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Following the scientific and technology roadmap issued in the European Network of Excellence on Innovative Production Machines and Systems (I*PROMS, see <http://www.iproms.org>), Schneider Electric actively worked in the continuous development of Key Enabling Features associated to the use of simulation (related to the Ambient Intelligence paradigm) in different phases of the life cycle of production control and automation systems. This paper summarizes research work performed within the project Produflexil, founded by the German government (BMBF). The project used Ambient Intelligence (Aml) concepts as one major objective to enhance the flexibility of production systems, by improving the adaptability and the self-configuration of control software. This had been achieved by the use of specific modular design concepts of the control software, as a prerequisite for Aml tools. Adding or removing devices was formalized to a standard procedure, so that it was possible to develop a software tool that supports operators and engineers if the production system has to be changed, without the need of re-programming. The advantages of the selected approach are that, on one hand it can be used on currently available software and hardware equipment, and on the other hand, that there are no breaks in the information flow between virtual and real control software design tools.

Key words:

Distributed control systems, ambient intelligence, reconfigurable automation systems

I. INTRODUCTION

Manufacturing companies are required to produce with a larger number of variants to meet cus-

tomers needs, which implies an increase of the engineering efforts and correspondingly the costs (Fig. 1). In addition, the time to market makes this situation even more difficult, as the company, which has the new product first will have the biggest profit.

The challenge is that in contrast to the increasing number of product variants and shorter product lifecycles, the production equipment has a longer lifecycle compared to that of the products, which leads to requirements for more flexibility and agility. [1]

Besides the requirement to manufacture different variants in one production line with small lot sizes (optimum: one-piece-flow), quickly changing capacity adaptation due to customer demand is a second driver for the requirement of more flexibility and agility. Furthermore, production systems are often used for more than one product generation. As a consequence, the engineering effort explodes. High flexibility on a daily base is not available in many cases.

One general answer to this problem is to reduce the engineering effort per variant by standardizing on modular components, which can be complex internally, but are simple to configure (Fig. 1). This is a well known approach in the software engineering.

The configuration of the control software, needs to be as simple as possible. In the best case, changes can be made automatically, so

Modular Control Software for Ambient Intelligence in Production Systems

that new intelligent technologies can be used.

There are different possibilities of system support for setting configurations. The focus of this work was to implement systems, which use Ambient Intelligence (Aml) technology for automation systems. [1] Ambient Intelligence (Aml) 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. In technological terms, Aml 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. Aml 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 adaption of the control logic in case of changes in the production environment. [2]

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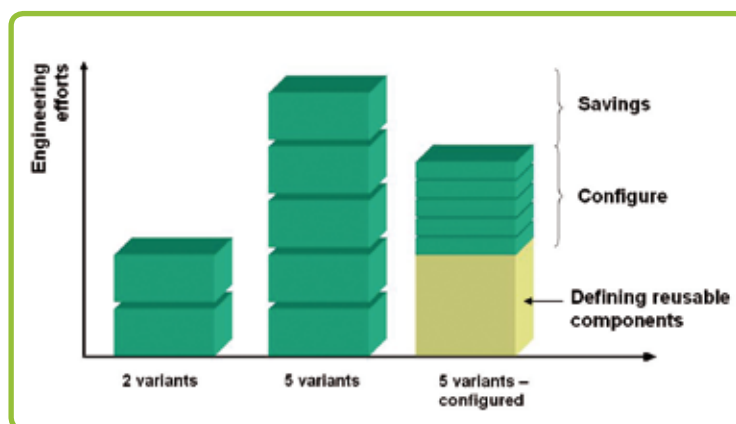
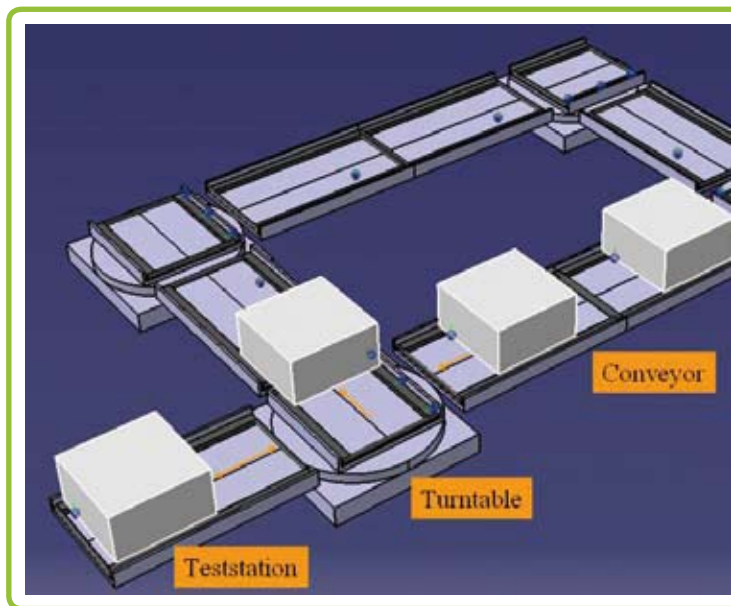


Figure 1.:

Example: Number of product variants increase from 2 variants to 5 variants. Defining standards and configure different alternatives instead of programming each case individually is the main challenge for new control software architectures

Figure 2.:

Test scenario to simulate a typical change in the lifecycle of a production system. A new bi-directional conveyor element is included in the production flow that transports products to a newly included test station.



The project ProduFlexil with partners Fraunhofer IESE, Fraunhofer IITB, Kuka Systems GmbH and Schneider Electric was created to analyze the possibility of the adaption of Aml concepts to production systems [3]. The aim was to enable production systems and industrial production facilities to be quickly reconfigured when changes occur. The authors were focused on improving modules' adaptability and self-configuration through flexible connections.

As prerequisite, individual modular control software components were required, so that an Aml-based software tool can operate on a well-defined environment. A second requirement was to have a seamless integration between virtual engineering tools and real applications. A special focus had been placed on development of a system that can be updated automatically, if there are changes in the virtual or in the real world. An Aml system was included in a loop, so that an engineer is supported if a new configuration of a production system has to be made. [4]

Thus, a consistent engineering process without model break between construction and control logic was supported. The ProduFlexil approach is based on the paradigm of "configuring rather than programming".

II. TEST SCENARIO

A test scenario was defined to reflect a typical situation in the lifecycle of a production system (Fig. 2). It consists of turntables, linked through conveyor elements and a test station (in the figure on the left this element is represented by a bidirectional conveyor).

Considering that the manufacturing process has been changed e.g. due to some quality problems of an imaginary product, a new element has to be integrated into the production flow to test the product. As an example, a turntable has been chosen, where a bidirectional conveyor is connected (Teststation). This conveyor is used to transport the products to the test station, where the products could be tested.

In order to answer to the requirement for an integration between real and virtual environments, 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).[5][6]

III. APPROACH

A virtual model was built to design the logic. As a tool, Delmia Automation [5] was chosen, because it allows the development of control software that is similar

to IEC 61131. It also allows defining control logic components in the simulation environment and exporting these elements into PLC software design tools later (e.g. UNITY [6] from Schneider Electric). This approach is useful, even if the control logic is completed in the PLC design tool, after the first definition in the virtual environment. Delmia Automation allows switching between a "Closed Loop Simulation", where the PLC is simulated by the tool, and a "Hardware in the Loop simulation", where a PLC is used to control the model.

For the complete scenario, the virtual model of the conveying system had to be connected to the control logic. Delmia Automation presented two options available:

- a.) the control logic is directly entered into Delmia Automation („Closed-Loop Simulation“) or,
- b.) the simulation model is connected to a real PLC via OPC connection („Hardware in the Loop Simulation“).

Through similar building of the control logic with function blocks and connections, it was even possible to generate automatically the PLC program for the tool Unity, from the developed in the Closed Loop Simulation program. Technically this is possible because both Delmia Automation, as well as UNITY, are able to import and export logic in XML format. Using this, an Aml tool, based on XML data manipulation, can be developed.

IV. IMPLEMENTATION & RESULTS

The first step to design the control software consisted in developing the conveyor logic, which is able to act individually without any hierarchical dependencies. The interaction between the different modules is reduced to only one communication protocol between the linked objects. In order to make this approach more flexible, the conveyor was developed with the possibility to parameter-

ize it with length and speed attributes. Three types of modular logic components have been designed: “conveyor”, “turntable” and “transport”.

The standard conveyor element has one sensor and in order to keep the demonstration model simple, a two step-like behavior (“transfer in” and “transfer out”) was used. One challenge was the queuing of products without a hierarchical decision mechanism. The conveyors are linked to each other through a communication protocol that issues a signal when the conveyor is ready to accept a new product. This model is suitable to create a complete system of conveyors (Fig. 3).

Another standard element developed was the turntable component. The basic algorithm of the standard conveyor could be used here too. As an enhancement of the single conveyor element, the logic was extended to a bi-directional behavior, so that two different behaviors exist for “transfer in” and “transfer out” respectively.

The last element built was the “transport” element - a bi-directional conveyor to the test station (not shown in Fig. 1). The same algorithm as the one used for the simple conveyor could be applied, with the only change being the direction of the motor, so that the “transfer out” behavior of the product is on the same side as the “transfer in”. The process of testing the product was simulated with a panel element and a button. The operator can simulate the test by pressing the button

and the product will move back into the system after this is being done.

The environment in the sense of Ambient Intelligence is given by the components and their interface, which are forming together the production system. A configuration can be defined as a set of these components and appropriate control software, so that the system functions properly. If it is working as expected, the quality can be defined as “good”, or,

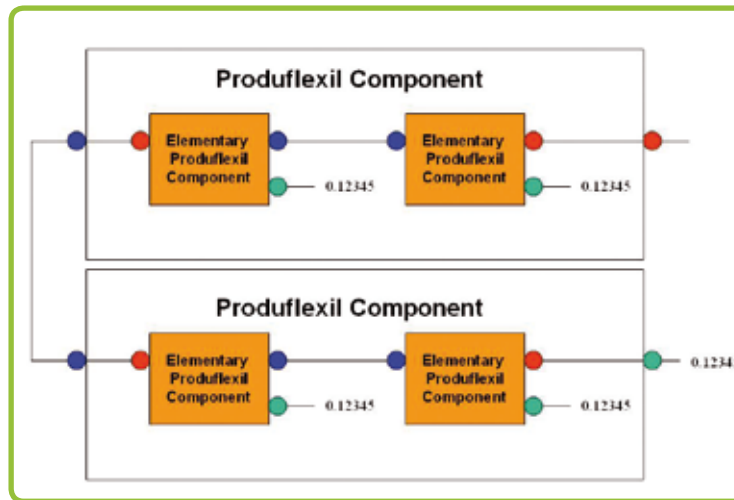


Fig. 3.

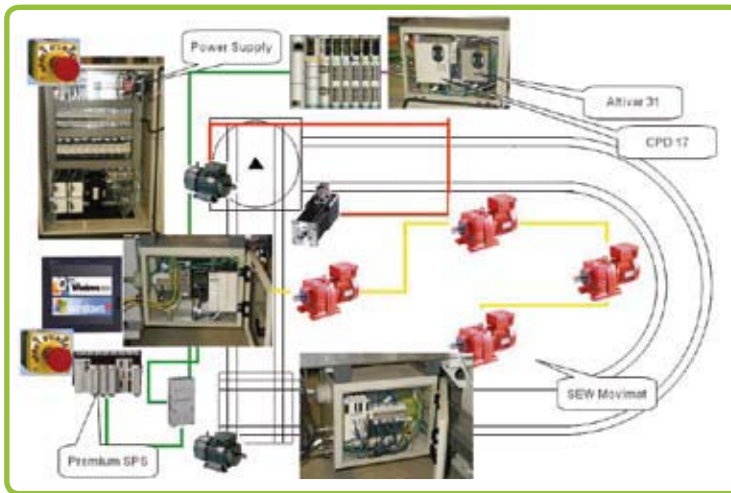
Design concept of the modular logic component. The boxes represent independent modules. The circles stand for parameters and variables that are interfaces to the module (ports). The green ports represent definitions of parameters (constants), the blue ports represent connection variables (private) and the red ports represent variables that are required or defined outside the module (public). The complexity is hidden in the elementary building elements (orange boxes). The specific control logic is defined by combining these elements to higher level structure, like a Russian doll.



Fig. 4.

A picture of the used test bed (KRAUSE)

Fig. 5.:
Graphical representation of the best bed



otherwise as “bad”. If an added component is not known, a registration process is required.

The implementation of the structure mentioned above, performed in Delmia Automation and in UNITY, proved that the described architecture is sufficient to control the behavior of the system, and drive the simulation model as expected according to the requirements of the system’s user.

V. TEST BED

The developed ProduFlexil concept (elementary building blocks, which contain the complex logic and can form more complex components and be used to build to overall control logic of a system) had been tested on real test bed: conveying system from KRAUSE, composed of conveying belts, a turn-table and different stations (Fig. 4). A Modicon Premium PLC was used to control the test facility. Some details of the construction of the test bed are shown on Fig. 5.

The first step was to verify whether different production scenarios

Fig. 6.:
Change scenario – Logical removal of one of the station

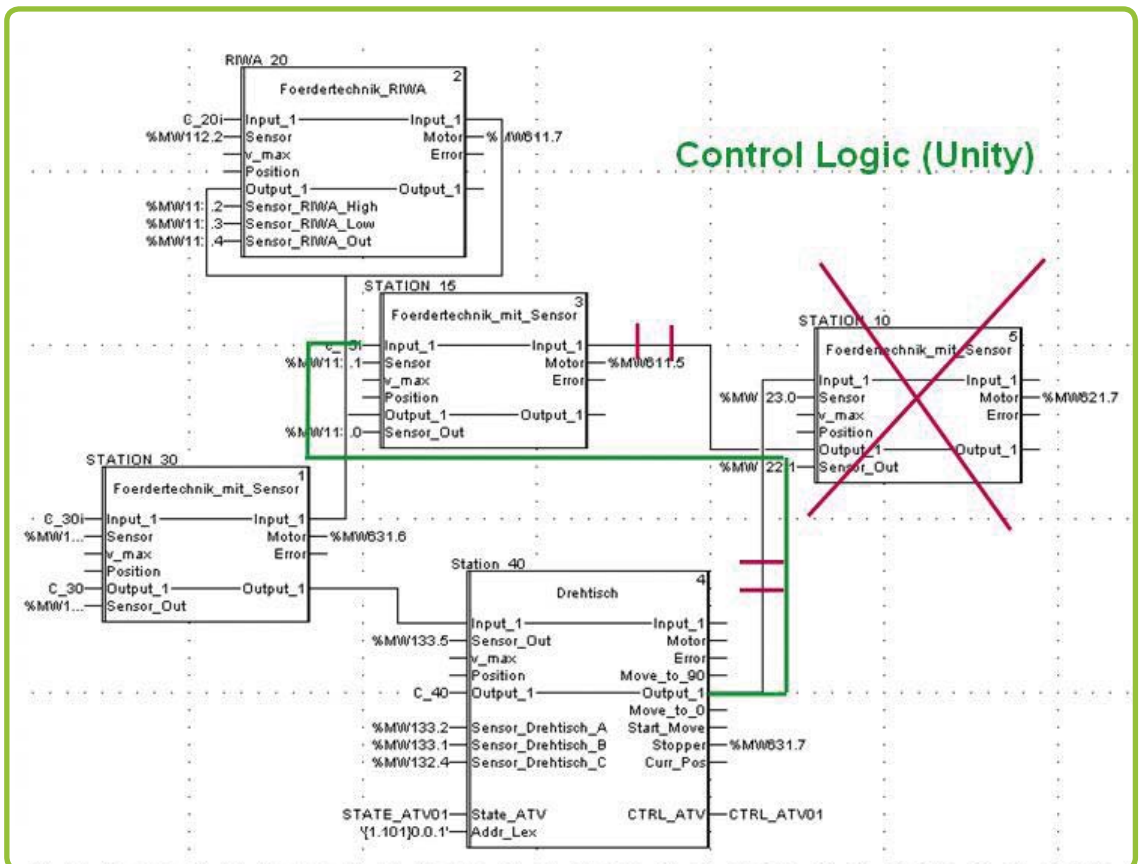
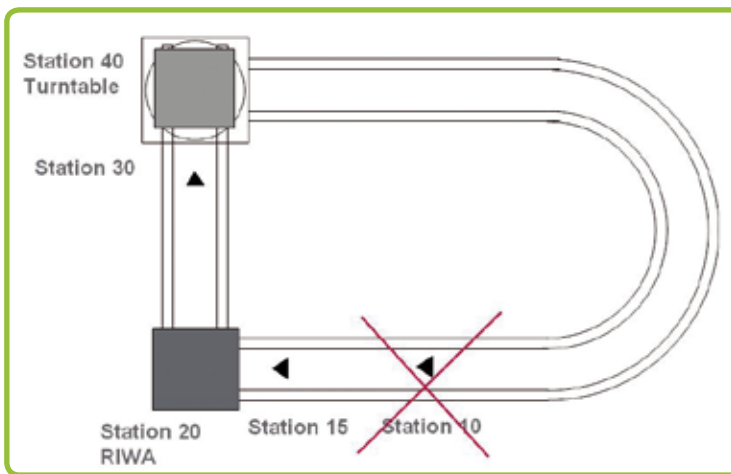


Fig. 7.
PLC logic reconfiguration in case of change in the test scenario

can be built with the developed re-usable components, without reprogramming the system, but only by reconfiguring it. This modular approach is a prerequisite for new approaches in automation technology, in our example, Ambient Intelligence.

For the development of the control logic, modular function blocks were used which have been developed for the virtual turntable demonstrator with the Delmia environment. The used components were "turntable" and "conveyor". Except for minor adjustments, the modular logic was imported without changes. These adjustments were caused, for example, by the fact that the time behaviour of the frequency converter was not reflected in Delmia Automation, and all the conveyors in the virtual model were fed from one source (in the real system a station with stopper, mechanical sensor, was associated to every conveyor).

These problems were solved by additional modular initialization logic without a fundamental change of the Produflexil concept.

In order to prove flexibility, we wanted to examine a change scenario in this particular production system. One of the stations was logically removed from the control logic (Fig.6). The result was that the palette was stopping no longer at that station (Station 10 in Fig.6) but was going further. In practice, such a case would occur if, for example, an assembly station is no longer needed. The adaptation of the control logic consisted in simple rebinding of some of the function blocks, achieved quite fast (Fig.7). For the conventional approach more time can be estimated, since usually a number of global parameters might be needed to be adapted.

The simple takeover proved how flexible can be built a PLC program for a new scenario, using the Produflexil components.

In this example, the control logic was adapted manually. In the project, as a common output of the partners work, was developed a tool, Aml software, to assist the user when a change in the production system occurs. In case of a change in the environment, the Aml software offers help for adapting the control logic (the links between the disconnected function blocks, from the above presented example, are generated with the support of the tool). The user accepts proposal or carries out modifications with the help of the Aml software. The control logic is then adapted to the new configuration. [4] [9] The selected modular design enables the tool to work on a well-defined database. Adding and removing devices is simplified to the creation of connections, setting parameters and defining ports to upper type logic.

VI. CONCLUSION

The main objective of the work exposed in this paper was to bring flexibility to control software as basis for the use of Aml-based architectures as a later step. The authors designed a control system based on flexible connections of modular components.

The proposed design concept has some major advantages compared to a more traditional, unstructured, programming. The elementary building modules contain the complexity of the control logic. In the best case, these reusable components can be configured, so that the control logic can be readjusted by reconfiguration, instead of reprogramming, if changes in the production environment occur. This is a prerequisite for the implementation of new automation technologies, in our case, Ambient Intelligence. Nevertheless, this approach is also useful for other technologies like Service-Oriented Architecture (SOA)-based automation systems, because the ProduFlexil concept is also based on distributed de-

centralized control units that are easy to configure [7] [8].

Another important advantage is the analogy of this concept to the hierarchical construction tree that is used in common CAD packages. The possibility to create control logic with the same structure as the construction tree, leads to a seamless information flow from product development to automation.

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