Available online at www.sciencedirect.com
ScienceDirect
Mathematics and Computers in Simulation 79 (2009) 1421–1439
MATHEMATICS AND COMPUTERS IN SIMULATION
www.elsevier.com/locate/matcom

Reactive mode handling of flexible manufacturing systems

Nadia Hamani [a,*], Nathalie Dangoumau [b], Etienne Craye [b]

[a] *Laboratoire Universitaire de Recherche en Production Automatisée (LURPA), 61 Avenue du Président Wilson, 94235 Cachan Cedex, France*

[b] *Laboratoire d'Automatique, Génie Informatique et Signal (LAGIS), CNRS UMR 8146, Ecole Centrale de Lille, BP 48, 59651 Villeneuve d'Ascq Cedex, France*

Received 25 July 2006; received in revised form 7 October 2007; accepted 13 December 2007
Available online 28 December 2007

Abstract

This paper deals with a new modeling approach for mode handling of flexible manufacturing systems (FMS). Based on a review of the modeling methods and the specification formalisms in the existing approaches, we show that the mutual benefit of functional modeling and synchronous languages is very convenient for mode handling problem. We start by introducing the context of our work and the basic concepts of the proposed modeling approach. Then we present the steps of functional modeling and we illustrate them through an example of a flexible manufacturing cell. Functional modeling is completed by generic behavioral specifications representing the states of a subsystem or the whole system. The specification method is modular, hierarchical and supports reuse concept. The established model is generic and well adapted to our control system context. Mode handling function role within the control system is then studied. This function enables a reactive update of the availability of the resources and functions and the transmission of high level control and reconfiguration orders.

Keywords: Flexible manufacturing systems; Control system; Supervision; Mode handling; Functional and behavioral modeling

1. Introduction

Due to increasing competitiveness, flexible manufacturing systems (FMS) were introduced to overcome the drawbacks of dedicated manufacturing lines (DML) [28]. Indeed, FMS are able to carry out several parts in small and average series while adapting quickly the production changes demand thanks to their flexibility [33]. Several research works focus on the design of fault tolerant control systems. However, the design of such systems for FMS is difficult due to increasing flexibility and complexity. Thus, the aim of our research project called CASPAIM[1] is to provide a fault tolerant control system dedicated to FMS. This control system ensures on line and real time management of failures.

We are interested in problems of monitoring and supervision in fault tolerant control systems. In view of a disturbance, the supervision role is to take necessary decisions to return to normal or accepted operation. The main approaches for

* Corresponding author. Tel.: +33 1 47 40 29 97; fax: +33 1 47 40 22 20.
E-mail addresses: nadia.hamani@lurpa.ens-cachan.fr, nadia.hamani@ec-lille.fr (N. Hamani), nathalie.dangoumau@ec-lille.fr (N. Dangoumau), etienne.craye@ec-lille.fr (E. Craye).

[1] The project CASPAIM (the French acronym for 'Computer aided design of control systems in manufacturing') is carried out by our research team in the LAGIS (the French acronym for 'computer science and automatic control laboratory').

0378-4754/$32.00 © 2007 IMACS. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.matcom.2007.12.002

discrete event systems supervision are given in the literature, control engineering approach [13,15] and supervisory control [12,32,38]. In addition, some authors combine the two approaches [14]. The supervision according to our system approach is made up of three functions: decision, piloting (also called real time scheduling) and mode handling. Mode handling function is the scope of this paper.

The operator supervising a production system should manage this latter both under nominal and degraded operation. Due to the complexity, he/she cannot apprehend all the constraints in a coherent and optimal way. Thus, mode handling function needs to provide a model of the system which takes into account the operating modes of the whole system and its subsystems. To this aim, it is important to use an adequate modeling method and powerful specification formalisms. The modeling method should be well adapted to the complexity and to the production system characteristics by allowing an easy representation of its operating modes. When setting up the production demand, the decisions are affecting all the subsystems of the production system. Therefore the specification formalism should support the hierarchy and represent several forms of preemption. Moreover, it must be sufficiently formal to allow carrying out formal verification.

Some research works in the literature focus on mode handling of automated production systems (APS). The modeling methods and the specification formalisms used in the existing approaches are compared in [22].

The modeling methods we studied are classified according to many criteria [22]. To deal with complexity, the system is decomposed into subsystems. Two approaches are distinguished [37], structural approaches [9,10,31] and functional ones [5,17,27]. The modeling steps, the specification of the modes and the specification formalisms are detailed in [22] for each approach. The role of the established models within the control systems is also studied. In structural approaches, the decomposition is based on structural relationships between the resources of the system. Reconfiguration actions are then taken on the resources, the workstations and the cells. Functional approaches are concerned with the services delivered by the system rather than the resources. The decomposition is based on functional relationships between subsystems. Such relationships enable the implementation of automated reconfiguration procedures.

Our study shows also that the specification formalisms should enable an easy representation of hierarchy, concurrency and preemption. They have to be also with rigorous semantics in order to guarantee some properties using formal proofs. Research works show that for the specification of operating modes, we have either:

- to extend common models like sequential functional charts (SFC) and Petri Nets (PN) which are used for representing low level control models [18], or
- to use a joint representation with a formalism suitable for the required characteristics like synchronous models for instance. Sartor is using SFC with Statecharts [26] to overcome the drawbacks of representing hierarchy using SFC. For the same raison, Gaffé recommends using SFC with Esterel language [8,11]. In complex APS, control models are specified using some variants of PN. Here also the authors are using either Statecharts [5] or Argos [27] for an efficient specification of operating modes. Statecharts suffer from their ambiguous semantics. To overcome this drawback, Argos [29] is used but safe state machines (SSM) [4] are more powerful than Argos and they take advantage of an industrial development environment [20].

The main conclusions of our comparative study show that the mutual benefit of a functional modeling approach and a powerful specification model using the graphical synchronous language SSM is very convenient for APS mode handling. Indeed, functional approaches are well suited for efficient reconfiguration procedures. Besides, the required characteristics of hierarchy, parallelism, and preemption are well represented using synchronous languages instead of common models such as SFC and PN. The interests of using synchronous formalisms rely also on their strong semantics. They are compiled efficiently and it is possible, using formal techniques, to prove that the behavior of the system respects some properties [24]. In addition, synchronous approaches ensure the preservation of the verified properties between the specification and the implementation phases of the development process (*What You Prove Is What You Execute: WYPIWYE*) [7].

The purpose of this paper is to present a modeling method dedicated to FMS mode handling. The approach is based on a functional modeling and a synchronous reactive approach using SSM [4]. The characteristics of CASPAIM control system as well as the integration requirements in that framework are also taken into account in our approach. The paper is organized as follows. After the presentation of the context of our study in Section 1, Sec-