MODELING OF COLLABORATIVE PRODUCTION SYSTEMS USING COLOURED PETRI NETS

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Abstract: Production Systems are undergoing continuous changes in order to be more competitive in a globalized market. In this scenario, there is a tendency to geographically distribute the production process to reduce development and production costs. The interaction between these components is characterized by the presence of a high number of concurrent and asynchronous processes. As a result, the development of production systems is a complex and difficult task. To cope with this complexity, this paper proposes a systematic approach for the modeling of collaborative production systems. This approach explores the potential of formal modeling language such as Colored Petri net to represent and analyze the dynamic behavior of the system. Additionally, the publish/subscribe paradigm is introduced to establish the communication in the coordination process of the system.

1 INTRODUCTION

Production systems (PS) perform a process using materials, equipment, human resources and other physical entities so as to produce goods or services (Villani et al., 2007). Increased competition in productive organizations triggered the development of different approaches in order to conceive new kinds of PS. In this sense, initially, a change from a PS centralized structure to a distributed structure was stimulated by economic factors, in which a displacement of manufacturing plants was made to countries with reduced operating costs (Shah, 2005).

However, nowadays, the paradigm changes are more stimulated by strategic parameters, seeking a quick production response, focused on the demand for customized products (Grefen et al., 2009, Shimizu et al., 2007). In this scenario, according to Ko and Nof (2010), recent and emerging advances in hardware (e.g., pervasive computing devices, wireless sensor networks, nano-electronics) and software (e.g., multi-agent systems, artificial intelligence, workflow and information integration) enables to a new class of PS, called Collaborative Production System (CPS).

The CPS has a distributed structure with a high degree of flexibility, in which customers, suppliers, operators and production facilities are geographically dispersed, interacting with the intent to develop a customized product. The CPS integrates new information technologies and controller devices in order to reach a flexible structure (Godara, 2010). The structural flexibility permits the expansion of the CPS and allows rapid reconfiguration to produce a wide range of products (Leitao and Colombo, 2006).

The distributed structure of the CPS makes necessary the use of flexible communication paradigms that address the dynamic and decoupled nature of these applications. The publish/subscribe paradigm is receiving increasing attention and is claimed to provide the loosely coupled form of interaction required in large distributed systems (Schneider and Farabaugh, 2004, Eugster et al., 2003).

The design and implementation of the CPS are complex tasks. In this sense, several approaches were proposed for modeling CPS. In Matsusaki and

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Santos Filho (2006), a multifaceted decomposition of a system was introduced in order to meet the CPS requirements of CPS. Thus, the logic control of the system is classified according to the semantics and functionality. In Junqueira and Miyagi (2009), a framework for distributed simulation was defined which the Petri net is used as a tool to model large and geographically dispersed PS. In Garcia et al. (2009), a characterization of a framework was presented for integration and coordination of services provided by components of a geographically dispersed PS. However, although these studies address the issue of distributed and dispersed PS from different points of view, they do not approach adequately the complexity of the communication process in terms of their dynamic and quantity of components that are involved in the coordination process.

Motivated by these facts, a systematic approach is introduced here for the modeling of CPS. To represent the behavior of the CPS, the use of two abstraction models is proposed. Initially, Message Sequence Chart (MSC) is used to represent the interaction between the components in different operation scenarios. Then, the functionality of each component is modeled by CPN. Finally, the components are integrated into a single model to analyze the properties and behavior of the overall system by means of CPNTools (Jensen et al., 2007).

The text is organized as follows: section 2 presents the fundamental concepts that support the work. Section 3 presents the architecture of the distributed SP. The 4th section presents a systematic approach for modeling and analysis based on CPN. Finally, in section 5 are the main conclusions obtained in this work.

2 BASIC CONCEPTS

2.1 Publish/Subscribe Paradigm

In the last years, this paradigm of communication has gained importance in the design and development of different class systems like stock exchange systems, air traffic control systems, defense systems and CPS and pervasive computing applications (Abawajy, 2009). This is due to the capacity of the publish/subscribe paradigm to completely decouple communication participants, allowing the development of applications with a high degree of flexibility (Ryll and Ratchev, 2008). This is one of the motivations for the use of this paradigm in this work.

In the publish/subscribe paradigm, communication can be anonymous, asynchronous and multicasting. The combination of these characteristics makes the publish/subscribe paradigm well suited to a variety of application areas, allowing the development of systems with a high degree of flexibility. However, this advantage is counterbalanced by increased complexity in the sense of understanding the functioning of the system as a whole. Furthermore, although the components of a collaborative system can work properly when examined individually, they may have an inappropriate behavior when working in a cooperative manner (Baresi et al., 2005).

2.2 Coloured Petri Net (CPN)

The Coloured Petri net (CPN) is a graphical language that combines the capabilities of PN with the capabilities of a high-level programming language, in which the PN provides a graphical environment and supports the formal description of the system and the programming language facilitates the definition of data types (Jensen and Kristensen, 2009). Thus, a compact and parametric model can be created. This type of PN allows the construction of hierarchical models that facilitate the description of the system. The CPN models can be hierarchically structured as a collection of small connected components in which each component corresponds to a model in CPN. This model structuring can be performed by replacing substitution transitions (specific terms of Petri net are in Arial Narrow). A substitution transition is a special type of transition used in the CPN to represent an instance of another model. This feature of the CPN allows the reuse of components already built, reducing the time and cost of development (Jensen et al., 2007). A more detailed description about the elements of CPN can be found in (Jensen and Kristensen, 2009).

3 PROPOSED ARCHITECTURE

The proposed architecture of the CPS considers that the dynamic evolution of the states is performed concurrently. Thus, CPS performs tasks in a parallel and independent way. Fig. 1 shows the architecture of the CPS.

The communication between the components that integrates the CPS is performed by exchanging asynchronous messages according to the publish/subscribe paradigm. The messages are grouped into **topics**. The **applications** are not directly coupled to each other and communication is

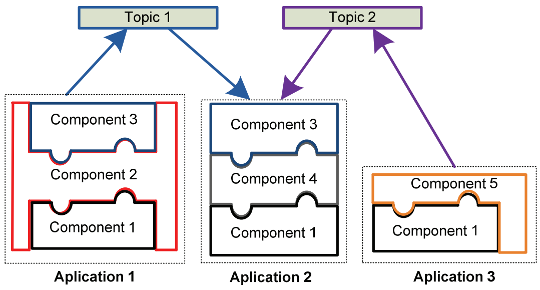

Figure 1: Proposed architecture of CPS.

carried out through the publication and subscription of data **topics**. The term component represents an independent unit that is functionally autonomous, which encapsulates its internal state and behavior (Szyperski, 2002). The proposed architecture is characterized by the composition of reusable components that are developed independently and are integrated to achieve a final goal.

The CPS **applications** are composed of components that can be reused to build other **applications**. Thus, a reduction of cost and time is achieved (Sommerville, 2007). Fig. 1 shows the utilization of "Component 1" in the construction of three others components. The models of the components are developed using the CPN. The input and output interfaces of the component are represented by places and the data are modeled by colored tokens. Once the models of the components are constructed, they can be simulated and analyzed in CPNTools to verify their static and dynamic properties.

One of the main features of the CPN is the possibility to assign attributes to the tokens, in order to differentiate one token from another. This feature is used to perform the communication component model. Thus, a message can be modeled as a colored token that identifies the data type (**topic**) and the data value (content).

4 MODELING PROPOSED PROCEDURE

A modular approach based on CPN is adopted here, and the complete system is divided into functional independent modules, which interact by exchanging messages via a communication network. This modeling procedure allows identifying each functional independent module, with different degree of detailing (i.e. assembly system, robot, actuator, sensor, etc.), which can be divided into reusable components. The behavior of these components and their interaction with the others is represented by CPN models. Hence, it is possible to represent the whole system in a computational model that can be used to perform different kinds of analysis (Jensen et al., 2007). The proposed modeling procedure comprises six steps, briefly described as follows:

Step 1: The scope and the main functionalities of the CPS are identified and delimited. At this stage, the stakeholders involved in the project discuss the CPS objectives and requirements.
Step 2: The topics of data are defined in order to establish the communication between the functional independent modules. This stage uses the publish/subscribe paradigm to perform the communication process.
Step 3: The message sequence chart (MSC) is used to model the interaction of the CPS. Thus, the behavior of the system can be represented by the interaction of the components in different scenarios.
Step 4: The basic components of the CPS are identified. The components are constructed considering the reuse of these models to develop others CPS.
Step 5: This step consists of the integration of the components in order to obtain the complete model of each CPS.
Step 6: The CPS is integrated into a single model that can be simulated. The simulation of the computational model allows the designer to refine or to create new strategies or specifications of the system, detecting errors and mistakes before the CPS implementation (Junqueira and Miyagi, 2009).

5 CONCLUSIONS

Although the use of distributed and intelligent components facilitates the production process, it introduces difficulties in the design of the control system, making the understanding of the overall CPS process a complex task. In this sense, this paper presents a systematic procedure for specifying the CPS. The approach proposes the use of the publish/subscribe paradigm to establish the communication between the components of the distributed system. This approach aims to facilitate the understanding of the communication process in systems that are complex in terms of their dynamic and number of components. In order to validate the proposed procedure, it is been applied in the modeling of a manufacturing system that emulates a dispersed CPS. This system is installed at the

Department of Mechanical and Mechatronic Engineering at the University of São Paulo (Junqueira and Miyagi, 2009).

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