The Supervisory Control of Automated Manufacturing Systems: A Discrete Event Systems Approach

Bertil A. Brandin
Systems Control Group
Department of Electrical an Computer Engineering
University of Toronto
Canada, M5S 1A4
brandin@control.utoronto.ca

Automated Manufacturing Systems

Automated manufacturing systems are generally composed of a number of interconnected material processing stations, a material transport system, a communication system, and a supervisory control system. The flexible manufacturing concept advocates that, as one of the options, manufacturing operations be carried out within workcells, each workcell being responsible for the production of a specific part family. Cells are usually interconnected by a transport system. Although workcell configurations may vary, these typically incorporate the following systems: numerically controlled (NC) part processing machines, material handling devices, part inspection/testing devices, in-process part storage systems, and a supervisory control system. The latter performs the following three tasks: supervisory control, communication and housekeeping. Supervisory control consists of (i) the monitoring of the workcell behavior via sensory feedback, (ii) control evaluation in accordance with a supervisory control law which maps the workcell behavior to corresponding controls, and (iii) control enforcement via the downloading and execution of the appropriate device programs. Communication allows sensory feedback and control enforcement to be performed. Housekeeping is the set of tasks related to supervisory control and communication which are necessary to their implementation, e.g. data-base management. Supervisory control system development consists in the procedure generating supervisors and control laws which specify how the supervisory control system is to react to the manufacturing system behavior in order to satisfy given behavioral specifications (routing, sequencing, safety, ...). To develop supervisory control systems, different techniques such as knowledge engineering, Petri nets and controlled automata may be exploited. The work presented is based on controlled automata, since these provide important advantages over other approaches.

The Supervisory Control of Discrete-Event Systems

Discrete event systems (DES) are dynamic systems that evolve in accordance with the abrupt occurrence of events. They are generally asynchronous (not clock driven) and non deterministic (some events may occur spontaneously). Such systems are encountered in a variety of fields, for example in manufacturing, robotics, computer and communication networks, traffic, and logistics.

The supervisory control of DES in accordance with behavioral specification is a new research area which is receiving increasing recognition. To ensure the orderly occurrence of events in DES (i.e. according to given behavioral specifications), some degree of supervision and control is generally required. Supervisory control is based on information feedback on the occurrence of events, formal languages and controlled automata concepts. Discrete-event systems are controlled as generators of a formal language; the adjunction of a control structure allows varying the language generated by the system within certain limits by accordingly enabling and disabling events; the desired performance of such controlled generators is specified by stating that their generated language must belong to some specification language.

This approach to supervisory control offers two important advantages over other design approaches:

- the controlled behaviors obtained are guaranteed not to violate the specifications considered: the supervisors are correct by construction; and
- the controlled behaviors obtained are guaranteed to be most permissive within the specifications: all events which do not contradict the specifications are allowed to happen.

Motivation

In the last decade, the manufacturing environment has changed dramatically. The two major driving forces behind the changes are the stiff worldwide competition among manufacturing companies, and the development and utilization of new technologies in automation. In the past, manufacturing systems were, in most cases, sufficiently simple to permit the use of intuitive and informal solutions in the development of supervisory control systems. The increasing level of automation, integration and flexibility encountered in automated manufacturing systems renders formal approaches to the supervisory control system development a necessity.

The controlled-automata based approach to supervisory control development considered in this work is one such approach and offers important advantages over other available approaches. The contribution of this work consists in the testing of the applicability of the method to the supervisory control of industrial automated manufacturing systems.

References

B. A. Brandin, W. M. Wonham, "The supervisory control of timed discrete-event systems", *IEEE Transactions on Automatic Control*, February 1994.

B. A. Brandin, W. M. Wonham, "Modular supervisory control of timed discrete-event systems", *1993 IEEE Control and Decision Conference*, San Antonio, December 1993.

B. A. Brandin, W. M. Wonham and B. Benhabib, "Manufacturing cell supervisory control - a modular timed discrete-event system approach", *1993 IEEE International Conference on Robotics and Automation*, Atlanta, May 1993, pp. 846-851.

B. A. Brandin, W. M. Wonham and B. Benhabib, "Manufacturing cell supervisory control - a timed discrete-event system approach", *1992 IEEE International Conference on Robotics and Automation*, Nice, May 1992, pp. 531-536.

B. A. Brandin, W. M. Wonham and B. Benhabib, "Discrete event supervisory control applied to the management of manufacturing workcells", *7th international Conference on Computer Aided Manufacturing Engineering*, V.C. Venkatesh and J.A. McGeough Eds., Elsevier 1991, pp. 527- 536.

P. J. Ramadge and W. M. Wonham, "The control of discrete-event systems", *IEEE Proceedings*, Vol. 77, No. 1, January 1989, pp. 81-98.

W. M. Wonham and P. J. Ramadge, "Modular supervisory control of discrete event systems", *Maths. of Control, Signals and Systems*, Vol. 1, No. 1, 1988, pp. 13-30.

About the Author

Dr. Brandin obtained his Ph.D. and M.A.Sc. in Electrical and Computer Engineering from the University of Toronto in 1993 and 1989 respectively, and his B.E. in Mechanical Engineering from the University of New South Wales in 1984. He worked for three years at the Swiss Federal Institute of Technology in Lausanne. His research interests focused on the supervisory control of discrete event systems, on the application of artificial intelligence and knowledge engineering techniques to control, and on the disturbance accommodation problem. Currently, Dr. Brandin is leading (for Canada) a collaboration project on Computer Integrated Manufacturing, between the Région Rhône-Alpes and the Province of Ontario, based on his research on discrete event systems. He is currently in Grenoble applying and testing the work carried out in Toronto to the experimental manufacturing cell of the Atelier Interétablissement de Productique (AIP) Dauphiné-Savoie.