can be simplified by using automatic identification and location services. Resources could then book themselves into the system automatically when they arrive and even inform the necessary persons. By automatically interacting with the booking protocols the data of the resource is refreshed within short periods of time.

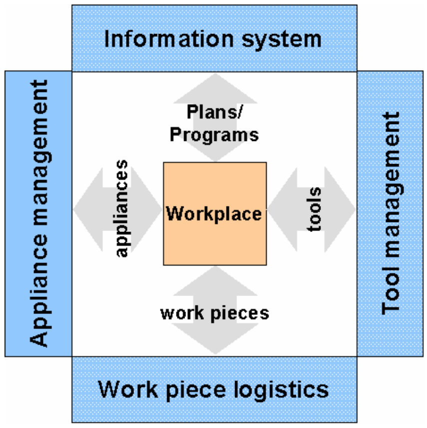

Figure 2: Work place/ process as the centre of interest

In a smart factory technical resources and work places will be able to communicate with their environment informing it about their condition status and location [5]. This will have a direct impact on availability and stocks. Production control will have a direct interface to the resource management allowing it to take production plans into account. The centralized control dissolves into decentralized structures, autonomous modules able to store the information they created and able to transfer necessary information to partner modules over wireless connections. Now that the central structure is virtually none existent there is a lower possibility of data overflows. The modules will be able to process data into reliable information instead of trying to send all the data into a central mainframe. Of course it is not possible yet to store a high amount of information and processing power on a drill. Information pillars will be used as knots in this network. Low mobility resources like for example milling machines are already connected to the intranet, the necessary energy supply. They are already able to store and process data so they could take over the position of the described information pillars. As shown now the work place and process is the centre of production. Because the process is also able to manage itself and to give out information rather then pure data human workers are able to concentrate on further optimize the central process instead of wasting efficiency trying to organize the peripheral system or to understand data code. Information between the workplace and the supporting systems is exchanged bidirectional, which keeps problem identification and reaction times low. Now that the vision is exemplified technological enablers are discussed.

3 TECHNOLOGICAL ENABLERS

3.1 Ubiquitous computing

In 1991 Mark Weiser, thought of as the founder of what we now term ubiquitous computing, wrote an article for Scientific American entitled "The computer of the 21st Century". In it he describes multiple computers in a room in the form of tabs, pads and boards, which roughly correspond to active Post-It notes, sheets of paper, and white boards and bulletin boards. Weiser´s vision of ubiquitous computing is one of the most discussed themes in the world of science. Many projects are in the domestic sector show the enormous potential of this new computing philosophy. According to his definition ubiquitous computing names the third wave in computing. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine working together over a defined desktop interface. Next comes ubiquitous computing, or the age of *calm technology*, when technology blends into the environment delivering and giving out information whenever needed. Instead of having a standard PC, the technology we use will be embedded into the factory. Among the things we need to rethink are user interfaces and displays but also location and identification systems and wireless communications. In the world of ubiquitous computing, technology will be implicit in our lives, built in to the resources we use, including the spaces. The proponents of this technology hold that this type of computing will be a more ergonomic tool, and thus a more powerful and effective one for humans to use [6].

3.2 Location

Location information is a critical factor when it comes to ubiquitous computing and context aware information flows. As more context aware applications approach, like for example the delivery of a special tool to a work space, modelling and the location of the object-environment situation is a key enabler for ubiquitous computing. In general three methods can be defined [7].

1. Triangulation:

This technique uses the properties of a geometric form in order to calculate the objects position and is the most common technique today.

Two methods are known, lateration and angulation. Lateration positions an object by measuring the distance between a minimum of three reference points. Basically the signals time of flight is measured. Well known examples are the cricket or active bat device using ultra sound or the global positioning system (GPS) using radio frequencies. GPS further advances using miniaturized receivers and a full outdoor coverage which makes it highly available at low costs. Another advantage is that after May 2000 the selective availability for civil application discontinued which made it even more effective. Now absolute positioning accuracies up to 10 m are possible. Even though accuracies advanced significantly this was not enough for some applications. There are still problems when it comes to inner city and indoor applications. Reference radiation sources using infrared, multiple radio frequencies etc. are used to multiply accuracy in the described problem areas. First ultra sonic positioning prototypes reached a three dimensional (3D) accuracies of up to 20 mm.

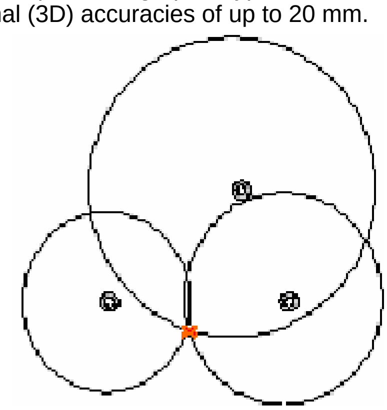

Figure 3: Lateration principle.

Angulation uses the measurement of angles to identify the position of an object. This is very handy when it comes to long distance location for example star mapping systems. By knowing the distance between the two sensors and the angle toward the object the positioning of the object is computed. The accuracy of the systems depends very much on the accurate measurement of angles.

2. Scene analysis:

The key idea using scene analysis is the fact that measurements of objects in the distance do not correspond to their real geometric measurements. Using this fact known features of the scene can be used to calculate the objects location. By using Terrain and horizon matching with the help of fixed or mobile cameras objects can be traced with high accuracies up to millimetres and higher. The line of sign may not be disturbed by other objects found in multilayer applications or dust in harsh environments.

3. Proximity

Proximity uses the limited range of all physical phenomena and therefore knowing when an object is near or not. A certain physical phenomena that is specific to the object is detected which means that usually no additional sensors are needed. One example would be the detection of metal using a detector. But also RF ID tags can be used to locate the position of a certain object as well as wireless devices as soon as they connect to a specific cellular network access point.

3.3 Identification

Beside the pure position or location data, information about the object itself has to be given without restriction concerning the line of sight. The significant advantage of all types of RFID systems is the non-contact, non-line-of-sight nature of the technology. Tags can be read through a variety of visually challenging conditions, where barcodes or other optically read technologies would have difficulties. A radio frequency identification (RFID) system basically consists of three components:

1. An antenna
2. A transceiver
3. A transponder (RF tag) programmed with unique information

Antennas emit radio signals to activate the tag and read and write data to it. They are the link between the tag and the transceiver, which controls the system's data acquisition and communication. Their shapes and sizes vary depending on the field of work. Mounted into the sealing of manufacturing facilities they could monitor material traffic passing through the system. The electromagnetic field produced by an antenna can be constantly present when multiple tagged objects are expected continually. If constant interrogation is not required, the field can be deactivated until a sensor device triggers action. By combining the antenna with a transceiver and decoder it becomes a reader unit. The reader can be a handheld or mounted. Once the RFID tag passes through the electromagnetic field, it detects the reader unit. The reader decodes the data integrated into the tags circuit (silicon chip) and the data is passed to the processing computer. RFID tags also come in a wide range of shapes. Tags can be shaped depending of the application. From heavy duty tags with sizes up to 100 mm³ to credit card shaped sizes for personal identification, down to foils that can be attached to virtually any object. RFID systems are distinguished by the operating frequency ranges and the energy support. Low-frequency systems, between 30 KHz to 500 KHz, require no special materials or complex circuits which makes them a low cost product. They are most commonly used in asset tracking. High-frequency systems that work between 850 MHz to 950 MHz and 2.4 GHz to 2.5 GHz or above, offer long read ranges (greater than 30 m) and high reading speeds. However, the higher performance of high-frequency RFID systems incurs higher energy demands.

RFID tags are also categorized as either active or passive.

1. Active RFID tags are powered by an internal enegie source (batteries) and are typically read/write, i.e., tag data can be rewritten and/or modified. Some active tag systems operate with up to 1MB of memory. In a typical read/write application a workpiece tag might give a machine a set of instructions, and the machine would then report its performance to the tag. This encoded data would then become part of the tagged part’s history. The battery-supplied power of an active tag generally gives it a longer read range. The trade off is greater size, greater cost, and a limited operational life of up to 10 years depending upon operation environment.

2. Passive RFID tags operate without a separate external power source and obtain operating power generated from the reader. Passive tags are consequently much lighter than active tags, less expensive, and offer a virtually unlimited operational lifetime. The trade off is that they have shorter read ranges than active tags and require a higher-powered reader. Read-only tags are typically passive and are programmed with a unique set of data (usually 32 to 128 bits) that cannot be modified. Read-only tags most often operate as a license plate into a database, in the same way as linear barcodes reference a database containing modifiable product-specific information.

3.4 Wireless data transfer

Several wire less communication systems have been invented during the last years. These technologies made it possible to connect 2 or more devices without the help of external infrastructure and make them the basic factor of ad-hoc networking. This is not only very cost efficient as infrastructure can be minimized but also new applications such as described before are now possible. During the last years the line of sight problem of infrared connections became more severe as users found it unhandy to change object positions before interaction. New radio frequency standard evolved, that make ad-hoc interaction possible and practicable.

1. Bluetooth: Bluetooth works within the ISM (Industrial, Scientific, Medical) standard, a frequency between 2,402 GHz und 2,480 GHz. Using a virtual frequency hopping method of 1600 changes a second means a higher interference resistance towards other radiant sources. Hopping frequencies combined with a 128 bit coding key makes this standard one of the most secure in wireless communication known today.

2. Wireless LAN: Following the IEEE 802.11 standard W-LAN worked within the ISM frequency band. 1999 IEEE 802.11 was added by the IEEE 802.11b, which changed specification towards an 11 Mbps transfer rate. Tests show that in field application effectively reach about 4Mbps of pure data rates. New efforts of the IEEE show that the new IEEE 802.11a will specify a rate up to 54 Mbps which goes together with a band shift to 5GHz. In average the coverage is between 35 to 100m in building, 300m and more outside. The connection is not interrupted abrupt but gets slower while moving away from the access point. With both standards, blue tooth and W-LAN, operating within the ISM band a combination of both methods is not advised. Bluetooth and W-LAN are very likely to interfere.

4 SUMMARY

This paper outlines the vision of a smart factory and outlines a possible scenario. The proposed solution takes the idea of ubiquitous computing into the industrial sector. Combined with ad-hoc networking a decentralized, flexible and active resource management is achieved. Other scenarios like logistics and business process simulations are mentioned to show the enormous potential of this idea to the manufacturing industry. Using these enabling technologies will bring us toward a new kind of factory that operates intelligently within new dimensions. To do so sensors have to communicate and a sensor network has to be achieved. By knowing the exact state of the environment at any given time, a dynamic resource adaptation is possible which reduces downtime. After talking about a possible scenario and outlining the advantages of the new structure enabling technologies are discussed. These technologies show the trend towards ubiquitous computing and the speed of development new organisational and technical concepts have to take into account.

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6 REFERENCES

[1] Westkaemper, E.
2001, Veränderung von Werten und Strukturen in der industriellen Produktion. Duddeck, Heinz (Hrsg.): Technik im Wertekonflikt. Opladen : Leske und Budrich .

[2] Westkaemper, E., 1977,

Reorganisation des Werkzeugwesens Industrie Anzeiger99, Nr.86, p. 1700-1703

[3] Doege, E., Besdo, D., Haferkamp, H., Toenshoff H.K., Wiendahl, H.-P. 1995, Fortschritte in der Werkzeugtechnik, Verlag Meisenbach Bamberg und Universität Hannover

[4] Hazas, M., Ward, A.

2002 A Noval Broadband Ultra Sonic Location System Ubicomp 2002, Springer Verlag, p. 264-280

1995 Entwicklung eines Produktlebenslaufverfolgungs-systems, Forschungsgemeinschaft Qualitätssicherung (FQS): Forschungstagung Qualität '95: Tagungsband, 12. Oktober 1995, Frankfurt am Main. Berlin u.a.: Beuth, p. 50-62

[5] Westkaemper, Engelbert; Niestadtkötter, Jan:

1995 Entwicklung eines Produktlebenslaufverfolgungs-systems, Forschungsgemeinschaft Qualitätssicherung (FQS): Forschungstagung Qualität '95: Tagungsband, 12. Oktober 1995, Frankfurt am Main. Berlin u.a.: Beuth, p. 50-62

[6] Weiser, M.

The Computer for the 21st century, 1991, Scientific American. p. 94-100

[7] Rothermel, K. et al

2002, Spatial models for context aware systems, Forschungsantrag des SFB 627, Universität Stuttgart