Maejo Int. J. Sci. Technol. **2009**, *3*(03), 408-414

Maejo International
Journal of Science and Technology
ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Full Paper

Novel method for heuristic modelling of flexible manufacturing systems

Payyalore R. Venkateswaran[1,*] P. R., Jayadeva Bhat[2] and S. Meenatchisundaram[1]

[1] Instrumentation and Control Engineering Department, Manipal Institute of Technology, Manipal 576 104 Karnataka, India
[2] Chemical Engineering Department, Manipal Institute of Technology, Manipal 576 104 Karnataka, India
* Corresponding author, e-mail: prv_i@yahoo.com

Received: 2 March 2009 / Accepted: 22 October 2009 / Published: 27 October 2009

Abstract: Flexible manufacturing systems (FMS) play an important role in industrial automation. They belong to a class of systems known as discrete event systems (DES) representing varying events with time. The modeling and control of such systems poses a challenge of handling uncertainties in resources and sequences for optimization. Presently the tools used for modeling such systems including Petri nets are constrained in the face of uncertainties in the system. A modified approach using new fuzzy logic formalism in Petri nets is proposed in this paper as a solution to overcome the problem. The utility of this formulation is that apart from the validity, it is adaptable to practical implementation in sequence controllers normally employed in FMS.

Keywords: flexible manufacturing system (FMS), fuzzy Petri nets, programmable logic controllers (PLC)

Introduction

The behaviour mapping of systems has undergone rapid change with advances in technology. The representation has become digital with state description of the behaviour. This manifestation is called discrete event systems (DES), exhibiting properties such as non-determinism, conflict and parallelism [1-3]. Supervisory control theory (SCT) [4-5] is chosen as a modeling paradigm and programmable logic controllers (PLC) [6-8] as an implementation tool for DES. This work investigates the use of fuzzy Petri nets in supervisory control and suggests a modified and improved version called fuzzy automation Petri net (FAPN) as a modeling tool. It presents a systematic approach to the synthesis of fuzzy-Petri-net-based supervisor for the forbidden state problem using supervisory design procedure. The controlled model of the system can be constructed from this FAPN net structure. The implementation uses the flexible manufacturing system (FMS) as an example of DES. The results can be interpreted and applied to high level manufacturing systems, where the role of the supervisor is to coordinate the control of multiple machines, or to low-level manufacturing systems where the control function is to switch on/off with respect to the dynamics between different valves.

Description of an FMS

The FMS shown in Figure 1 represents a packaging process that can be controlled by a programmable logic controller. In this application the objective is to control the speed of two conveyors which are used for packaging products. The strategy is to optimize the speed of a motor driven belt conveyor so that productivity in terms of packaging is achieved.

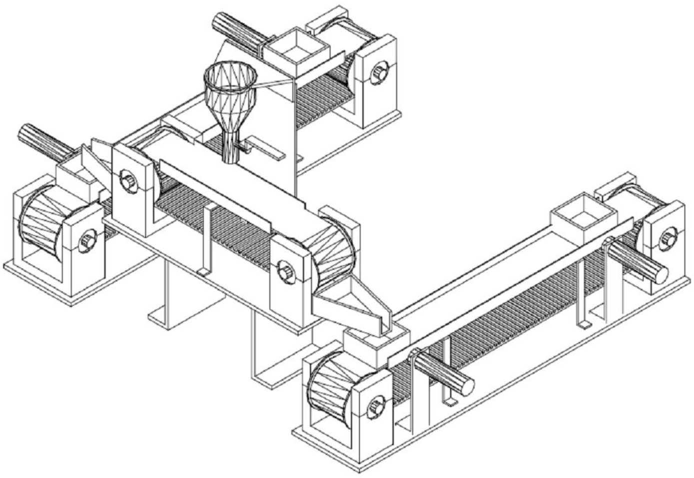

Figure 1. Schematic picture of the FMS considered for operation

Products are carried at irregular intervals in both the right conveyor (C_R) and left conveyor (C_L). The speeds of both conveyors are controllable. The processes in the conveyors C_R and C_L are identical and are as follows. Both conveyors are started together and the system will wait for a signal from either the sensor in C_R (designated as S_R) or the sensor in the C_L (designated as S_L). Suppose S_R (a box is detected on conveyor R) occurs (if not it will check for left conveyor), the hopper feed conveyor is moved towards right (HCR). Now if the box has arrived at the box detector of the right conveyor D_R (D_R occurs), the hopper valve is opened (V_I). The valve remains open for a time T and then it is closed (V_0). The conveyors are again started and the flow starts. In the case that the box is detected first at conveyor L (S_L occurs), the same sequence is followed at the left conveyor. The most important thing to note here is that in the time interval A_1 (i.e. the interval between the instant S_R occurs and D_R occurs), a control action needs to be such that both C_R and C_L are controlled. The same procedure is true for the other cycle. This system represents a typical conveyor system of a process of the manufacturing system.

Controller Synthesis using the Inhibitor Arc Method

Fuzzy automation Petri net (FAPN) is a variant of automation Petri net (APN) in the work of Greene [9] and Uzam [10], and is used to capture the uncontrolled behaviour of the system. The representation of the system using FAPN is as in Figure 2. This is derived as a result of literature review [11-14]. There are fifteen places, $P = \{p_0, p_2 \ldots p_{14}\}$, and ten transitions, $T = \{t_1, t_2 \ldots t_{10}\}$, with firing conditions defined as: χ_1=I0.0, χ_2=I0.0 (same on/off switch for both conveyors for simultaneous operation), χ_3 = I0.1, χ_4 = I0.2, χ_5 = I0.3, χ_6 = I0.4, χ_7 = I0.5 and χ_8 = I0.6, associated with them for the first eight transitions respectively. The last two of the transitions are defined by timers. If there is a token in p_0, then the conveyor is said to be in *on* status. If in transition, the token is passed to p_2 then the left conveyor is in *off* status. Similarly, the presence of token in places p_1 and p_3 define the *on* and *off* status respectively of the right conveyor. A token in the place of p_4 or p_5 indicates the presence of box sensed at the entry of either the left or the right conveyor as can be seen in Figure 2. . A token in place of p_9 or p_{10} indicates the running of the hopper feed conveyor (HFC) towards the left or right of the conveyor as in Figure 2. The hopper feed valve (HFV) status is indicated by places p_{11} and p_{12}.

The initial conditions for the system are the conveyors (C_L and C_R) switched off, the HFC idle, the HFV closed and the buffer of C_L and C_R full. Conveyors C_L and C_R can be started with a start switch. Whenever a box is detected at the entry of either conveyor, the hopper feed conveyor if ready should start moving towards that particular conveyor. In the case that the hopper feed conveyor is already engaged, it should wait till the operation gets completed. The box travels to the filling station where it gets filled through the hopper and then finally gets dispatched.

The reachability diagram for the system can be considered in two phases. The first one is said to be an uncontrolled FAPN model where the flow of events is unregulated and is shown in Figure 3. There are 57 arcs representing the firing of transitions in the uncontrolled model and there are 19 nodes, $M = \{M_0, M_1 \ldots M_{18}\}$, representing all possible markings reachable from the initial marking M_0. The events $\chi = \{\chi_1, \chi_2 \ldots \chi_8\}$ represents the firing of the corresponding transitions $T = \{t_1, t_2 \ldots t_{10}\}$. All time delays associated with the transitions are implied although not indicated. "Bad states" in a reachability diagram will happen under two circumstances: (i) the states are not reached as per specifications identified as forbidden-state specifications, and (ii) the states are in conflict with the constraints of the system parameters. Initially, the system specifications are considered for defining the "bad states". Such system specifications are called forbidden-state specifications and are denoted as follows:

(i) The boxes should not leave the conveyor without getting filled.
(ii) The hopper feed conveyor should not respond to transition without completing the current operation.
(iii) The hopper feed conveyor should not run till the conveyor in which the box is detected is stopped.

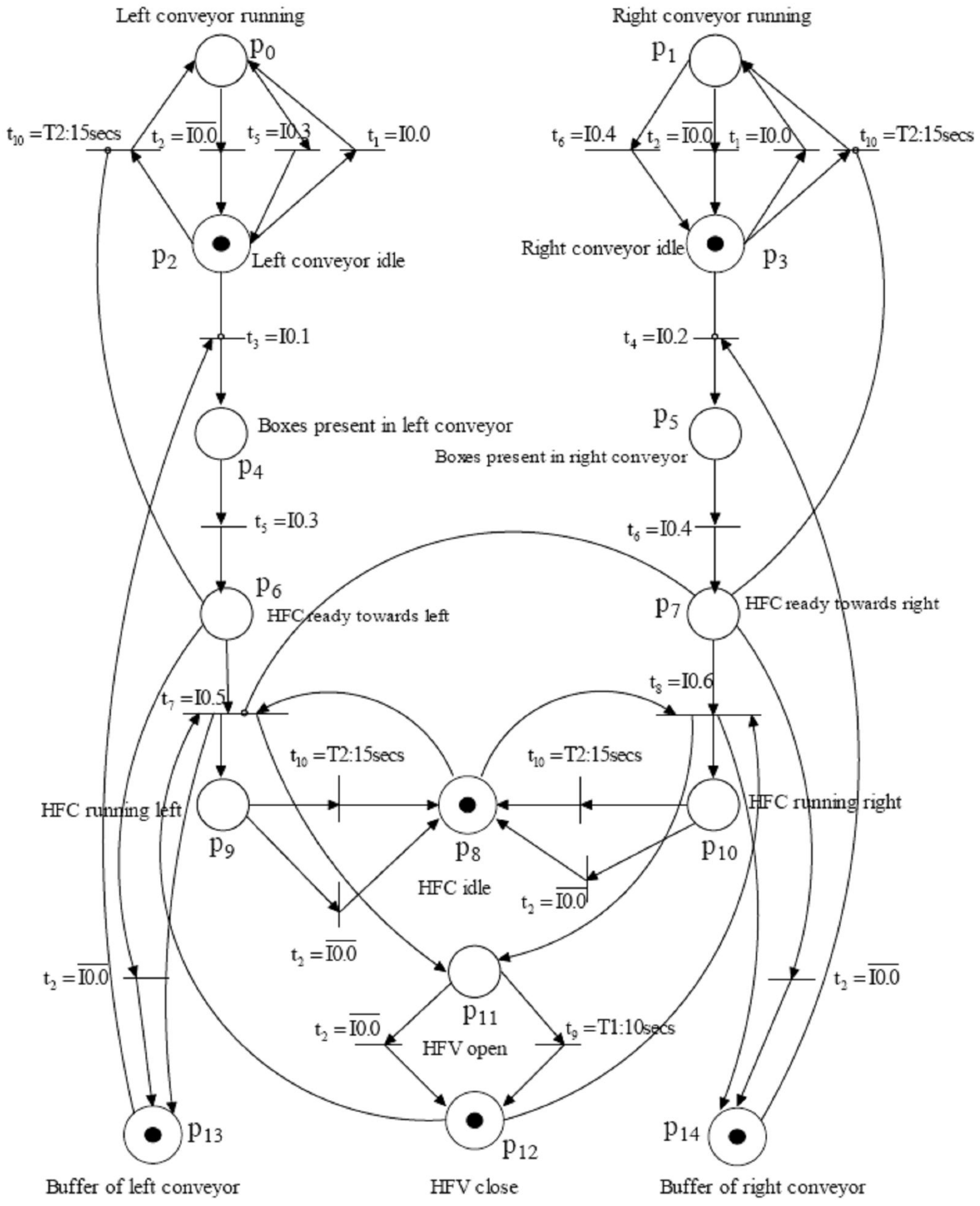

Figure 2. FAPN model of a flexible manufacturing system (FMS)

To identify the system with respect to its specifications, all of these specifications are considered. In addition, the constraints imposed on the system due to operating/working conditions are also considered. The states which do not agree to any of these specifications are eliminated in the reachability diagram. When a state is removed, the transitions that lead to it become redundant and lose their meaning. Consequently all the transitions leading to/from “bad states” are also eliminated. For example, let us consider a case of M_{14}=[2,3,6,7,8,12]. Here all the conveyors are in the idle state. This indicates that all the conveyors are idle simultaneously inferring that no useful work is done in the system. This must be prevented from happening although it is not against specifications per se. Thus, apart from M_0, the states M_9, M_{10}, M_{11} and M_{14} in which all the conveyors become idle are to be

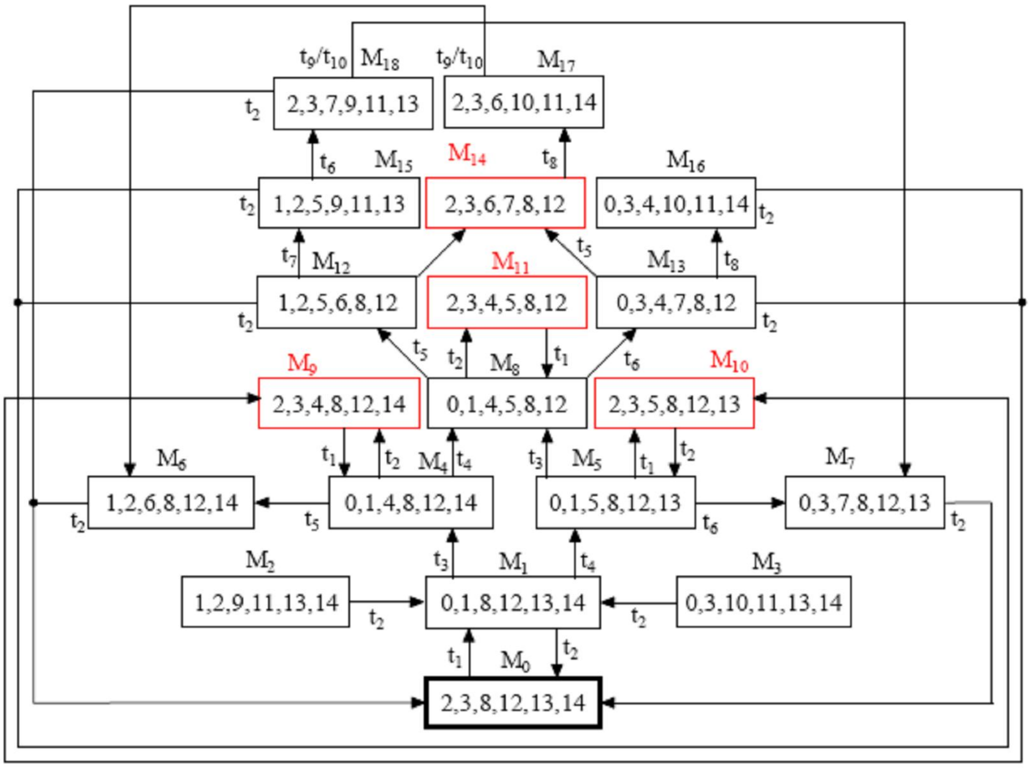

Figure 3. Reachability diagram of the FAPN model

removed from the reachability diagram. This includes all transitions terminating and originating from the individual states. In addition, there is a state called M_{16}, which when reached in the system does not lead anywhere. This is because there is no transition that originates at M_{16}. Therefore, it should be made sure that M_{16} does not occur. If M_{16} is to be removed, then as a natural extension, M_{13} is also to be removed. Similarly, for states M_2 and M_3, there are no input transitions. They cannot happen in the flow of the system. The final diagram makes sure that for all defined states, there is a sequence which will be followed to complete the operation. By following the above sequences, the following objectives will be achieved:

1. If there is no sign of machine starving or blocking, then keep the production surplus close to zero. In other words, produce at a rate more or less equal to demand.
2. If an undesirable event (upstream or downstream buffer full or empty) is about to occur, then ignore surplus levels and try to prevent starting or blocking by increasing or decreasing the production rate accordingly.

Results and Discussion

The implementation was with a prototype conveyor system in the PC Instrumentation Laboratory of Manipal Institute of Technology, Manipal, India. A Siemens PLC (CPU 226) was used to control the process and Step 7 Version 4.0 was used as the software interface for the PLC. If all possible states in the system are to be considered, there will be an exponential increase in the reachability diagram resulting in state space explosion problem. The effects of the state explosion problem on the conventional methods are twofold. The first one is that the computation of the supervisor becomes very difficult as the system becomes bigger. The second effect is that the bigger the system is, the bigger is the number of places and transitions required as the supervisors. However, this problem was overcome by the inclusion of the system modeling using FAPN. The representations of states became linguistic in nature and hence eliminated the exact number replica of states in a system. In addition, the supervisors obtained were correct by construction. For implementation, the supervisors obtained were converted into ladder logic diagrams (LLD) to be implemented on any PLC. The design was based on the premise that the DES considered are controllable and observable and the result can be extended into a wide array of DES. The summary of all the approaches are presented in Table 1. The applications of these methods could range into different types of DES exhibiting unique characteristics of uncertainty, vagueness and imprecision. Thus, all modern systems classified into the domain of DES can be included as systems of interest for implementation.

Table 1. Performance review of methods for FMS

	Ladder logic method [15]	Inhibitor arc method [15]	Enabling arc method [15]	Fuzzy automation petri net method
Number of places used	NA	14	14	12
Number of transitions used	NA	14	14	10
Number of LLD rungs proposed	15	Infinite	Infinite	140

Conclusions

A formal design of fuzzy-Petri-net-based complied supervisors for DES control problem and their efficient implementation are a challenging problem. In this paper, a flexible manufacturing system was used to illustrate the applicability, strengths and drawbacks of the design techniques using fuzzy Petri nets. It is proved by experimentation that application of fuzzy in modelling and programming for discrete event systems is useful in handling uncertainties. Since the derivation of the formalism is generic in nature, it can be applied to a wide distribution of DES. In addition, the problem of state space explosion is eliminated by using fuzzy automation Petri nets (FAPN). The design was based on the premise that the DES considered are controllable and observable and the result can be extended into a wide array of DES.

References

1. A. Hellgren, "Modeling and implementation aspects of supervisory control", Technical Report No.350L, Control and Automation Laboratory, Department of Signals and Systems, Chalmers University of Technology, Sweden, **2000**.

2. G. Cohen, D. Dubois, J. P. Quadrat and M. Viot, “A linear system theoretic view of discrete event processes and its use for performance evaluation in manufacturing”, *IEEE Trans. Autom. Control*, **1985**, *AC-30*, 210-220.
3. R Valette, J. Cardoso and D. Dubois, "Monitoring manufacturing systems by means of Petri nets with imprecise markings", IEEE International Symposium on Intelligent Control, September **1989**, Albany, NY, USA, pp. 233-238.
4. P. J. Ramadage and W. M. Wonham, "Supervisory control of a class of discrete event processes", *SIAM J. Control Optim.*, **1987**, *25*, 206-230.
5. P. J. Ramadage and W. M. Wonham, "The control of discrete event systems", *Proc. IEEE*, **1989**, *77*, 81-98.
6. A. Taholakian and W. M. M. Hales, “PN↔PLC: A methodology for designing, simulating and coding PLC based control systems using Petri nets”, *Int. J. Product. Res.*, **1997**, *35*, 1743-1762.
7. M. Courvoisier, R. Valette, J. M. Bigou and P. Esteban, “A programmable logic controller based on a high level specification tool”, Proceedings of IEEE Conference on Industrial Electronics, **1983**, Amsterdam, pp. 174-179.
8. R. Valette, “A Petri net based programmable logic controller”, in "Computer Applications in Production and Engineering (CAPE’83)" (Ed. E. A. Warman), North-Holland Publishing Co., Amsterdam, **1983**, pp. 103-116.
9. J. Greene, “Petri net design methodology for sequential control”, *Meas. Control*, **1989-1990**, *22*, 288-291.
10. M. Uzam, "Petri net supervisory control of discrete event systems and their ladder logic diagram implementation", *PhD. Thesis*, **1998**, University of Salford, UK.
11. S. S. Peng, "Ladder diagram and Petri-net based discrete event control design methods", *IEEE Trans. Syst. Man Cybern. Part C Appl. Rev.*, **2004**, *34*, 523-531.
12. R. David and H. Alla, "Petri nets for modeling of dynamic Systems: A survey”, *Automatica*, **1992**, *30*, 175-202.
13. T. Cao and A. C. Sanderson, "Modeling of sensor based robotic task plans using fuzzy Petri nets", Proceedings of the 4th International Conference on Computer Integrated Manufacturing and Automation Technology, **1994**, Troy, NY, USA, pp.73-80.
14. M. Hanna, "Determination of product quality from an FMS cell using fuzzy Petri nets", *Proc. IEEE*, **1994**, *2*, 2002-2007.
15. P. R. Venkateswaran, "Fuzzy logic supervisory control of discrete event systems", *PhD. Thesis*, **2008**, Manipal University, India.