

Chapter 1

Nonblocking Supervisory Control of Flexible Manufacturing Systems based on State Tree Structures

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ABSTRACT

Much research has been addressed to nonblocking supervisory control of Discrete-Event Systems (DES) such as Flexible Manufacturing Systems (FMS), and a variety of approaches have been developed. One especially powerful approach, due to Chuan Ma, is based on DES representation by means of State Tree Structures (STS). Using STS, this chapter develops nonblocking supervisory control of a well-known benchmark FMS example taken from the literature, for which the description was given originally as a Petri net. The authors straightforwardly obtain the optimal (maximally permissive) and nonblocking supervisory control, and display the control logic for each (controllable) event transparently as a binary decision diagram.

1. INTRODUCTION

A flexible Manufacturing System (FMS) (Li, Zhou, and Wu 2008) is a typical Discrete-Event System (DES). In the last two decades, much research has been addressed to the supervisory control problem for DES, subject to the requirements

of maximal permissiveness and global nonblocking (of which deadlock-freeness is a special case), and a variety of approaches have been obtained (Abdallah and El Maraghy 1998; Fanti and Zhou 2004; Iordache, Moody, and Antsaklis 2002). In this chapter we present a new approach to solve the synthesis problem for FMS. Our plant model

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is represented using a State Tree Structure (STS). It is shown that the specifications are controllable and that the supervisor is nonblocking.

STS is a modeling method for DES (Ma and Wonham 2005a). It is an extension of the automaton model in Ramadge-Wonham theory (Wonham 2012) which introduces natural hierarchical structure into the system model. The synthesis algorithm based on STS can often successfully manage state explosion, which is notoriously exponential in the number of system components. The algorithm can design nonblocking optimal supervisors for systems with state space size, remarkably, up to 10^{24} ; furthermore, the supervisor is both tractable to implement and often transparent to comprehend (Ma and Wonham 2006).

Supervisory control based on STS can be used for all DES, and is especially suitable for large scale systems, like the standard examples of Automatic Guided Vehicles (AGV) (Moody and Antsaklis 1998), FMS, Production Cell (Cai and Wonham 2010) and the AIP system (Brandin and Charbonnier 1994).

This chapter is organized as follows. Section 2 presents background on FMS. Section 3 introduces the basics of STS. Section 4 presents the modeling of our FMS and its specifications. Section 5 gives the results of synthesis. Conclusions are presented in the last section.

2. BACKGROUND OF FLEXIBLE MANUFACTURING SYSTEMS

In the example of this chapter, our Flexible Manufacturing System (FMS), as shown in *Figure 1*, is built up from ten components. They are: four machine tools M1-M4, three robots R1-R3 and three Input/Output buffers B1-B3. Three different types of workpiece enter the FMS to be processed (Li, Zhou, and Wu 2008). Each machine tool can hold two workpieces at the same time, while each robot can hold one workpiece at a time. A work-

piece of type i ($i = 1, 2, 3$) enters the system from its buffer B_i (as a B_i decrement) and leaves the system through its buffer B_i (as a B_i increment); the overall model is thus closed and cyclic. In the process diagrams of Figures 1 and 2, B_i is shown as I_i in its role as supplier of ‘raw’ workpieces of type i , or respectively as O_i in its role as receiver of ‘finished’ workpieces. The buffer sizes are: 3 for B_1 , 7 for B_2 , and 11 for B_3 . Each size is roughly matched to the respective holding capacity of the buffer’s downstream process, a choice that renders the problem more logically demanding. A workpiece of type i undergoes manufacturing process P_i , as detailed below.

Buffers store workpieces, machine tools process workpieces. M1 can process P3 workpieces, M2 can process P1 and P3 workpieces, M3 and M4 can each process P2 and P3 workpieces. The robots transport workpieces among the machines and buffers. Thus R1 moves P3 workpieces from I_3 to M1, P3 workpieces from I_3 to M3, and P2 workpieces from M3 to O_2 . R2 moves P1 workpieces from I_1 to M2, P1 workpieces from M2 to O_1 , P2 workpieces from M4 to M3, P3 workpieces from M3 to M4, and P3 workpieces from M1 to M2. R3 moves P2 workpieces from I_2 to M4, P3 workpieces from M4 to O_3 , and P3 workpieces from M2 to O_3 . The sequencing for each of the three production processes is displayed in Figure 2.

P1: $I_1 \rightarrow R_2 \rightarrow M_2 \rightarrow R_2 \rightarrow O_1$.

P2: $I_2 \rightarrow R_3 \rightarrow M_4 \rightarrow R_2 \rightarrow M_3 \rightarrow R_1 \rightarrow O_2$.

P3: $I_3 \rightarrow R_1 \rightarrow M_3 \rightarrow R_2 \rightarrow M_4 \rightarrow R_3 \rightarrow O_3$ or $I_3 \rightarrow R_1 \rightarrow M_1 \rightarrow R_2 \rightarrow M_2 \rightarrow R_3 \rightarrow O_3$.

The specifications for the FMS are as follows:

1. For the four machine tools M1-M4, each machine tool can hold two parts, possibly of different types, at the same time.
2. For the three buffers B1-B3, each buffer must not overflow or underflow.

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