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An Integrated Simulation Method to Support Virtual Factory Engineering

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Abstract – This paper presents a structure and architecture of an integrated simulation method (ISM) to meet the requirements of virtual factory engineering (VFE). Combining CAD, VR and discrete event simulation techniques, the ISM provides static and dynamic simulation functions for implementation of VFE throughout the lifecycle. The static simulation can be used to evaluate the factory layout. The dynamic simulation enables us to evaluate ergonomics of factory, process performance of production system, feasibility of production plan and operation of factory, and to train operators safely, which cover the whole VFE lifecycle. The principles of the key techniques of VFE, including virtual factory data management system (VFDMS), static and dynamic simulation, are also discussed. To demonstrate and validate the ISM, a case study has been carried out in an assembly factory.

Keywords: **Virtual factory, Static simulation, Dynamic simulation, Virtual reality**

1. Introduction

In order to survive in severe market competition, operation of factory from design to maintenance must be agile. Traditionally, simulation has been applied, as an interesting strategy, to support workshop level decision such as operation planning and so on. However, traditional simulation cannot meet the requirement of virtual factory engineering (VFE) throughout the lifecycle. Recently, fueled by price and performance improvements in the hardware and software technologies, virtual reality (VR) is quickly becoming a powerful tool for manufacturing system analysis and design. What's more, VR can be supplementary to traditional simulation, which fails to provide a virtual environment computer-generated in which the operator can be immersed. It's natural to consider the feasibility of an integrated simulation method (ISM), combining VR and simulation techniques together, to support the VFE at different lifecycle phases.

1.1. Definition of virtual factory

There seem to be two different understandings of what exactly virtual factory is: the "strategy management" and the "techniques of implementation" point of view.

For the former, the term virtual factory refers to manufacturing activities carried out not in one central plant, but rather, in multiple locations by suppliers and partner firms as part of a strategic alliance [1].

For the latter, sophisticated computer simulations-what might be called virtual factory-call for a distributed, integrated, computer-based composite model of a total manufacturing environment, incorporating all the tasks and resources necessary to accomplish the operation of designing, producing, and delivering a product [2].

In fact, there is a close relationship between them: the former is based on the latter. This paper will focus on the latter and mainly discuss the ISM to support activities involved in VFE from design to maintenance.

2. Related work

Banerjee described virtual factories in the future whose the key techniques included: simulation, controlling, self diagnosis [1]. For monitory and control of complex manufacturing system, four dimensions can be conceived to express complexity: space, time, process and network. Learning from past effort, the requirements of efficient factory model were discussed.

Klingstam classified the current simulation software tools into two kinds of way: discrete event simulation and geometric simulation [3]. Major applications of discrete event simulation are as follows: material flow simulation, manufacturing system analysis, and information flow simulation. These applications can be decomposed into smaller, more precise tasks to examine, e.g., inventory, work in process, queues or transporting time. Contrary to discrete event simulation, geometric simulation proceeds time-linearly, and therefore also is referred to as continuous simulation. Geometric simulation systems simulate the geometry of a part of, or the whole manufacturing system, usually in three dimensions. The necessity of integration in simulation was also discussed.

Lin represents the virtual factory in an analytic form so that many existing mathematical analyses can be

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applied. New pseudo resources can be added to form a new virtual environment, and control policy designed by engineers will be evaluated before being issued [4].

Dessouky described the contents and development methodology of a Virtual Factory Teaching System (VFTS) whose aim is to provide a workspace that illustrates the concepts of factory management and design for complex manufacturing systems. The VFTS is unique in its integration of four domains: web-based simulations, engineering education, the Internet, and virtual factories. Evolutionary development of the VFTS is accomplished by separating the simulation model from the graphical interface and user interaction [5].

Despite the fact that some researchers dealt with the key technologies to support virtual factory, there has been little research reported on combining VR and simulation technology to support the VFE in the lifecycle [6-10].

3. Overview of the ISM to support VFE

This paper presents a structure and architecture of the ISM to meet the requirements of VFE (see Fig. 1). Concurrent engineering takes an important role in reduction the time of factory design and implementation and improvement of the efficiency of factory operation. Every stage of the VFE lifecycle is involved in concurrent engineering. At the stage of virtual factory design, factory layout needs to be evaluated and ergonomics analyses of manufacturing system are needed. At the stage of virtual factory implementation, there are needs to train operators. At the stage of virtual factory operation and maintenance, feasibility of operation plan have to be evaluated before being issued and performance of manufacturing system also needs to be evaluated. The all requirements above constitute demand layer of virtual factory.

Demand layer can be met by virtual factory's function of static and dynamic simulation. Static simulation can provide an efficient and visible environment where we can evaluate static characteristic of virtual factory. With dynamic simulation VR-based, we can immerse in virtual reality environment to evaluate the performance of virtual factory or train operators. With dynamic simulation based

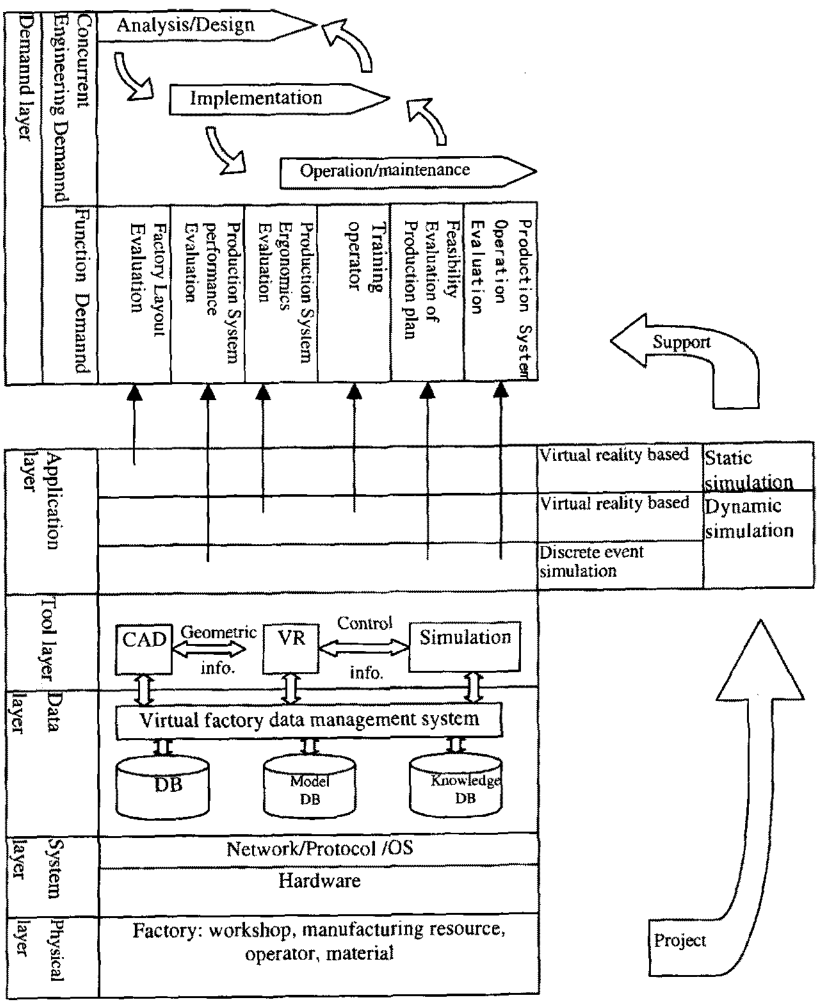

Fig. 1. Architecture of the ISM.

on discrete event simulation, virtual factory operation plan and strategies of operation management can be tested safely. The functions above constitute the application layer of virtual factory.

In tool layer, CAD (computer aided design), VR and simulation tools are integrated, which provide a sound support to requirements of application layer. With virtual factory data management system (VFDMS), there are three databases integrated in data layer: databases, model database and knowledge database. The data and information abstracted from real factory can be saved in database related at data layer. The system layer provides a support of software operation system and hardware for layers above. Finally, under the support of ISM, real factory can be projected into virtual one.

4. Key technologies of ISM to support VFE

4.1. Virtual factory data management system (VFDMS)

For traditional PDM(production data management) system, structure of product is established in a view of design to meet the requirements of CAD/CAM. Therefore, it's design-oriented. At the same time, in MRP/ERP system, structure of product is built in a view of production plan to support manufacturing and assembly. So, it's production process-oriented 6. However, the requirements of design and manufacturing must be satisfied in VFE. In the paper, we propose virtual factory data management system (VFDMS) to organize and manage the data and information of VFE (See Fig. 2).

The major functions of VFDMS are as follows:

- Support process management of VFE, which is key of implementation of concurrent engineering.
- Provide a distributed collaborative environment. By classifying the users into group and defining the roles of users, we can configure personal work environment, shared data environment and rights of user operation, which enable data distributed in multitude of internal and external users and systems to be managed in a seamless, logic manner.
- Support interoperability requirement. VFDMS provide support for various types of clients, different hardware platforms and a multitude of simulation application through its interoperation requirements by combining Java and CORBA (Common Object Requirement Broker Architecture) technologies.

4.2. Static simulation

Static simulation aims to evaluate the static characteristic of virtual factory, such as factory layout. In order to reuse the static simulation model, the requirements of dynamic simulation should be fully considered during the process of static simulation modeling. To take factory layout for example, the steps are as follows:

1. Input information of factory plan that includes the shape sizes of facilities, operation room and so on.
2. Generate an initial layout by invoking optimization algorithm.
3. Evaluate and edit the layout until accepted.
   a) Read the initial layout (See Fig. 3). Then iterate facilities in the factory. The strategies of geometric modeling for facilities are determined, which include: invoking from resource model database, editing model in resource model database or creating with CAD. After that, the initial factory layout is created according to factory plan specification. It needs to point that the file format of model created in CAD has to be transferred before it inputs into VR.
   b) In VR environment, the initial layout can be evaluated qualitatively and in view of ergonomics and functionality, which result in a complicated report of layout. Modify and evaluate it again until accepted.

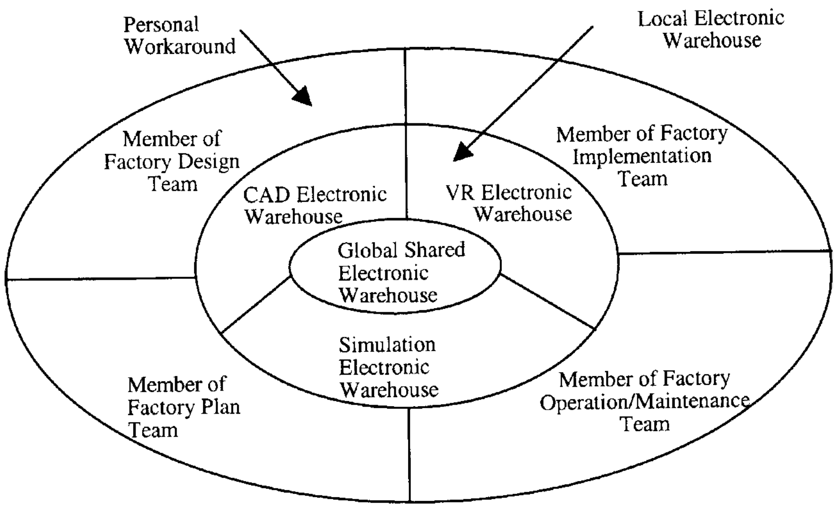

Fig. 2. Structure of VFDMS.

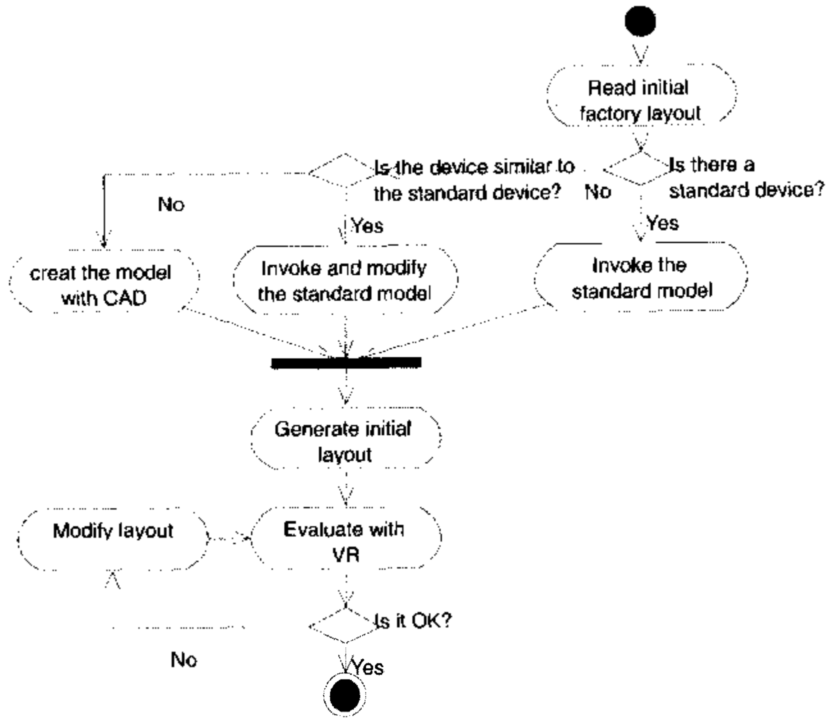

Fig. 3. Activity Model of static simulation.

4.3. Dynamic simulation

Dynamic simulation of virtual factory can be divided into one based on VR and the other based on discrete event simulation. Dynamic simulation VR-based enables operators to immerse in VR environment so that they can be trained without any danger. On the other hand, dynamic simulation based on discrete event simulation can be used to evaluate the feasibility of operation plan and performance of virtual factory. The process of dynamic simulation is as follows (See Fig. 4):

1. Assign task to each workstation. At different stage, there are different tasks. At the stage of virtual factory design and implementation, tasks are designed according to factory plan. When feasibility of operation plan is evaluated, tasks are generated by the operation plan into which factory level production plan is decomposed. When operation of virtual factory is evaluated, tasks are determined by the real-time state of virtual factory operation.
2. Generate resource model. Part of resource information can be obtained from layout specification files, others come from previously assigned tasks.
3. Generate control model. With assigned tasks, control model can be generated (See Fig. 5).
4. Generate simulation model. With control model and resource model, we can generate simulation model that is descried in simulation language.
5. Run, evaluate and edit simulation model until accepted.

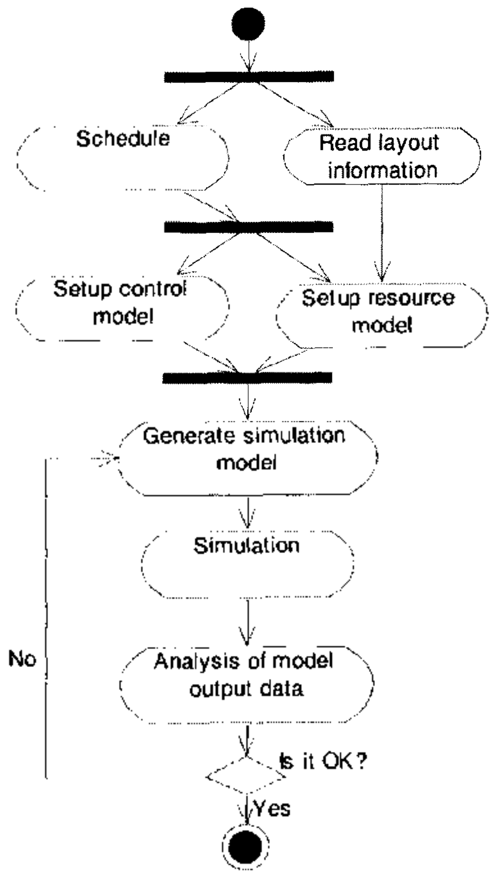

Fig. 4. Activity model of dynamic simulation.

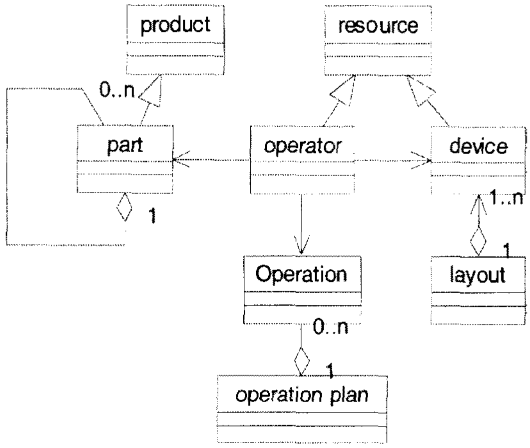

Fig. 5. Control Model.

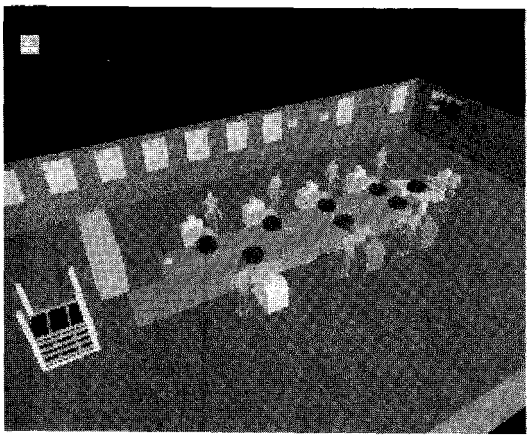

Fig. 6. Simulation of an assemble line.

5. A case study

Based on Envision, the proposed ISM has been implemented on SGI Octane workstation. According to the process described in section 4.2, using the standard resource database created, static simulation model of assembly workshop layout was generated. Using a pair of stereo glasses, we can obtain stereoscopic view of static simulation (See in Fig. 6).

According to the process described in section 4.3, with layout and job sequence, resource model are generated. At the same time, control model are created according to job sequence. Combining resource and control model, we can generate simulation model, which is described in Graphical simulation language (GSL). With dynamic simulation (See in Fig. 6), we can obtain the operation parameters of assemble line and operators, which can be used to evaluate the feasibility of operation plan and performance of virtual factory.

6. Conclusion

This paper proposes a structure and architecture for an ISM to support the VFE throughout the lifecycle. The structure of ISM is divided into six layers: demand layer, application layer, tool layer, data layer, system layer and physical layer. Demand layer defines the requirement of virtual factory throughout the whole life cycle. Application layer provides the functions of static and dynamic simulation. CAD, VR and simulation tools are integrated in tool layer. The function of factory data management and data transportation can be achieved in data layer. System layer provides software operation system and hardware to support layers above. Physical layer represents the real factory.

The key technologies to support the ISM include VFDMS, static and dynamic simulation. VFDMS provides functions to manage database, model database and knowledge database. Static simulation VR-based can be used to evaluate the factory layout. There are two kinds of dynamic simulation: one VR-based and the other based on discrete event simulation, which can be applied to evaluate ergonomics of VFE, performance of virtual factory, feasibility of workshop level operation plan and operation of virtual factory.

Finally, a case study has been carried out to demonstrate and validate the ISM. It is envisaged that the ISM and tool developed will be further enhanced in future industrial application.

Acknowledgments

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