Smart Connected and Interactive Production Control in a Distributed Environment

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Abstract

The European research project INT-MANUS embedded in the I*PROMS European network of excellence addresses the increasing demand for flexibility and adaptivity, which is summarized by rapid reconfigurations of complete factories as well as related aspects in Human Computer Interaction (HCI), Software, and Production Systems. The project's main goal is to develop a new technology for the production plants of the future, the Smart Connected Control Platform (SCCP). This platform allows controlling a factory with the help of an open distributed learning agent platform that integrates machines, robots, and human personnel.

Keywords: Smart-Connected-Control Platform (SCCP), Advanced Maintenance, Virtual Reality

1. Introduction

Today's production and manufacturing systems are challenged by an increasing demand for flexibility and adaptivity which is summarized by the rapid reconfiguration of a factory. While improvements are already being undertaken with respect to technical requirements, interactive processes and interaction technology in a highly dynamic environment still needs further attention.The European research project INT-MANUS [1] has been launched from the I*PROMS European network of excellence [2] in order to address these issues in addition to aspects of Human Computer Interface (HCI), Software, and Production Systems.

The Smart-Connected-Control Platform (SCCP) for manufacturing enterprises allows controlling a production plant with help of an open distributed learning agent platform that integrates machines, robots, and human personnel. The Smart Connected Control Platform will allow higher automation capabilities in production, delivering a decentralized concept for connecting machines and interaction devices. Ubiquitous augmented reality technology will provide better control abilities for factories, starting with an enhanced communication infrastructure. Integrating interfaces and support for human personnel in every aspect of the production process thereby leads to a better control of the production and manufacturing process.

Each peer (machine tool, robot or other device) is equipped with a local control system that is in charge of local control and communication with the Enterprise Service Bus (ESB). Data collected from sensors are partially processed by the local control systems and after filtering sent over ESB to SCCP services for storing and higher-level analysis. The system then applies its decision-support techniques and if necessary sends updates to control systems and notifications.

Connecting numerous devices to the SCCP communication infrastructure, a common access platform is needed. This component, the platform peer, fulfils an important task. It receives (e.g. sensor) data from the device attached and makes them accessible to other peers. Therefore the data have to be collected, classified and referenced to the semantic data description model, a part of the model ontology available in the network. Two processes for the distribution of semantic referenced/annotated data are designated. The Platform Peer can proactively send the data (including a classification reference) to a peer that is known to need them. The more recommended process is having the Platform Peer providing events for each data that can be observed by interested peers. This way the Platform Peer does not need explicit knowledge of workflow and data routing. Thus the semantic backbone will mainly use the event based data transmission.

2. SCCP Production Service Bus (PSB)

The SCCP communication protocol is defined in the Production Service Bus (PSB) as illustrated in figure 1. The PSB provides a service infrastructure to guarantee an easy and reliable transmission of semantic referenced data. A PSB consists of two layers: Peer Infrastructure Services allow implementing a decentralized peer index and contain functions that help to keep the network consistent and connected.

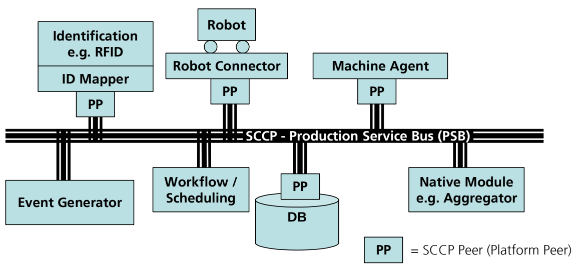

Fig. 1. PSB Bus System

The PSB describes processes for typical network situations (register, Index Node drop out, network split …) that have to be implemented by all participating peers. The second PSB layer describes services allowing SCCP event based data transmission. On the basis of these services every peer is able to provide events to observe and can send data according to events occurred. Additionally proactive data transmission is possible as well. Object-oriented models [11] and processes provide semantic messaging and decentralized workflow control.

3. Mobile Control System (MCS)

The main task of the INT-MANUS MCS is to allow on-site operators to supervise production processes and control manufacturing machines remotely by a handheld computer. The system has three operating modes:

- The Global View Mode offers an interactive map, where the position of the machines, robots and other tracked objects can be seen (see Fig. 2). The map can be scrolled and zoomed easily. To simplify recognisability, all objects are represented by colour-coded geometrical figures: machines are represented by rectangles, while users and robots by circles. Double clicking on an object shows more detailed information of a particular object. The mode may be easily extended for hierarchical visualization of the whole factory.
- The Local View Mode offers the possibility to get a closer view of a chosen object. For manufacturing machines it shows speed, feed, name and progress of a part program and allows an operator to change some parameters, to stop the machine, and to schedule it for maintenance.
- In the Product View Mode, an operator is able to select a part/product and to see a geometrical model of it. He can send a command to the SCCP for scheduling its production. With the use of an external miniature camera, which can be connected via USB to the handheld computer, all produced objects can be photographed. The operator can visualize a geometrical model of the product and overlay it with the live image thus comparing the produced part with its model. Moreover, the operator may identify the object automatically on the basis of Scale Invariant Feature Transform (SIFT) algorithm [6], which is

able to extract repeatable characteristic feature points from images and generate respective descriptors.

The MCS is developed under Windows™ OS with Microsoft Visual Studio™ 2005 and is mainly written in C++. The Qt framework is used for the implementation of the system's graphical user interface. The MCS has two communication modules: one for monitoring and controlling manufacturing machines via the SMART tool and the other one for information exchange with supervisory semantic services of the SCCP. Where necessary for the communication, C++ data structures are serialized in XML with the help of the gSOAP toolkit. The system is presented in detail in [5].

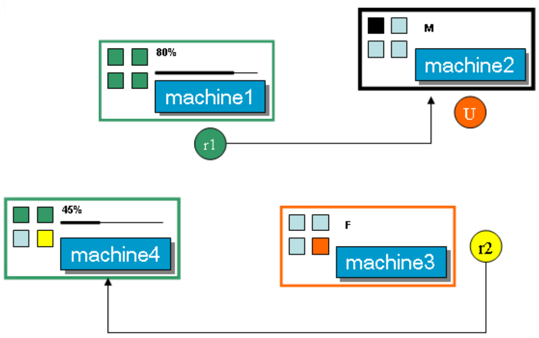

Fig. 2. Interactive visualization of the shop-floor

4. Virtual Reality-based Customization System (VRCS)

The VR-based customization system allows configuring products from parts and immediately scheduling their production through the SCCP services. The system is based on the virtual reality framework [7] and supports both large-scale Virtual Environments and standard personal computers. The input for the toolkit is an abstract grammar, which describes all possible variants of the base product. The grammar is realized in an XML-based format as a tree structure of all variants of parts, which may form the product, with additional information, such as time and costs needed for a part production, links to respective geometry files, lists of compatible parts. The output of the system is a set of parts that have to be produced for the customized product as well as information about connections of all involved parts. These results can be represented both in binary and visual forms and sent to the SCCP for rescheduling of production process.

The user-friendly interface of the VRCS is based on widgets and allows performing the following operations:

- add parts to the scene by selecting them from the menu;
- remove parts from the scene after selecting them;
- connect compatible parts, disconnect them, see current connections in a semi-transparent mode;
- change illumination and material properties;
- save results and send them to the SCCP supervisory services.

The toolkit supports multiple workspaces, thus allowing simultaneous design of multiple products and easy comparison. Furthermore, in the TwoView VR display [8] the toolkit supports simultaneous work of two users. The system renders individual perspectively correct stereoscopic views for each user. Therefore both users observe correct relative alignment of physical and virtual objects. This allows a designer and a customer to work together in a collaborative environment (see Fig. 2). The toolkit has been developed under Linux OS and is mainly written in C++ and Scheme programming languages. The system is described in detail in [9].

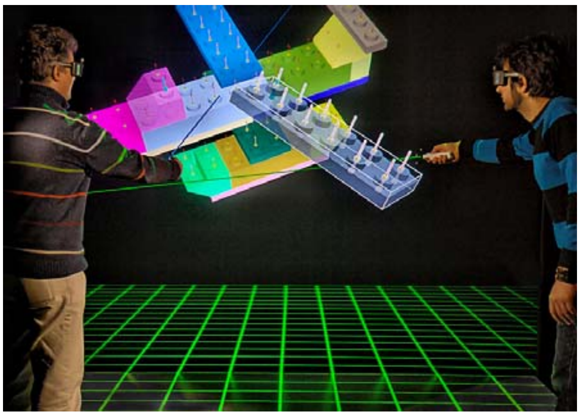

Fig. 3. Collaborative product customization

5. Integration of Machines and manufacturing equipment in the Interactive Production Control

Nowadays, the Machines and manufacturing equipment are controlled by different type of control systems. In the case of machine-tools they have Open Numerical Controls, controls that offer several interfaces allowing access to the managed internal data. Other manufacturing equipments are managed by different kind of controls but in general they also offer interfaces allowing access to the managed internal data. These interfaces make it possible the integration with higher levels of the automation pyramid.

In order to provide richer functionalities we use a framework based on Industrial Agents (SMART framework) that is especially devoted to a manufacturing environment. In SMART, the agents are considered as intelligent entities that can collaborate through communication and update mechanisms. Microsoft .NET and web-based interfaces were used as the base technology. This framework offers functionality for data collection, monitoring and data logging. The SMART distributed scenario is shown in the figure.

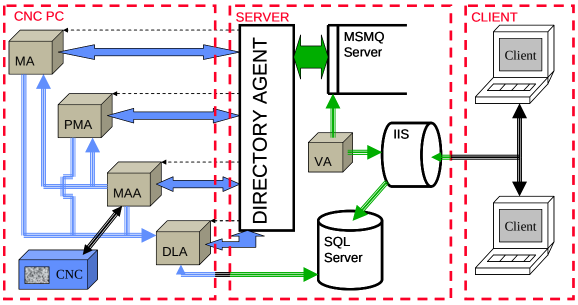

Fig. 4. SMART - Distributed scenario

As a result of the requirements of the INT-MANUS project, a new interface with the numerical control has been decided, based in the GSOAP Toolkit. This implementation of the SOAP protocol allows its use in different programming environments. Therefore using GSOAP we keep the current functionality and we extend the platform to new clients, for example GSOAP can use plain C++ programming.

In the process of keeping the agent base platform but having a lighter version it is possible to re-design the application to use a more state of the art developing paradigm such as Service Oriented Architecture (SOA). The Services could be intrinsically unassociated units of functionality, which have no calls embedded in them to other services. It is just another way of component inter-operation similar to the agent paradigm. Instead of having services embedding calls to each other in their source code, some protocols are defined to describe how one or more services can talk to each other. This architecture then relies on a high-level process to link and sequence services, in a process known as orchestration, to meet global system requirement.

Agents and SOA modules are collaborative pieces of software; they all explain how to interoperate. Agents are autonomous whereas SOA modules require an expert to make the orchestration. The integration of this new approach to the application will benefit from the fact that SMART agents relay on Web Services, so making it possible to change one agent based architecture to service based architecture.

Interactive processes are modelled using a semantic description that is directly related to the production context via instances. The identification is achieved through technologies such as RFID (**Radio Frequency Identification**) and optical recognition. Semantic Message communication is the key feature used in the decentralized communication process. Semantic annotation and content-based routing will enable loose coupling between components and flexible extensibility even at run-time. By semantic annotation, full compatibility can be maintained throughout different protocol versions. Furthermore, semantically encoded performance indicators or maintenance data can be routed along the same communication infrastructure.

6. Robotic Transport System

The Robot developed by ROBOSOFT for the INT-MANUS project is based on a RobuLAB80 indoor mobile platform which was designed to carry high payload. The RobuLab80 mobile platform has been improved for the INT-MANUS project.

The **robot software control architecture** does not only address the capabilities of the robot to assume its own displacement. The robot displacement capabilities are a part of the global control architecture which allows also communication between SCCP, supervisor (fleet manager) and robot. The communication between the robot side (robot and supervisor) and SCCP is made using the .Net technology from Microsoft. Running on the .Net environment ROBOSOFT has chosen the Microsoft Robotic Studio [10] product to develop its robotics control software called RobuBOXTM [3]. The basic principle is to divide a robotic application into communicating services [4], which can run on any CPU of the control system. The control architecture of the INT-MANUS robot allows advanced maintenance by considering the failure detection of robot components (hardware and software).

The interface between the SCCP and the robot is made through a supervisor with fleet management capabilities (**Fleet Supervisor**). It allows to send a mission to the robot but also to monitor the state of the fleet of robots working in the factory. This fleet manager allows also the optimization of the route attached to a mission.

To allow a complete flexible and reconfigurable navigation of the robot, a set of software agents will be developed to complete this fleet manager.

These software agents will concern the detection of problematic situations and the simulation of rerouting and reassignments of the robot mission in case of failure on a production machine. The detection of problematic situations encountered by the fleet of mobile robots while carrying out their assigned tasks, such as traffic problems, unexpected obstacles or inaccessible targets will allow reconfigurable navigation.

The localization of mobile robot **(Robot Localization)** can be sometimes a problem for the navigation in flexible environment. The most classical method, wire guiding, is definitely not adapted to this type of navigation. To allow the flexibility of navigation, a localization method using reflective landmark was developped. this solution requires a minimum configuration of infrastructure for maximum of possible reconfigurability. As an experimental validation of reflective landmark free application, a SLAM algorithm will be implemented. This will be tested in order to validate the reliability of this solution for a fully flexible and reconfigurable navigation of mobile robot in the factory.

7. Evaluation in the industrial environment at CRF

For the industrial environment, the project brings high innovation in the field of customized production, allowing to achieving a complete flexibility in terms of variety of parts produced, with fast reprogramming and reconfigurability. In the case of automotive production, parts may be quickly customized, modifying the geometries and reprogramming in a smart way the whole process chain, thanks to a VR representation of the impact on the whole production flow of the plant. The process and material flow for the new product is generated, with all the details on process time and machining scheduling inside the production plant. Finally, production can start. As it is important to test the integration of the different components, the whole prototype will be setup in order to simulate the production of an automotive component, such as an engine part, which requires an optimised planning of the production. In fact, in plants where high series are produced (many thousands/year), like in the automotive environment, no delays are allowed due to failures of machines and tools, because it would mean loss of production and delivery delays, with high costs for penalties to be paid by suppliers, if they are not able to provide the products on time. It follows that quick failure detection and an accurate maintenance program are of fundamental importance for the industrial overall performance. The Advanced Machining Laboratory is used to set up the demonstrator, connecting the machine tools and having a first assessment of the customisation possibilities of the parts and of the production process. The system can rely on 3D cad models of the components, which can be used and varied by an user. If the modifications fulfil the machine capabilities, the parts will be produced accordingly. The tracking system will keep an eye on every movement in the shop floor and allow optimising the production flow.

8. Maintenance Concepts

Predictive Maintenance concepts are transferred from definition-oriented to a context-based approach supported by an adaptive system. The objective of condition-based predictive maintenance applied to machine tools is the “measurement” of the slow degradation taking place in mechanical components in advance of the consequent failures and the evaluation of the residual life in order to better manage the total Life Cycle Cost.

The architecture selected for this achievement is shown in the following figure:

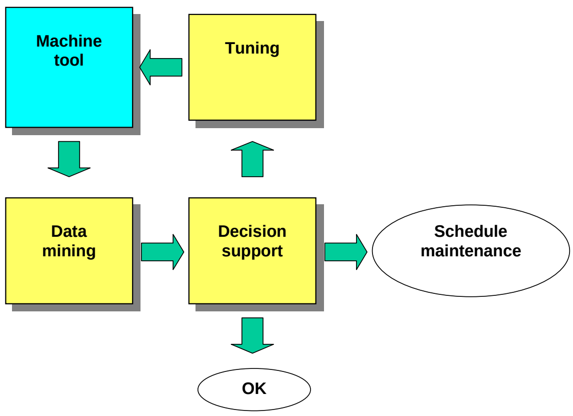

Fig. 5. Maintenance Architecture

Sensors collect data from the Machine Tool; the Data Mining software module is organized in form of a data processing pipeline and can be split in three main phases, comprising data collection from sensors with the suitable frequency, data filtering and extraction of some indices indicating the state of “health” of the mechanical parts (meaning the status of wearing out of components) like vibration critical frequency, damping factor, backlash (error at the inversion of the direction of movement), maximum and average value of current, ripple of current.

The Data Mining software provides indicators to a Decision Support module that selects the possible action, choosing among the following:

- Do nothing because the system is working very close to an optimal situation;
- Self-tune the system, whenever possible, in order to achieve a different trade-off between accuracy and time; in fact, for instance in the production of moulds and dies, the tuning of a machine tool is usually based on the selection of a suitable compromise: if the working operation is faster, it is normally less accurate, and vice versa. The optimal compromise depends on the kind of operation; for instance during a roughing operation, accuracy is not at all required, therefore the tuning should optimize the execution time (and cost, as a consequence).
- After a certain threshold, it is not efficient anymore to slow down the machine, and an intervention for the substitution of a mechanical part is needed. The resulting reorganisation of the plant schedule should be automatically performed. The production plant supervisor should be notified about this decision and the possible reason and mechanical parts to be substituted.

In a following phase, several machine tools (some of them of the same kind, some of them of different kind) are connected to a Remote Knowledge Repository where all data are stored. Stored data are relative to:

- Previous faults;
- Results of previous evaluations of residual life;
- Results of previous tuning operations;
- Results of previous rescheduling operations.

The Knowledge Repository has to be able to transform information into knowledge, and learn by the correlation of data. For instance, applying this philosophy to diagnosis, the system will be able to correlate machine failures with factors like the climate or with the use of the machine.

9. Summary and Conclusion

INT-MANUS provides a decentralized peer2peer platform for production control, integrating advanced maintenance, robot system for transport, RFID, access to numeric controls and AR / VR technology for enhanced user experience. The project will develop further two prototypes which will focus on the semantic technologies and messaging as well as advanced recognition and interaction technologies supported by a knowledge base.

Acknowledgements

INT-MANUS Project is funded by the European Commission and has emerged out of the European Network of Excellence I*PROMS, supported by its virtual Institute VIMATION.eu.

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