Ubiquitous computing
factory layout system
smart factory

Engelbert Westkämper

Lamine Jendoubi

Thomas Ertl

Mike Eissele

Smart Factories - Manufacturing Environments and Systems of the Future

Regarding the Stuttgart Model on adaptive enterprises 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. This information is used to bridge the gap between digital planning and work shop. The approach is a dynamic system that manages production fluctuations using decentralised communication, planning, and information support. Using a meta-model of the smart factory location, sensor integration, and communication structures are developed and integrated into an augment reality device. This provides a decentralized system, that uses intelligent manufacturing equipment in order to accomplish a highly flexible production as well as a feedback tool to further reduce inefficient preparation results. As a result a minimum in complexity, cost and time consumption is created. In this paper, the potential and architecture of smart factories based on wireless communication, location technologies, augmented reality, and integrated sensors will be presented with a focus on management of mobile resources in the production environment.

1 INTRODUCTION

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

2 SMART FACTORY

2.1 From the digital to the smart factory

A *digital factory* is defined by multiple elements. The first step is a full geometrical, scaleable model of the factory. With respect to this 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 simulations. The so called *virtual factory* enables planers to optimize production facilities or to evaluate changes by applying a defined load onto the model. This simulation process allows logistic and process optimization at different scales. Suppliers and operators may use the same data base as engineers or consultants. The changes within the factory are faster established because more experts are able to work together in parallel. In return, this saves costs and simulation allows focusing 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. This gap between reality and digital data is bridged by the smart factory. In this third step the fusion of virtual and physical world is achieved by feeding virtual models with field data. Even after the factories are running, data can flow back into simulation models, using e.g. augmented reality to archive closed loop feedbacks between layout planners and workers. These mechanisms will solve the problem of outdated information and data overflow by processing and storing data as close as possible to the resource, while relevant information is passed forward by the nexus owned federation layer. The consequence is a *smart factory* that optimizes throughout the entire life cycle of manufacturing systems by using data collecting and filtering technologies. These blend into the environment and at the same time holds the enabling technologies to use all the essential company knowledge.

2.2 Factory Layout Planning

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 systems. Therefore, layout planning (transport systems, warehouses, machines, etc.) and the synchronization of their usage is a central element of factories with high demands in productivity and flexibility. It is shown that insufficient planning may cause the factory to work far under the expected output levels. The long live of a production system and the ever changing setup of the systems makes it impossible to use the initial simulation code as a support tool while production phase is in progress. What usually happens is a time and cost intense analysis to modify the production model in order to update the digital model. With embedded computers this actualization can be automated to a high degree giving the manager the possibility to consult the technical intelligence at any time. Bridging the gap between reality and the digital data is, therefore, a key element of future production systems with dramatically enhanced dynamics. It is also very useful when new production lines have to be planned.

Nowadays, the usage of digital models allows significant benefits when it comes to layout or re-designs of factories. During the upcoming years this benefit of digital models will be further increased by using real environment to enrich the knowledge base used to plan a new system. Even though artificial intelligence used by simulation tools is in many respects more advanced than human possibilities it is still necessary to use the experience of planners and workers. An augmented reality (AR) device is able to show the user critical data in the real environment making tools more ergonomically and more efficient than state of the art technologies. In our prototype a planning tool is connected to an AR-device and shows the relevant information to the user who is now able to judge the system in the real environment without the risk of perspective errors, which are quite common. It is especially suitable to visualize dynamic information about tools, like position, next job, or condition. At the same time augmented reality gives us the possibility to further enhance standard procedures e.g. the maintenance of machines and tools.

In order to satisfy all these requirements new approaches in technical intelligence and data organization are necessary. Decentralized intelligent systems are used in order to react more efficiently to fast changing parameters mentioned earlier.

2.3 Mixing Reality and Digital Data

The most challenging problems for systems that enrich the physical world with digital data is the timeliness of the data and the federation of different data sources, specified in different formats. In addition, most data represents information related to real world objects and is therefore location dependent. An open platform that is able to handle this kind of data and solves the problems involved is the Nexus platform [3, 4]. Nexus is a middleware that connects providers and clients of location-aware applications and information. The platform provides a detailed model of the real world to location-aware applications that can be used in in-door and out-door scenarios. Arbitrary data sources, including sensors, production machines, work flows, management systems, etc., can be connected to the platform to retrieve and insert any kind of data needed. Nexus is designed to efficiently handle large databases of location dependent data. The model for the Nexus database is called augmented world model (AWM), it combines physical data, e.g. machine temperature, with virtual data, e.g. machine specifications. Furthermore, location-aware applications are able to access the data whereas the platform automatically merges all the available information from different sources via a federation layer. This functionality is also important to combine different data sources, e.g. different tool management systems, to a consistent data model within a smart factory. The technology of augmented reality offers a novel approach to visualize and work with location-dependent data. Many projects, e.g. the ARVIKA project [5], have shown the benefit of utilizing AR technology in manufacturing environments. Implementations of augmented reality applications are supported by Nexus through mechanisms that are able to generate an abstract representation of the AWM data, specific to AR applications.

To show the advantage of AR visualizations a prototype of a factory layout planning system was built. Whenever planners optimize the factory layout or try to integrate new working facilities they may not think of all problems or dependencies of their proposed layout. An on-the-spot expert using an AR visualization of the temporary planned factory layout can interactively comment the proposed layout and affect the layout-planning process. Our prototype is build upon the Nexus platform and can therefore access all the information and data contained in the augmented world, including planning data, tool specifications, tool conditions, etc. The database of an existing real-time planning tool [6] that allows interactive factory layout planning was integrated into the Nexus platform in order to allow other applications access to the current factory layout. The prototype interactively visualizes the factory layout utilizing an optical-see-through head-mounted display to help the expert to identify problems of the planned layout. In Figure 1 an example AR visualization of the manufacturing area is shown, including installed production machines and virtually planned machines.

Fig. 1: AR visualization of the factory layout planning prototype

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”. 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, 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, identification systems and wireless communications. In the world of ubiquitous computing, technology will be implicit in our lives, built into the resources we use. The proponents of this technology propose that this type of computing will be a more ergonomic tool, and thus, a more powerful and effective utility for humans to use [7, 8].

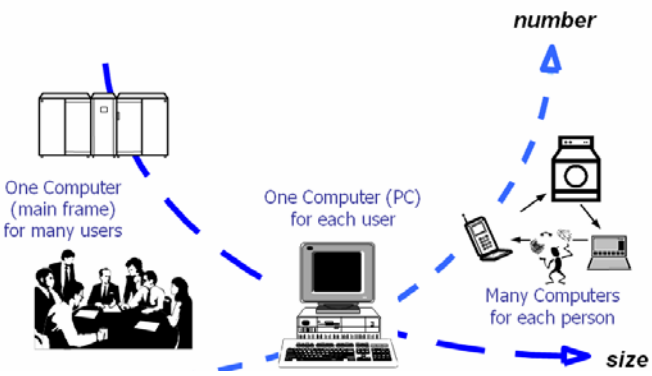

Fig. 1: Principle of ubiquitous computing

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 emerge, e.g the delivery of a specified tool to a work space, modeling the location of object-environment situation is a key enabler for ubiquitous computing. In general three methods can be defined [9].

1. 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. Using terrain and horizon matching with the help of fixed or mobile cameras objects can be traced with high accuracy 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.

2. Proximity

Proximity uses the limited range of all physical phenomena and, therefore, knows if an object is near or not. A certain physical feature, that is specific to the object, is detected and therefore 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 cell within the network their position has to be within the cell.

3. Triangulation:

This technique uses the properties of a geometric form in order to calculate the position of the object 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 emerges using miniaturized receivers and a full outdoor coverage which makes it highly available at low costs. Another advantage is that since 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 accuracy advanced significantly this was not enough for some applications. There are still problems when it comes to inner city or indoor applications. Reference radiation sources using infrared, multiple radio frequencies etc. are used to enhance accuracy in the described problem areas. First ultra sonic positioning prototypes reached a three dimensional (3D) accuracies of up to 20 mm.

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. This method is also used in our smart factory prototype were a “UBIsense positioning system” is used in order to track mobile resources within a given space or to specify the view direction of a person using augmented reality devices [9].

3.3 Identification

Besides the raw 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 identification technologies would have difficulties. A radio frequency identification (RFID) system, which uses specific electro magnetic frequencies to identify an object, 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 use the memory embedded in the tag. 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 application. Mounted into the ceiling 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. If constant interrogation is not required, the field can be deactivated until a sensor device triggers an 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 mm^3 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 ranges reads(greater than 30 m) and high reading speeds. However, the higher performance of high-frequency RFID systems results in higher energy demands [10].

Fig.2: Tool with embedded ID-Tag

3.4 Augment Reality Devices

The visualization plays an important rule when a huge amount of data has to be examined. Different visualization algorithms, but also different devices can be used for specific tasks. Especially in AR applications the choice of the device is important for the acceptance of the system, as users might be conservative in using the new, uncommon devices. Any device that is able to augment the reality with virtual information can be classified as an AR device. The Nexus platform can be used to drive any AR device, head mounted displays are the most common, but also tablet PCs, personal digital assistants (PDA), or smart phones are supported. The left head-mounted display depicted in Figure 4 is an optical-see-through HMD where the operator can see thought the display device to see the real world. The other class are video-see-through HMDs (Figure 4, right), here the surrounding is captured with video camera(s) and displayed on the HMD.

Fig. 4: Optical-See-Through and Video-See-Through Head Mounted Display

An optical-see-through device has the advantage that in case of any system failure the user is still able to see the environment. In contrast, if a video-see-through system fails it might display no image at all and the user can no more interact with the environment. Therefore, video-see-through devices cannot be use in hazardous environments, e.g., workers operating a manufacturing machine.

4 SUMMARY

This paper outlines the vision of a smart factory and outlines a possible scenario. The proposed solution maps the idea of ubiquitous computing into the industrial sector. Combined with database networking a decentralized, flexible and active planning system is achieved. Other scenarios like logistics and business process simulations are mentioned to show the enormous potential of this idea in the manufacturing industry. Using these enabling technologies will bring us towards a new kind of factory that operates intelligently within new dimensions. To do so a sensor network has to be achieved that enables new forms of man-machine-cooperation. By knowing the exact state of the environment at any time, a dynamic adaptation is possible which reduces downtime and uses the given resources at an optimum. After talking about an example scenario and outlining the advantages of the new structure, enabling technologies were discussed. These technologies show the trend towards ubiquitous computing and the speed of development that new organizational and technical concepts have to take into account.

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