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COMPONENT-BASED DEVELOPMENT OF CONTROL SYSTEMS FOR BATCH PROCESS INDUSTRY

КОМПОНЕНТНО-БАЗИРАНА РАЗРАБОТКА НА СИСТЕМИ ЗА УПРАВЛЕНИЕ НА ПЕРИОДИЧНИ ПРОЦЕСИ

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Abstract: Modeling of batch process control over several hierarchical layers is proposed in ISA S88, independently of a concrete implementation. IEC 61499, describes models to implement distributed control systems. This contribution proposes to combine the concepts of ISA S88 for hierarchical design with the models of IEC 61499 for distributed implementation. To formally describe and analyze the control sequences, Signal Interpreted Petri Nets are utilized. From the verified description, the implementation is derived using pre-defined IEC 61499 function blocks either by hierarchical aggregation of the blocks or by using a scheduler. The scheduler approach allows re-configuration of the sequences without altering the implemented controller. The proposed approach offers analyzable formal models, re-usable basic components, and re-configurable distributed implementation.

Key words: Batch control, IEC 61499, ANSI/ISA S88, Petri Nets

INTRODUCTION

In the process industry ANSI/ISA S88 [1, 2] and its IEC standard equivalent IEC 61512 [3] provide domain specific models for design and control of batch production processes. The models allow the description of continuous production of finite quantities of materials (batches) from two distinct views. The first view, the one of a chemical engineer, focuses on the problem "What has to be done?".The second view, the one of a control engineer, focuses on the problem "How is it to be done?".

S88 defines models and proposes a development process. However, it does not specify means to implement designed controllers. Here, the engineer relies on concepts from the domain of control engineering. Current state of the art for implementation of logic controllers is the technology described in IEC 61131-3 [4]. This standard defines a software model and programming languages for centralized control systems based on PLCs. Recently, due to the increasing demands on modularity, re-use, and reconfigurability the concept of distributed controllers covered in the IEC 61131 follow-up standard IEC 61499 [5], becomes more and more attractive to control engineers.

The methodology proposed in the following combines the S88 standard for batch process design with the IEC 61499 standard for distributed control implementation. Related works that combine the use of S88 and IEC 61499 are presented in Peltola et al. [6] and Thramboulidis et al. [7]. Their approaches adopt Procedure Function Chart (PFC) according to S88, as specified in ANSI/ISA-88.00.02 [2], to describe the batch procedure. After design, a one to one mapping from PFC into an IEC 61499 function block network is performed. This has the drawback, that changes in the operation sequences require changes of the PFC as well as of the FB connections.

To avoid this drawback, in this publication the S³ approach according to Panjaitan [8], proposing a software architecture that deals with re-configurability by task scheduling of basic functions in IEC 61499, is added to improve the flexibility of the resulting control system. To address dependability aspects, the formal model of Signal Interpreted Petri Nets (SIPN) given in Frey [9, 10] are used in order to describe the execution schedules in a formal way for analysis of the system.

The paper continues the research topics described and discussed in [11, 12] and is organized as follows: the next section briefly describes the component-based approach combining S88, SIPN and IEC 61499. Section 3 presents a case study that will be used to illustrate the proposed approach. Finally some conclusions are drawn and an outlook on the further work is given.

DESCRIPTION OF THE COMPONENT BASED APPROACH

The approach presented in this paper is related to the development of common functional components.

By using this approach, once the generic functional components are built, their control property can be reused for a component with similar functionality. Hence, engineering time can be reduced.

The proposed approach is divided into three activities: functional component development, control recipe modelling using SIPN, and mapping of the model to an IEC 61499 application. Fig. 1 illustrates the proposed concept to combine ISA SP88 (high-level) and IEC 61499 (low-level).

The goal is to provide highly reusable components concerning batch process and an easy way to reconfigure their executions. As a result, the control strategy can be flexibly managed.

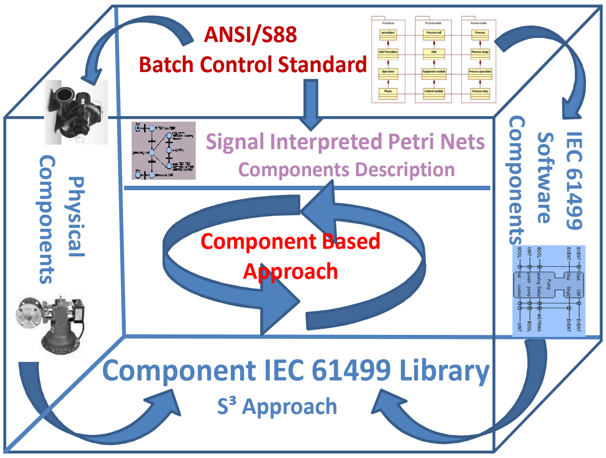

Fig.1: Proposed Component Based Approach

CASE STUDY: INDUSTRIAL PLANT FOR DISTILLATION OF SULPHATE TURPENTINE

The proposed approach is illustrated on a real plant for batch rectification of sulphate turpentine located in Velingrad, Bulgaria. Turpentine is a volatile oil recovered as a by-product from chemical pulping of pines.

Short technological description: Crude sulphate turpentine is a complex mixture of C_{10} monoterpene hydrocarbons composed mostly of alpha pinene (60-65%), beta pinene (25-35%) and Δ^3-carene, which are the derivate products and the starting materials for the synthesis of a wide range of fragrances, flavors, vitamins and polyterpene products.

A widely used technology to separate turpentine uses batch rectification. The P&I diagram of the installation studied is shown in Fig.2. The equipment may be classified in the following main categories: Tanks (B-01, B-02, B-03, B-04), Evaporator, reboiler (W-01), Rectification column (K-01), Condensers (W-02, W-03, W-04), Pumps (P-01, P-02, P-03, VP-01, PV-01), many different types of valves, an air compressor system, a steam ejector system, and a vacuum creation system.

The process starts with pumping a batch of liquid feed into the batch tank B-01. When the tank is about 80% full, the feed is stopped and the content of the batch tank is heated to boiling by the preheated steam in the reboiler W-01. Once the mixture starts to boil, vapour is carried up the packed column K-01 and is condensed in the overhead condenser – W-02. Vapour rising through a column above the tank combines with reflux coming down the column to effect concentration. The condensate flows either to a reflux drum or to a decanter. Reflux is then pumped back to the top of the column. At start up, the system is operated at total reflux until the required purity of the most volatile component is achieved. At this point, the product is withdrawn at a rate controlled by the reflux ratio. The reflux ratio is set according to data from an on-line analyzer or temperature profile in the column. When the reflux ratio becomes too high (typically 15 or 30 to 1), then it is no longer economical to continue producинг a top product. The flow is diverted to a slop out tank, and the reflux ratio is reduced. Eventually the most volatile component will be completely driven off. The steps can be repeated for each volatile component required recovering.

The installation is controlled by some pneumatic feedback controllers. The most important of them, which are taken into consideration here, are: pressure feedback at the top of column; pressure difference feedback in the column, level feedback in B-02, and time based reflux ratio control. Currently all discrete control activities are manually done by two operators. This way, the defined three operating phases have the following continuances: 2.83 hours for the start-up, 36 hours for the separation and 8 hours for the shutdown. The process requires considerable operator intervention and the development of an automatic discrete control system is expected to: shorten the batches, improve the quality of products and increase the system reliability.

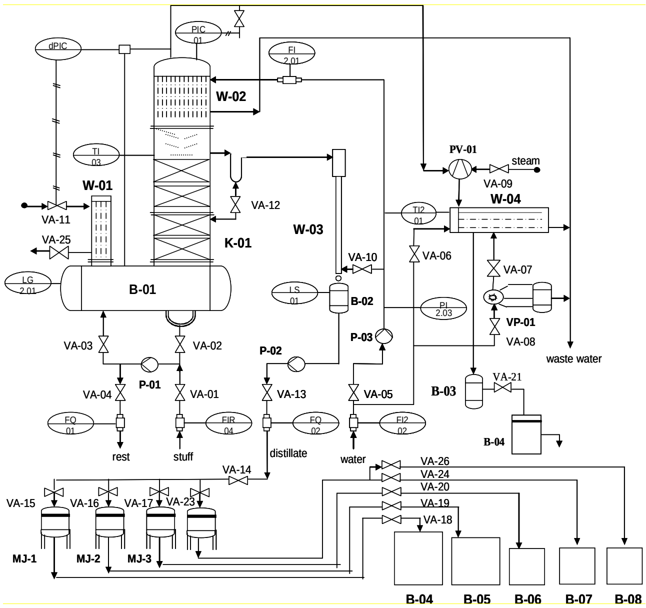

Fig.2: P&ID of the Industrial plant for Distillation of Sulphate Turpentine (UNIT according to S88)

The processes are divided into three unit procedures: Preparing, Rectification, Shutting down. The equipment and control modules of the industrial plant for Unit – Preparation according to the S88 Standard are listed in table 1.

Table1: S88 Equipment and Control Modules

Units	Equipment Module	Subordinate Equipment Module	Control Module
Preparation	Charge Distillation Cube	Command Station (Start up) Loading System	Electricity Pulte Compressor Transfer Valves Circulation Pump
	Air Compressor Vacuum System Ejector System	Vapour Steam System Cooling Control System	Compressor Vacuum Pump Ejector Tank Valve Condenser Evaporator Pressure Controller Differential Pressure Controller

These three unit procedures of the plant are controlled by the functional components such as valves and pumps along with some analogue indicators. The reuse of software components depends on the functional requirements of each unit procedure. At the procedure level, these units will be run in series for the batch process: <Preparing, Rectification, Discharging (Shutting down) >, Fig. 3. After the batch is done, a new batch can be processed.

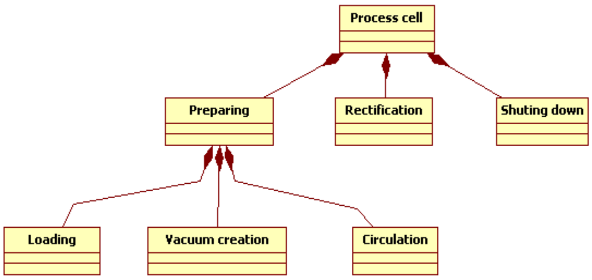

Fig.3: S88 hierarchy of the Industrial plant for Distillation of Sulphate Turpentine

At the beginning, the elicitation of functional component requirements is done. Basic functional components required for Impregnation unit are listed in Table 2. They are instantiation of valve and pump software controller.

Table2: Controlled FBs in the Preparing unit

FB	Description
Mixture Control (Loading row material)	1.Open supply valves (VA-01, VA-02, VA-03) 2. Start Pump (P-01) 3. Transfer Material (charge column) 4. Material Probe 5. Stop Pump (P-01) 6. Close Charge Valve (VA-01, VA-02, VA-03)
Injector (Vacuum Creation)	1. Close all pumps and valves 2. Start Air Compressor (14) 3. Open Valve (VA-06) 4. Start Vacuum Pump (VP-01) 5. Start Vapour Ejector (VP-01) 6. Control loop (PIC-01)
Circulation	1. Start Pump (P-01) 2. Circulation from B-01 into K-01 3. Stop Pump (P-01) 4. Start Pump (P-03) 5. Control loop dPIC01 (Δp=0.9) 6. Control cooling water by FI2.01 (20m³/h) 7. Stop Pump (P-03)

The SIPN model of Mixture Control is shown in Fig. 4. It is modelled by six places and five transitions. Places with a circle shape show the related component which is valid if it has a token. For valve, 1 means opened and 0 closed. For pump, 1 means turned-on and 0 turned-off. Besides, level sensor is mapped into transition (i.e. bar), while the time condition is represented at the arc (i.e. directed arrow). Once the token reaches the final place in Mixture Control, the sequence will move to Injector Control of the Preparing Unit. The Mixture Control will be reexecuted for a new batch process.

Mixture Control is a component which is responsible to control the route to distillation cube. The FB composes four valves and two pumps. It is responsible to open and to close the route to the distillation cube. The reuse of FB valve is three times, of FB pump is one time.

The implementation of Mixture Control in a composite FB is shown in Fig. 4. As a start point, the elements of SIPN model represent the schedule model of Impregnation unit control is interpreted by FB's identity (Table 2). S^3 technique is applied with corresponding FBs (Scheduler, Selector, and Synchronizer) to control the component based on the given component schedule. The component schedule representation uses the following SOP (Scheduler of Operations), SOP_Setup = [21,1,2]; SOP_Stop = [12, 26].

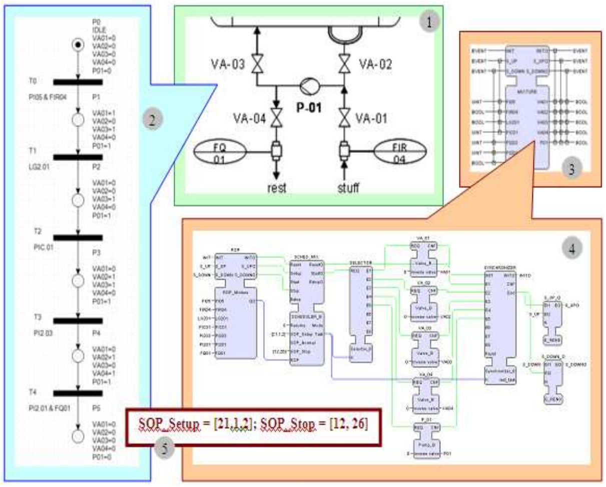

Fig.4: Mixture control

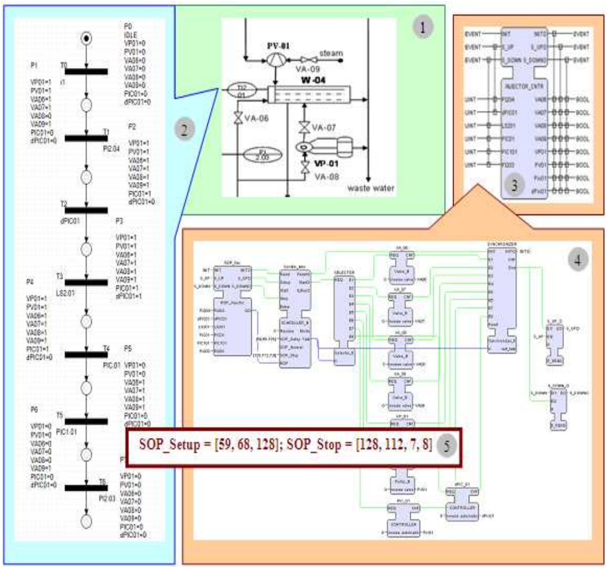

Fig.5: Injector Control

At the beginning, the elicitation of functional component requirements is done. Basic functional components required for Injector FB are listed in Table 2.

The SIPN model of Injector Control is shown in Fig. 5. It is modelled by eight places and seven transitions.

The FB Injector comprising four valves, two pumps and two controllers, Fig.5. It is responsible for vacuum creation in system. The reuse of FB valve is three times, of FB pump is one time and one time of controller reuse.

The component schedule representation uses of SOP. Injector Control uses the following SOP: SOP_Setup = [59, 68, 128]; SOP_Stop = [128, 112, 7, 8].

At the beginning, the elicitation of functional component requirements is done. Basic functional components required for Circulation FB are listed in Table 2.

The SIPN model of Injector Control is shown in Fig. 6. It is modelled by five places and four transitions.

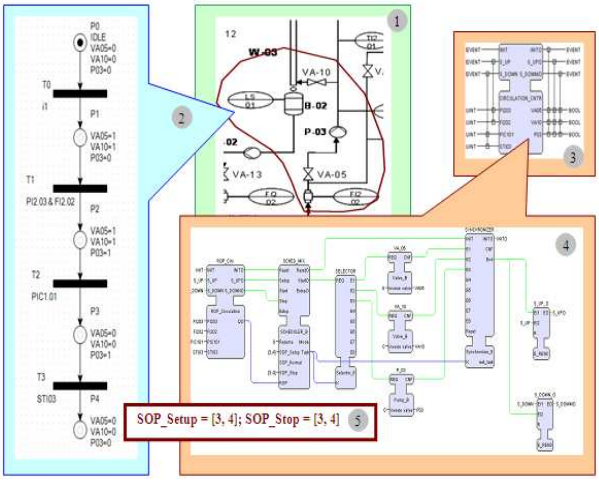

Fig.6: Circulation Control

SIPN model describes the sequence of component execution, is mapped into IEC 61499 applications. The model is used as control scenario that will be implemented in FB based system.

The FB Injector comprising two valves and one pump. It is responsible for circulation in system. The reuse of FB valve is one time.

The component schedule representation uses of SOP. Injector Control uses the following SOP: SOP_Setup = [3, 4]; SOP_Stop = [3, 4].

Furthermore, all unit procedures are managed in the procedure level in a series order as the most case in batch control. The series order is quite simple and reduces the complexity in managing the unit procedure. Their sequence therefore can be managed by direct connection between FB of each unit procedure.

If the order among unit procedure is not series from first unit to the last one, direct connections cannot be implemented easily. For instance, SOP for distillation batch process is <Preparing, Rectification, Discharging>. Task value can be given to each unit and become the elements of their SOP. This SOP is then set at the Scheduler. Moreover, the component reusability of the proposed functional components is high. FB Valve is reused three times in the mixture unit, three times in Injector unit, and two times in Circulation.

CONCLUSIONS

The proposed approach supports the development of reusable software components based on the combined use of three different formalisms: the IEC61499 standard for distributed process measurement and control systems, the ANSI/ISA S88 standard for batch control and the Signal Interpreted Petri Nets (SIPN), which are used as a formal mean in order to verify the correctness in the behavior of the developed components or systems.

The approach is applied to the industrial plant for distillation of sulphate turpentine. Further work will be directed to finalization of the industrial study. In a next step the derived controller shall be connected to a simulation environment for intensive testing prior to real implementation at the plant for batch control. The presented approach integrates three different formalisms – IEC 61499, ISA S88, and SIPN – to get re-configurable distributed batch control based on reusable software components.

REFERENCES

1. ANSI/ISA-88.01 (1995). Batch Control Part 1: Models and Terminology.
2. ANSI/ISA-88.00.02 (2001). Batch Control Part 2: Data Structures and Guidelines for Languages.
3. IEC 61512 (1997). Batch control, part 1: Models and terminology.
4. IEC 61131-3 (2003). 2nd Ed: Programmable Controllers Part 3: Programming languages.
5.
6. Dimitrova, D., Panjaitan, S., Batchkova, I. and Frey, G.(2008). IEC61499 component based approach for batch control systems. *IFAC World Congress*, Seoul, Korea, pp. 10875-10880.
7. Frey, G. (2002). Design and formal Analysis of Petri Net based Logic Control Algorithms, Dissertation, Universität Kaiserslautern, Shaker-Verlag, Aachen.
8. Frey, G. and Wagner, F. (2006). A Toolbox for the Development of Logic Controllers using Petri Nets. *WODES 2006*, Ann Arbor (MI), USA, pp. 473-474.
9. IEC 61499-1 (2005). Function blocks - Part 1: Architecture.
10. Ivanova, D., Frey, G., and Batchkova, I. (2008). Intelligent Component Based Batch Control Using IEC61499 and ANSI/ISA S88. *Proc. IEEE Int. Conf. on Intelligent Systems*, Varna, Bulgaria, Vol. 1, pp. 4.44-4.49.
11. Panjaitan, S. (2008). *Development Process for Distributed Automation Systems based on Elementary Mechatronic Functions*, Dissertation, Universität Kaiserslautern, Germany, Shaker-Verlag, Aachen.
12. Peltola, J. P., Christensen, J. H., Sierla, S. A., and Koskinen K. O. (2007). A migration path to IEC 61499 for the batch process industry. *INDIN’07*, Vienna, Austria, Vol. 2, pp. 811-816.
13. Thramboulidis K., Sierla, S., Papakonstantinou, N. and Koskinen, K. (2007). An IEC 61499 based approach for distributed batch process control, *IEEE INDIN’07*, Vienna, Austria, Vol. 1, pp.177-182.