Design and engineering processes in highly adaptive plants with ambient intelligence techniques

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Abstract
Ever more complex engineering processes, shorter product lifecycles, increasing cost pressure and a wider range of product variants force plant manufacturers and operators to enhance adaptivity and interoperability of their plants. In addition to the modularization of hardware, this requires a high degree of flexibility of the associated software. In view of these challenges, methods and mechanisms have been developed in the ProduFlexil research project resulting in modified requirements for the plant planning procedure. In this article, changes will be contrasted with the state of the art. Thereby, both, advantages and challenges of the 'automation of automation' will be highlighted.

Keywords: Engineering, Flexibility, Design method

1 INTRODUCTION
In the following publication, engineering is viewed as a process to which multiple parties contribute using a wide variety of tools (see [1]). This process is both cost-intensive and error-prone and includes a multitude of technical as well as human interfaces. To enhance the adaptivity of plants, it is necessary to find generic, reusable solutions to meet these very challenges. In this context, adaptivity and interoperability refer to the capability of plant (components) to cooperate with each other and to interact with their environment. Ultimately, hardware and software must be as adaptive as possible, which means that they have to be able to adapt flexibly to known modifications in a plant as well as to modifications not known so far. The ProduFlexil¹ research project ([2], [3]), sponsored by the Federal Ministry of Education and Research, deals with adaptivity and self-configuration of manufacturing plants by developing appropriate software mechanisms and architecture patterns that allow plant and plant components to be integrated in an existing production system as efficiently as possible. In this context, the focus is, for one thing, on enhancing the flexibility of the plant software and, for another, on the configuration and integration of superordinated systems, e.g., a production monitoring and control system. In line with the definition by Polke [4], a production monitoring and control system is meant to support shop-floor staff in operating their plants and controlling and monitoring the production processes. By 'configuration' the authors mean the unambiguous name of a constellation (hardware and software) in a production site on the basis of which a certain product can be manufactured in a specific quantity and quality. Each modification to the configuration which does not have any impact on output and quantity is called a new version of the configuration.

The following article will describe the actual state in the plant engineering and configuration process to be found with the application partners of the project. The actual state will then be contrasted by a description of the new workflow, which supports human beings through Ambient Intelligence mechanisms when modifying existing plants or taking new plants into operation. The employment of the newly developed mechanisms and components affects both the work with the digital factory and PLC programming as various preconditions need to be taken into account. In addition, the customization of the production monitoring and control system, which was previously carried out manually, is automated. This article will therefore highlight the aspects that result from the aforementioned changes. To enable the automated proposal of optimum configurations, the data gathered from the production monitoring and control system is evaluated and used for optimization.

2 DESCRIPTION OF THE CURRENT PLANT PLANNING PROCESS
To highlight the contrast to the methods of tomorrow, the standard procedures actually in use (state of the art) will be described in this chapter, i.e. the methodologies currently applied by our partners (similar to [5]). In this context, tribute has to be paid to the fact that factory planning is a very dynamic process in which all phases of the project are performed in several iterations.

2.1 Customization of a new plant
The customization of a new plant is broken down into the phases of rough and layout planning, hardware engineering, software engineering and start-up (Figure 1).
During the start-up phase, the hardware is checked first of all. This means that a functional test of all components, sensors and actors is performed. In this process, all components are checked in view of the question whether they work in the way expected by the software. The start-up of the software is carried out in three stages. First of all, the software is loaded, tested manually and optimized. Afterwards, the cycle time model is executed in a step-by-step mode. Finally, a functional and performance test is performed. Once this test has been completed, the cycle time and process quality has to be verified and optimized, as necessary. During the optimization phase, the settings, the parameters and the structure itself are usually modified. Thus, the real-world plant and the digital model drift apart. As a consequence, the digital model has to be verified against the real-world plant when the plant is altered or upgraded, at the latest. If cycle time and process quality are satisfactory, the plant is approved. Before the plant is finally approved by the operator (customer), the plant manufacturer (KUKA) approves the machines and equipment purchased from suppliers. These machines include robots, transportation devices, controllers, welding guns, etc. Basically, the documentation of the individual devices and aggregates is checked in view of consistency and completeness and certified afterwards. The functionality must be proved by the functional and performance test in this phase of the project. The final approval of the overall system and its release to the operator is essentially the certification of the provided scope of delivery and service. One significant result is that the digital model comes as close to the real-world system as possible at that point in time. According to the state of the art, the digital model comprises all the software and data (documents, images) describing the overall system (product, process and resources). It is in the interest of both the supplier and the operator of the system to document the approved state as close to reality as possible. When the system is finally approved by the operator, a full backup of the entire software (programs and data) is made and archived by the plant manufacturer (KUKA).

2.2 Modifications to an existing plant (alteration)

If an existing plant is modified or altered, various steps have to be executed (see Figure 2). Usually, the current plant no longer complies with the state of the archived final documentation and the software backup for a wide variety of reasons. In most cases, the plant in operation is modified and optimized even after it has been approved. For this reason, the first step is always the update (verification) of the documentation on the basis of the real-world plant. At least, it has to be verified whether the documentation as archived during the final approval, is still up to date. During the planning phase of the modification, the new requirements have to be specified and taken down in a requirements specification, new components have to be selected, a schedule needs to be drawn up and each of them has to be approved by the operator of the system.

If new known components are to be included, they are added to the updated project of the component data management (CDM) at the appropriate places. By extending the CDM project, basically a new modification cycle is started. The process then continues with the component data management.

If a new unknown component is to be integrated, the manufacturer and/or supplier of the new component has usually been identified during the modification planning. In cooperation with this supplier, the scope of delivery and service has to be specified.
The next step is a complete technical specification of the new plant. This includes data such as engineering and dimension drawings, energy requirements (electricity, voltage and air consumption), information on emissions, safety and accident prevention measures, wiring and connection diagrams, transportation and set-up instructions as well as the interface with the superordinated control (input/output signals – analog or digital). Once this data has been provided, the new component is added to the component library of the CDM. Now, it is known and the further procedure that follows is in line with the one for a new known component (see above).

3 THE PRODUFLEXIL APPROACH

Figure 3 shows the conceptual view of the ProduFlexil architecture developed by Fraunhofer IITB. The heart of ProduFlexil is the change management comprising the components for adapting the plant. The change managers are the central components coordinating the modifications to a plant. The control software managers are the interfaces with the control components of a plant. They transmit modifications to them, monitor them and notify modifications to the change manager, which, in turn, triggers the superordinated production monitoring and control system. The change managers can access the configuration and component data. The data of the currently loaded configuration is automatically transmitted to the production monitoring and control system engineering. There, the information is processed further and the linkage of the control technology to the process signals is triggered, for instance. The quality data returned by the production monitoring and control system, in turn, is stored in the configuration library by the change manager. In addition, the change management is responsible for comparing the two (real and virtual) worlds. Owing to the symmetric structure of both worlds, the comparison is a rather straightforward process.

ProduFlexil is usually illustrated by a cycle of turntables and conveyor belts, among other things. By way of example, a test station is to be connected or disconnected to its free ports. In order to show the practical use of the results, application cases were defined on the basis of the demonstrator and implemented in the project. For one thing, a new unknown component or a new known component can be added to the configuration of the system. For another, a new system configuration can be created, or users can shift to another known configuration.

![Figure 3: Overall ProduFlexil architecture.](image-url)
4 CHANGES IN THE PLANNING PROCESS

4.1 Aml support

Ambient Intelligence (AmI) is the vision of 'intelligent' environments that respond to the presence of human beings and objects sensitively and adaptively and provide a wide range of services to human beings. This refers to human beings in all situations of life, i.e. people going out for work, elderly singles or men and women in their leisure time. In technological terms, AmI is usually based on a network of nearly invisible, networked computing units that collect information using various sensors, process this information and have an effect on their environment and thus on human beings by means of actors. AmI technology can be applied to the optimization of the engineering workflow in a number of ways. In the context of ProduFlexil, the focus was on the adaptation of the control logic subject to changing marginal conditions. The starting point was a plant structure consisting of components the communication interfaces of which are described in a way that allow for a defined control logic by linking the ports to other components. In this process, meta information on the interfaces allow certain inter-connections of the components under review to be rejected and, in unambiguous cases, the only possible connection to be identified. However, the modification of the control logic cannot be carried out in a fully automated way for safety reasons. In order to prevent accidents, for example, it will always be necessary to have a human being who understands and approves a modification and who is responsible for it in the follow-up process. The way in which the modification is carried out, by contrast, has a potential for optimization. To this end, ProduFlexil makes use of AmI technology to create a control loop in which human beings are included as a control authority. Possible modifications to the control logic are proposed by the system, and other adaptations that cannot be performed automatically are supported in an intelligent way (Figure 4).

4.2 The ProduFlexil workflow

The following list summarizes several important points of style to keep in mind when preparing your paper for the

The phases of rough planning and hardware engineering (compare Figure 1) remain unchanged even when the ProduFlexil approach is applied. In that area, the digital factory described in the next paragraph is of greater significance. The ProduFlexil workflow also starts with a quantity structure and an first concept, on the basis of which the supplier can create an offer for the OEM (Original Equipment Manufacturing). The phases of software design and start-up, however, change radically. The precondition of the ProduFlexil approach is to develop a library of reusable components. The internal structure of these components may be very complex since any state or event has to be processed flexibly. In addition, the internal state has to be well defined at all times. This is roughly in line with the programming of user dialogs. Older systems used to proceed sequentially, i.e. step by step. State-of-the-art, windows-based dialogs, by contrast, manage a large number of possible events and define possible responses. The aforementioned section 2.1 entitled 'Customization of a new plant' described the workflow applied today to developing the control software. In this process, changes to the plant layout indispensably result in the system being re-programmed. New plant components such as 'add test station' result in new hardware addresses and changes in existing as well as the redefinition of logical inter-relations. For this reason, software engineers have to understand their predecessors' minds when integrating a new component. The right addresses have to be identified and composed to form new logical networks.

The ProduFlexil approach is based on the paradigm of 'configuring rather than programming'. The control concept of this approach can be seen from Figure 5. For the individual elements, encapsulated elementary components are developed which work in a decentralized way. The system can be programmed solely by combining and linking the elementary components. This fundamentally changes the engineering workflow as the engineer can select elements from a library and link them to each other using well-defined interfaces. This opens the door for the development of automated and ambient concepts.

In addition to affecting software engineering, this approach also has an impact on the start-up phase. Up until now, the alteration of plants has been very cost and time-intensive owing to the associated re-programming, in particular. Furthermore, alterations frequently cease to be documented and updated in the digital model in practice for a lack of time ('always hurry on the building site').

Figure 4: Modifications supported by Aml software.
Thus, the verification of current plant configurations against their digital model is utterly time-intensive at the moment. This situation can only be remedied by standardized alteration processes as provided by ProduFlexil. In ProduFlexil, the engineering of the plant was carried out in parallel in the PLC customization tool (here: Unity by Schneider Electric) and the digital factory (here: Delmia Automation). In this process, the digital model was planned on the basis of the aforementioned elementary components in such a way that only straightforward, well-defined modifications to the real-world plant are required.

4.3 Digital factory

The vision of the digital factory is aimed at mapping the real-world factory in a data model that is as realistic as possible. This basically results in three new challenges for the digital factory.

- New engineering methods (which may even go as far as a paradigm shift)
- Integration: redundancy-free storage of data, networking with construction site/sub-suppliers/customer/…
- High degree of standardization: libraries of components/processes/interfaces/…

The following considerations are based on the precondition that a ProduFlexil-compliant library of mechatronic components is available. For the planning process of the operating resources, the existing approaches can be maintained. The higher degree of standardization even simplifies this phase. This results in a much more practice-oriented model for simulation. Since simulation is no longer based on abstract components, the degree of accuracy can be enhanced. For the buffer design in automotive shell engineering, for instance, downtimes and probabilities are assumed. If it succeeds to introduce the module-based approach as early as into the rough simulation, the simulation will be put on a much sounder data footing. Fine simulation, by contrast, is not based on approximated logics; instead, it is based on control logics, which will later be deployed in the real-world plant. This allows for a much sounder simulation. The challenge is to create a control logic that is as realistic as possible, e.g. for the safety mechanisms in logics. For the start-up phase, there are simulations which take account of all marginal conditions (such as manual operation and errors) in a realistic way. This renders the follow-up adjustment far less time and cost-intensive. Start-up is implemented in three steps. The first step includes a closed loop simulation. Here, the simulation is performed in the virtual environment exclusively. In a second step, a ‘hardware in the loop’ simulation is carried out. In this process, the simulation responds to the control logic in the same way as the real world, with the control logic running on a genuine PLC. The last step is the operation of the plant itself.

4.4 Customization of the production monitoring and control system

Before a production monitoring and control system can be deployed in real-world operation, it has to be customized. In general, customization consists of three tasks: customization of the plant, customization of I/O and customization of the visualization. In plant customization, the topological and structural make-up of the plant is determined manually. During I/O customization, the topological and structural make-up of the plant is determined manually. During I/O customization, the customization manager links the real-world process signals to the individual elements of the appropriate plant either manually or in a semi-automated way. In the context of the customization of visualization, the desired process signals and plant components are represented by graphical objects or I/O fields. In this process, both the images are created and the elements are linked to the process signals that have been pre-processed by the production monitoring and control system.

The new workflow of production monitoring and control system customization and/or engineering introduced by ProduFlexil significantly reduces the manual and thus error-prone part of the configuration. The data relevant for the production monitoring and control system is now transmitted from the change management in the standardized CAEX format (Computer Aided Engineering Exchange, see [7]), while the production monitoring and control system (CS) plant customization, the CS I/O and the CS visualization customizations are carried out in an automated way (also see [8]). CAEX is a supplier-
In specific cases, the scope of the evaluations can be extended, as necessary. The evaluated data is returned to the simulation in the form of an XML document. In this process, the result is independent of the production shifts since it is merely based on the runtime of the configuration. The advantage of the time-based evaluation and the XML-based results is that they allow the data to be processed electronically. It can thus be used by the change management to assess the configuration. Thus, the optimum configuration can be proposed to the user.

5 SUMMARY

This article has described the workflow of plant design and engineering and the changes introduced by the methods and mechanisms developed in the context of ProduFlexil. These range from PLC programming to the use of the digital factory and the customization of the production monitoring and control system. At the same time, new potentials are opened up by using the information obtained in the virtual world. This allows the control loop between the real and the virtual world to be closed. For a wide variety of reasons, the information status of the real-world factory does not comply with the status of the digital factory. With respect to the ProduFlexil architecture, this means that the data in the change manager of the real-world plant and the data in the change manager of the digital model will not be identical at all times. However, to be able to make the most of a digital factory optimally while keeping additional costs at a minimum, it must be able to synchronize the real-world and the virtual plant. Thus, a verifying or synchronizing mechanism has to be implemented, which allows users to identify the differences between the real and the virtual worlds and to decide how they can be harmonized. In order to be able to provide these kinds of ‘wizards’, modifications have to be executed in a well-defined way.

6 REFERENCES


