A hierarchical model of distributed simulation of manufacturing systems

*B. R. Babic*¹⁾, *G. D. Putnik*²⁾

¹⁾ *Production Engineering Department,
University of Belgrade, Mechanical Engineering Faculty,
27. marta 80, 11000 Belgrade, YUGOSLAVIA,
Fax: +381 11 3370 364*

e-mail: babib@alfa.mas.bg.ac.yu

²⁾ *Production and Systems Engineering Department
University of Minho, School of Engineering
4800 Guimarães, PORTUGAL*

Fax: ++351 (0)53 510268

e-mail: putnikgd@eng.uminho.pt

Abstract

Concept of hierarchical distributed simulation system is established and realized as a prototype software tool. HDSS is developed as an open architecture. This structure makes possible to introduce different external simulation resources, and some of them may be physical models controlled by computer. As the simulation controller has the structure of real manufacturing system controller it can be easily converted in a real controller.

Keywords

Manufacturing Systems, Distributed Simulation, Hierarchical Model

INTRODUCTION

Concept of distributed simulation (DS) has recently received a great deal of attention as an effective strategy for realization of a computer model equivalent to a real manufacturing system in information aspect. In order to integrate various levels of the manufacturing system and use different simulation models over a network of computers hierarchical model is introduced. This approach allows reconfiguration and extension of a system by offering systematic and modularized

knowledge of manufacturing and it makes computer support activities transparent for human understanding (Kimura, 1993).

Hierarchical distributed simulation system (HDSS) could be described as a family of models dealing with the behaviour of the manufacturing system at different levels of abstraction. For each level there is a set of relevant characteristics, variables and principles describing the behaviour of the system.

The individual models are developed at different hierarchical levels and then integrated by the control structure of the simulation system. The architecture of HDSS system follows the architecture of control system of the real manufacturing system.

In this paper an architecture and some implementation issues of HDSS are discussed. Presented structure incorporates both multilevel and multilayer concepts. The multilevel concept (Mesarovic *et al.*, 1970) is characterized by the division of the control of an interconnected complex system into local control units with local goals.

BASIC CONCEPTS

The architecture for a hierarchical system must describe the decomposition of the system into individual subsystems and functional decomposition of these subsystems (Smith *et al.*, 1996). The architecture should also provide the guidelines necessary to develop model of subsystems so that they can be transparently integrated into system of models. The goal is to develop structure of HDSS whose submodels are completely independent so that individual models can be developed at different locations and can be replaced or updated as necessary without adversely affecting the rest of the system.

An architecture of the manufacturing system control can be divided in three levels (Smith *et al.*, 1996). From the bottom of the hierarchy to the top (Figure 1) are the equipment, workstation and shop levels. The equipment level is defined by physical shop floor equipment. The workstation level is defined by the layout of the equipment. Processing and storage machines that share services of material handling equipment together form workstations. The shop level acts as a centralized control and interface point for the system.

Figure 1 Control architecture of manufacturing system.

In accordance with manufacturing system resource model, given in (Wysk *et al.*, 1995) a manufacturing system can be defined as follows.

We define $EM = \{em_1, em_2, \dots, em_s\}$ as indexed set of available equipment models, where em_i , $i=1,2, \dots, s$, describes a particular equipment model. In accordance with equipment types EM is partitioned into $\{MSM, MHM, MTM, ASM\}$, where:

MSM - machining station model

MHM - material handler model

MTM - material transporter model

ASM - automated storage model

For each piece of equipment there is a set of commands necessary for performing a task. The instructions consist of a set of machining station programs (MSP) and a set of material handling programs (MHP), i.e. $I=\{MSP, MHP\}$. MSP include NC files for numerically controlled machine tools, CMM commands for co-ordinate measuring machines, etc. MHP contains robot programs, instruction for AGVs, etc.

A workstation is made up of one or more pieces of equipment under the control of a workstation level controller (Smith *et al.*, 1996). A workstation model WM_i is formally defined as:

$$WM_i \in WM$$

$$WM_i = \langle WCM_i, EM_i, BSM_i \rangle \text{ where:}$$

$WM = \{WM_1, WM_2, \dots, WM_n\}$ is an indexed set of workstation models

WCM_i is model of workstation controller

$EM_i = \{MSM_i, MHM_i, MTM_i, ASM_i\}$

BSM_i is buffer storage unit.

The workstation controller carries out commands received from the shop controller and is responsible for moving parts between the various pieces of equipment in the workstation and for specifying part processing performed at this equipment.

The shop includes all workstations and is responsible for selecting the part routes (at the workstation level) and for communicating with the workstations for transport and storage services used to move parts, tools, etc. between the workstations. The shop model can be formally defined as follows:

$$SM = \langle SCM, WM \rangle, \text{ where}$$

SCM is model of shop controller.

The production requirements input describes the technical requirements for the parts to be manufactured in the shop and are provided by master production schedule. The production requirements include the processing requirements and handling requirements. The processing requirements for a part are specified by the process plan which include part routings and associated tooling and fixturing requirements. A set of n process plans for n parts can be defined as $P = \{P_1, P_2, \dots, P_n\}$.

Based on formal definitions given above the HDSS for a manufacturing system is defined as follows:

$$\text{HDSS: } P \times \text{WM} \rightarrow \text{SM}$$

Based on the production requirements defined by the set P from the set of workstation models the workstations needed for the satisfaction of production requirements are chosen and composed in the configuration for simulating analysed manufacturing system.

IMPLEMENTATION

Established concept is realized through development of the multilevel distributed simulation system. HDSS has three levels according to the structure of manufacturing system defined above. The simulation resources may be distributed over the computer network.

The first two levels of the control architecture (shop level and workstation level) are covered by the simulation controller. The third level is represented by the set of process simulators (milling simulator, turning simulator, robot simulator, measuring machine simulator, etc.). The simulation controller is universal data driven simulation system capable for simulation of different manufacturing structures. The structure of observed system is described by the set of input parameters. The simulation controller has following important functions:

- *simulation resource management*: Simulation controller manages the process simulators available within computer network and invokes them when they are required.
- *communication service*: Simulation controller provides communication service and distribution of information needed for the operation of process simulators (NC programs, robot programs, etc.)
- *process synchronization*: The important problem in distributed simulation is the synchronization of concurrent processes. The universal clock with a fixed time interval is used as the synchronization strategy.

The basic logic for the shop level simulator incorporated in simulation controller is given by the activity cycle diagram in Figure 2. Regarding the fact that simulation controller must deal with a number of models of various types the concept of open system architecture of modelling is introduced. The open system architecture consists of well-formalized modules for modelling and simulation that have carefully decomposed functions with well-defined interfaces with other modules. This modularity in the open system architecture facilitates group work in developing model classes and simulation services and also parallel processing in executing simulation (Iwata *et. al*, 1995).

Figure 2 Activity cycle diagram for simulation controller.

Proposed model is applied for development of the application software which represents the prototype of software tool for distributed simulation. Developed simulation controller is capable for controlling up to 20 different processes simulated at PC computers within local area network (LAN). Required number of process simulators, corresponding to the number of the machining centres and lathes in analysed manufacturing system, are activated at different PCs. The process simulators in standby status wait for commands from the simulation controller. The simulation controller distributes jobs to the workstations, in accordance with the process plans, and also downloads NC programs to the equipment simulators. After the job is assigned to the equipment simulator, the controller at the local level takes over the control for machining according to a NC program downloaded on it. When the job is finished the information is passed to the simulation controller which takes care for further steps (transportation to the next machining station, manipulation, etc.). The illustration for distributed simulation system - software tool is given in Figure 3.

Figure 3. Distributed simulation system - software tool.

ILLUSTRATIVE EXAMPLE

The HDSS must be able to accommodate virtually all control circumstances encountered in manufacturing. Proposed concept will be illustrated on the manufacturing cell installed at Centre for advanced technologies - Mechanical Engineering Faculty - Belgrade. Functional layout is shown in Figure 4. Manufacturing cell consists of CNC lathe Potisje PH42 served by robot and horizontal machining centre HMC 500 with palette buffer.

Figure 4 Example manufacturing cell.

Figure 5 Simulation controller display.

The hierarchical simulation model for the manufacturing cell can be formally defined as follows:

Shop level: $SM = \langle SCM, WM \rangle$

Workstation level: $WM = \{WM_1, WM_2\}$, where

$WM_1 = \langle WCM_1, EM_1 \rangle$ (CNC lathe serviced by the robot)

WCM_1 - workstation controller for lathe and robot

EM_1 = <model of lathe control unit

$WM_2 = \langle WCM_2, EM_2, BSM_2 \rangle$

WCM_2 - workstation controller for HMC and buffer

EM_2 = <model of HMC control unit

BSM = <buffer storage model.

Developed simulation controller - software tool has built in logic for SCM and WMs as well as material transport cart control. Concept of universal data driven simulator is used for development of simulation controller (Babic, 1999). This concept enables adaptation of simulation controller to the structure of the specific system. Open system architecture with high modularity provides the means for integrating of different simulation resources. For described manufacturing cell it was necessary to develop two types of simulators with appropriate interfaces: HMC simulator, and CNC lathe simulator. Animation display of the simulation controller providing monitoring of status of each equipment model during the simulation is shown in Figure 5. Figure 6. shows animation of machining process which is the output of HMC simulator.

Figure 6 Example of process simulation.

CONCLUSION

A three level hierarchical distributed simulation system has been presented. For the individual architectural components formal definitions are provided. Proposed concept offers generic structure under which the specific implementation can be described. HDSS represents an open architecture and makes it possible to “plug in” external simulation resources. In order to utilize the simulation resources via computer network simulation controller is designed and prototype is developed. The architecture of HDSS can be effectively applied for constructing and operating of manufacturing system controller.

REFERENCES

- Babic, B. (1999) Axiomatic design of flexible manufacturing systems, *International Journal of Production Research*, Vol. 37, No. 5, pp. 1159-1173.
- Iwata, K.; Onosato, M.; Teramoto, S.; Osaki, S. (1995) A Modelling and Simulation Architecture for Virtual Manufacturing Systems, *Annals of the CIRP*, 44, pp. 399-402.
- Kimura, F. (1993) Product and Process Modelling as a Kernel for Virtual Manufacturing Environment, *Annals of the CIRP*, 42, pp. 147-150.
- Mesarovic, M.D.; Macko, D.; Takahara, Y. (1970) *Theory of Hierarchical Multilevel Systems*, Academic Press, New York.
- Smith, J.S.; Hoberecht, W.C.; Joshi, S.B. (1996) A Shop Floor Control Architecture for Computer Integrated Manufacturing, *IIE Transactions*, 28(10), pp. 783-794.
- Wysk, R.A.; Peters, B.A.; Smith, J. (1995) A Formal Process Planning Schema for Shop Floor Control, *Engineering Design and Automation*, 1(1), pp. 3-19.

BIOGRAPHIES

Dr. Bojan R. Babic received his MSc and Ph.D. from Belgrade University, both in domain of discrete simulation and intelligent manufacturing systems. Dr. Babic's current position is Assistant Professor at the Department for Production Engineering, Faculty of Mechanical Engineering, University of Belgrade, Yugoslavia for subjects in domain of CAPP. His interests are manufacturing system design theory and implementations.

Dr. Goran D. Putnik received his Dipl. Eng., M.Sci. and Dr.Sci. from the Belgrade University, both M.Sci and Dr.Sci. in domain of Intelligent Manufacturing Systems. His current position is Associated Professor in the Department of Production and Systems Engineering, University of Minho, Portugal, for the subjects CAD/CAPP, CAM, Intelligent Systems for Manufacturing and Design Theory. He is also the Director of the Master and Postgraduate Course on Computer Integrated Manufacturing (CIM) and the Director of the Centre for Production Systems Engineering (CESP) of the University of Minho. His interests are manufacturing system design and control, theory and implementations, and machine learning.