Innovative Control System for Industrial Environment

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Abstract

In this paper we present preliminary results of the ongoing research of a new industrial control system with a special stress on user interfaces and data representation. The main focus of our research is the combination of traditional control interfaces for manufacturing machines with new ubiquitous services, handheld computers and Virtual Reality installations. Our system can support both industrial operators and managers by providing them with a new powerful tool, which can help them monitoring their environment and supervise production processes in a very convenient way. We also describe a miniature simulation model produced for development purposes. The research has been performed within the framework of EU-supported project INT-MANUS.

1. Introduction

The complexity of manufacturing systems is permanently increasing. Industrial automation systems with centralized client-server architectures and predefined deterministic programs still exist, but since the beginning of 90s are considered as obsolete [1]. A new generation of manufacturing systems referred to as "intelligent manufacturing systems" and "agent-oriented manufacturing" paradigm have been extensively studied in recent years [2-5]. There is a tendency to use intelligent, programmable I/O devices connected directly to sensors and actuators interconnected by peer-to-peer networks [6-8].

The fast development of software and hardware technologies allows the creation of new intelligent services, devices and control interfaces intended for industrial environments. For example, the SmartFactory^{KL} project [9] develops a new flexible network connecting arbitrary components, which should work autonomously, and user interfaces, which could allow communication with the components on the basis of a universal standard. The WearIT@Work [10] project develops new wearable devices, which should increase productivity, flexibility and safety of workers. The ULTRA [11] project applies Augmented Reality technology for industrial service and maintenance applications.

Recent research [12] shows that use of semantic web services is necessary to overcome interoperability barriers in factory automation, but additional research efforts are still required. Some research has been done in information semantics representation for manufacturing systems, which facilitates inter-enterprise collaboration [13], and in failure semantics in intelligent manufacturing systems [14].

Continual integration of new systems and devices leads to an increase of information flows, which may result in information input overload [15]. Thus, new approaches and interfaces allowing users to deal with the great number of events and messages of a modern manufacturing plant are needed.

Virtual Reality (VR) systems are widely used for industrial design and simulation [16-19]. However, they are usually not connected directly to manufacturing environments and additional efforts are required to transfer models and simulation results from a VR system back to the manufacturing level.

The European research project INT-MANUS [20-24] contributes to investigations aimed at improvement of flexibility and adaptability of industrial systems by integrating and evaluating most advanced concepts. Furthermore, the project develops new human computer interfaces. The main research areas of the project are:

- Control of industrial environments with an open distributed agent-based platform with semantics and learning abilities. The INT-MANUS platform integrates machines, robots and human personnel; it supports decentralized communication and has centralized services.

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- User-friendly hierarchical representation of industrial processes. The INT-MANUS approach allows supervising the whole manufacturing plant on different levels: from individual machine states to major factory objects. The interfaces to the platform based on this approach make it a "literally visible, effectively invisible" system [25], allowing operators to concentrate on most important tasks.
- Product customization in a 3D Virtual Reality-based system directly connected to the INT-MANUS manufacturing environment. This allows higher automation and reconfiguration capabilities in production.

The core technology of the project is the Smart-Connected-Control Platform (SCCP) for manufacturing enterprises. The platform integrates machines, robots and human personnel and provides three specific interfaces: the web-based interface, the interface for wearable computers and the interface for VR systems. The former two interfaces allow visualization and control of industrial environments and the latter is intended for product customization tasks.

Before applying our interfaces and concepts in a real manufacturing environment, we wanted to evaluate them in a laboratory environment. Therefore we have designed a miniature factory model, which simulates a production chain and does not require much space.

In this paper we briefly describe the SCCP architecture, present the miniature factory model and introduce the control interface for handheld computers, which allows controlling industrial environments on the basis of our innovative approach.

2. Ubiquitous computing industrial environment

In the INT-MANUS project a ubiquitous computing industrial environment is formed and managed by the Smart-Connected-Control Platform. It is an open distributed learning agent-based system that integrates machines, robots and human personnel. The overall architecture of the SCCP is presented in Fig. 1.

The platform is organized as a two-layer structure. All manufacturing machines, robots and other devices and services are connected together via TCP/IP interface and considered as peers. Each peer is equipped with a local agent that is in charge of local control and communication with other devices. The peers form the first layer, which keeps the network consistent and connected and maintains a decentralized peer index.

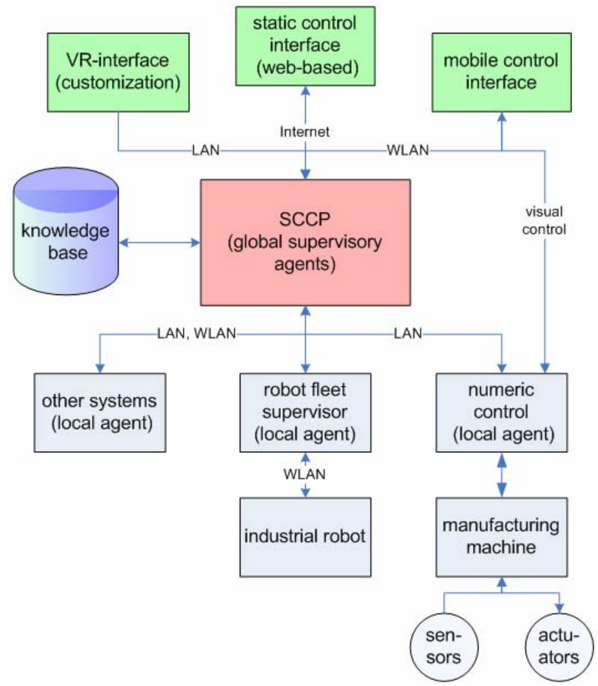

Figure 1. The architecture of the SCCP

Data collected from sensors are partially processed by the local control systems (for details see [24]) and after filtering sent over the network to SCCP services for storing and higher-level analysis. The services then apply their decision-support techniques and if necessary send updates and notifications to control systems or back to peers thus forming the second layer of the SCCP structure

The semantic-based services of SCCP are responsible for storing important data in the database, workflow control, generation of important notifications and corrective actions. Data are collected and distributed according to peer-specific security policies. Learning techniques may be applied. The structure of the SCCP services is presented in [22-23] in detail.

SCCP has three specific interfaces. The web-based interface allows operators to see the states of all peers and processes of the SCCP in a simple text-based format and can be used both by on-site operators and remote users. The mobile interface for handheld computers is particularly intended for on-site users. It allows hierarchical two-dimensional colour-coded visualization of the whole industrial environment, as well as control of individual machines, taking into account specific abilities of such devices and semantics. The VR-interface should allow engineers, designers and customers to work collaboratively in a large-scale VR installation directly connected to the production environment and interactively customize their desired products leaving most of production reconfigurations for the SCCP services.

Prototypes of the control interface for wearable computers and the web-interface have been already developed, whereas the prototype of the VR-interface is underway. In the next paragraphs we describe our dedicated test bed and present the mobile control interface using the test bed as an example.

3. Factory simulation model

Before applying our technologies to a real manufacturing plant, we developed our interfaces and tested our approach in a laboratory environment. Furthermore, we wanted to demonstrate the main concepts of the INT-MANUS project at fairs and exhibitions. For this purposes we have developed a test bed that emulates a production chain. Below we describe the design and scenario of the test bed.

Our factory simulation model includes active elements that represent industrial machines and a miniature mobile robot for transportation of materials. This factory makes "beams" using "cubes". Fig. 2 shows this test bed. The four machines, namely the cube dispenser, beam maker, quality controller, the delivery bay and a miniature robo, can be seen on the picture.

A typical working scenario of the test bed is described as follows:

- We execute a command to manufacture a “3 cube beam” (a “beam” built out of 3 cubes).
- The cube dispenser ejects a cube.
- The robot carries it to the cube inlet of the beam maker, which takes in the cube, turns it on its side, and pushes it into the beam chamber. This task is repeated three times and then the beam maker pushes out the finished beam to its outlet.
- The robot carries it to the quality controller, where the beam is taken up a ramp and dropped from there. A beam that comes out in one piece is declared good and is taken to the delivery bay by the robot.

As a miniature robot we have chosen the Khepera2 robot from K-Team[1] with a gripper turret.

For flexibility reasons we decided to build our own model machines. We used X-form beams made of aluminium as frames for the machines, so that the mounted parts can be easily adjusted along the direction of the frame. As building blocks for the beams we used magnetic cubes.

[1] http://www.k-team.com/

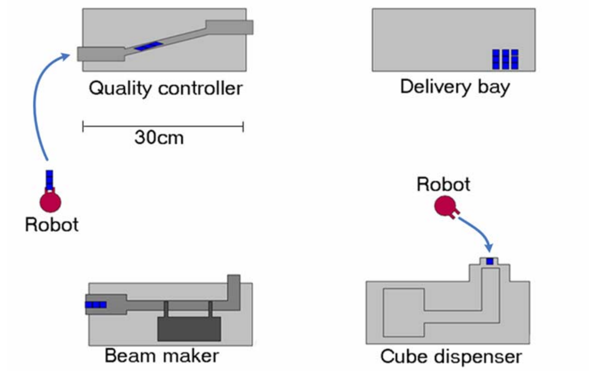

Figure 2. The layout of the miniature model

The machines have sensors like magnetic switches, light barriers and mechanical position switches. They also have actuators like pistons and conveyor belts, which are driven by electric motors. The motors and sensors are connected to the electronics on each machine, and these are in turn connected to a central embedded system, a single board GNU/Linux computer DiL/NetPC[2]. The computer runs atomic actions on the machines and communicates with the test bed control software via a TCP/IP interface. This embedded system is physically a central system, but it represents independent elements – the machines. Thus, the machines have individual interfaces and control procedures.

We have set up two localization systems in our laboratory: the Ubisense[3] position tracking system for localization of mobile devices and an optical tracking system for localization of the robot. The former is a commercial system based on ultra-wideband technology and is able to locate objects (so called “tags”) in 3D with accuracy of ~20 cm. The latter is our own one-camera-based 2D tracking system developed on the basis of OpenCV[4] functionality. It is able to track the position of the robot on the table with the accuracy of ~0.5 mm.

The test bed as a whole can be considered as a cell of an industrial hierarchical structure, with its specific resources and tasks.

The structure of the test bed software is shown in Fig. 3.

[2] http://www.dilnetpc.com/
[3] http://www.ubisense.net/
[4] http://www.intel.com/technology/computing/opencv/

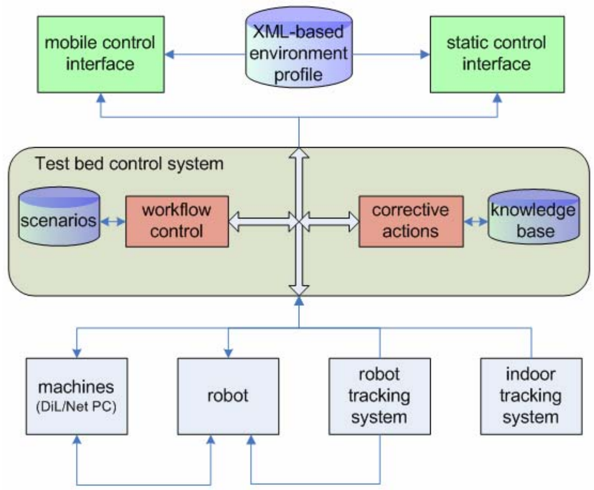

Figure 3. The structure of the test bed software

The test bed control system (TCS), which represents the SCCP services described above, communicates with the Dil/NetPC embedded system via TCP/IP low level exchange protocol, with the robot via a serial link or Bluetooth and with other systems via Simple Object Access Protocol protocol. The TCS can read test bed scenarios from XML files, execute instructions for the robot and the machines and generate corrective actions when needed. The TCS allows test bed objects to communicate with each other; however some objects can also communicate directly.

Two control interfaces provide users with information about all objects and processes, and allow them to interfere with the processes when necessary. The static control interface is currently relatively simple and used for development purposes, while the mobile control interface is intended for end-users. It is described in the next paragraph in detail.

The communication between the TCS and the interfaces is organized via a network abstraction layer. This separation allows applying a universal data format to simplify adaptation of the interfaces in a new industrial environment.

4. Mobile control interface

After evaluation of different devices we have chosen the SONY VAIO U8[5] handheld computer (see Fig. 4). It is slightly bigger (167x108x26.4 mm) and heavier (550 g) than a PDA, but it features 800x600 touch panel, 900 MHz Celeron processor, USB interface and has full Windows compatibility and wireless LAN support.

Development of software systems that are used by people moving around is a challenging task. Limited screen size and interaction mechanisms on mobile devices require special approaches to user interfaces on this type of equipment [26]. If the software system is supposed to be used on various devices or in different contexts, an adaptation mechanism has to be designed [27]. Moreover, operators are normally get used to existing numerical control interfaces, so the new interfaces should not differ from them, but rather should complement them.

Based on analysis of end-user demands we have formulated the following requirements. Our interface should provide a simple and intuitive access to the workplace of the user. They should be able work on handheld and stationary computers; however the target platform is a handheld PC. Even without specific knowledge of our system a user should be able to connect to different machines and interact with them. At the same time the system should allow visualization of the whole industrial environment the user has to control. Furthermore, the interface should deliver notifications and messages coming from individual machines and SCCP services.

Our interface supports different operation modes. The user can easily switch between the modes, turn on/off full-screen mode and zoom in/out. The modes are as follows:

Interactive visualization of manufacturing plant. In this mode users will see hierarchical structure of a manufacturing plant. The structure may have several levels. The upper level shows higher-level elements of a factory, for example, production halls. The medium level shows different cells in a hall. The lower level shows the shop-floor as an interactive map with locations of mobile devices, robots, and machines (see Fig. 4). To simplify comprehension and provide basic information about objects' statuses, all objects are displayed as geometrical figures using different colours on the basis of user's preferences. For example, in the lower level the machines are represented as rectangles, the robots and handheld devices as circles. Additional information, such as the name of current part program, the degree of fabrication and sensor data of a machine can be also visualised in different ways. For robots actual routes can be shown; for tracked objects – actual positions.

The knowledge base of the SCCP is able to produce semantic information according to the state of a parameter by analysing its value, maybe in relation with other values in the system (for example, it may be "good", "suspect" or "dangerous"). In this case the parameter may be visualized as green, yellow or red object. Based on such analysis SCCP can also derive states of objects. For instance, machines can have the following states: "working", "working ineffectively",

[5] http://vaio-online.sony.com/prod_info/vgn-u8g/specifications.html

"failure", "waiting", "switched off", "scheduled for maintenance" and others. The state is then visualised as a green, yellow, red, grey, black etc. border around the figure.

Similarly, the SCCP is able to derive the state of a cell or a higher-level object.

The user can execute specific commands available for the level he is supervising. He also receives messages critical only for his current level. In case of a fault, the SCCP sends notifications to some users according to their profiles and the importance of the event. For example, if a machine has a failure, but its tasks can be overtaken by another machine in the cell, SCCP will reschedule production automatically and notify cell supervisor and machine operator. The SCCP can also keep track of a maintenance schedule and notify users when maintenance has to be done. By double-clicking an object the user enters a lower level, down to individual machines and robots. Such an approach allows the user to quickly estimate importance of a problem and localize its causes.

Control of individual objects. This mode offers the user the possibility to get more detailed information about a chosen object. The mode is device-specific. If a numerical control interface for the object exists, it should be used in the interface design. In this mode the user normally sees low-level sensor and actuator information and the current state/task of the object. In addition to that, he may also see object specific commands supported by the SCCP and execute them.

Visualization of parts. In this mode the user can select a part/product and see its geometrical model. He can send a command to the SCCP for its production. With an external miniature camera, which can be connected via USB to the handheld computer, all produced parts can be photographed. The user can visualize a geometrical model of the product and overlay it with the live image. He can then compare the produced object with its model thus controlling production quality on-site.

The hierarchical industrial environment has to be previously described in an XML-based profile. The profile has to be loaded to the interface before its execution. For all objects the profile contains the description of their states, sensors, actuators, commands, as well as location information.

The interface is implemented in C++ with Qt toolkit for MS Windows platform. The software is fully integrated with the test bed described in the previous section. Using the interface we could execute commands for the whole test bed to produce beams with different number of cubes. We could also control the machines and the robot individually and receive notifications from SCCP.

The simulation model allowed us to evaluate our interfaces, data representation techniques and SCCP decision-making methods before applying them in a real industrial environment.

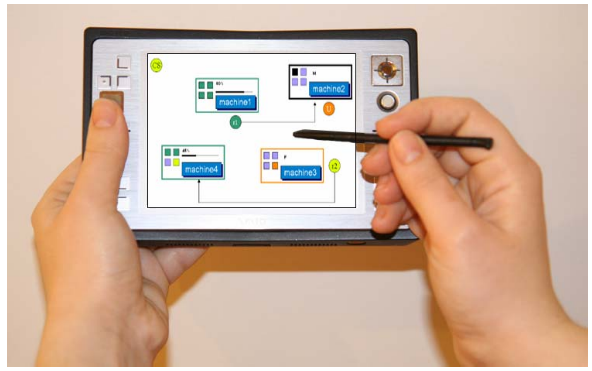

Figure. 4. Shop-floor visualization

5. Future work

In our future work we plan to extend the functionality of the mobile control interface, to develop the VR-interface and to evaluate both interfaces in a real manufacturing environment.

The performance of current handheld computers allows us to apply algorithms that previously required stationary PCs. Our first experiments on automatic identification of objects on the basis of SIFT [28] algorithm were successful. This allows us to implement automatic part identification for the part visualization mode. The user can connect a web-camera to the handheld computer, make a photo and after its automatic analysis see all part-related information.

It is also possible to integrate communication with an RFID reader to allow automatic identification of RFIS tags on the handheld computer.

Furthermore, we plan to integrate voice communication into the mobile control interface. Thus, the interface can be a very powerful tool, combining hierarchical interactive visualization, automatic identification and communication systems in one device.

We are also developing the VR-interface, which will be integrated with a manufacturing environment. The interface should allow multi-user flexible customization of a product in Virtual Reality directly connected to the industrial environment via the SCCP services. The users working in the VR system will be able to assemble a product from parts, which may be produced by manufacturing machines of the plant. Moreover, they will be able to apply different materials to the product, see it under different illumination conditions, change geometry of parts, find out time and costs needed for production and finally schedule production. If the changes to part geometry they made are significant and cannot be applied automatically, the SCCP will notify respective operators. If the machines are able to produce all the parts, SCCP will reschedule and optimize the production automatically and will supervise production and assembly processes.

6. Conclusion

In this paper we presented the Smart-Connected-Control Platform for manufacturing enterprises as the basis of a ubiquitous computing environment in factories. We described a miniature simulation factory model, which helped us to develop and evaluate our interfaces and approaches. We presented a new control interface for handheld computers. The interface allows visualizing complex manufacturing plants interactively. Finally, we established the agenda for our future work.

Acknowledgments

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