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CONFIGURATION OF AN AUTONOMOUS DECENTRALIZED SDIGITAL FACTORY USING PRODUCT AND MACHINE AGENTS

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The configuration of an autonomous decentralized manufacturing system using multi agent technology is proposed to get more flexibility. In this digital factory, all elements such as machine tool, assembly machine, AGV, and product are installed as agents. The product agents take the initiatives in the system. When a blank workpiece is put on the shop floor, the product agent is dynamically generated with the product model. The product agent can autonomously plan the manufacturing process and the allocation of machines for the production of the final product through negotiations with other product agents and machine agents. The trial implementation of product agents and machine tool agents has been done by structuring a virtual machining system.

1. INTRODUCTION

A high-mix very-low-volume production such as order-made production is accommodated by an autonomous decentralized manufacturing system. In this manufacturing system, a manufacturing activity unit such as a machine tool, assembly machine, robot, AGV (Automatic Guided Vehicle), and/or manufacturing cell has autonomous functionalities. Multi-agent technology is recently being well applied to construct such kind of virtual factory for production planning. In this virtual factory, manufacturing activity units, especially manufacturing devices, are configured as agents and flexible production planning is performed (Brussel et al., 1998) (McFarlane and Bussman, 2000) (Sugimura et al., 2003) (Fujii et al., 2004) In these cases, the system structure is a device oriented structure. To establish more flexible order-made production and to use manufacturing devices more efficiently, the digital factory should be configured by an event driven structure.

This paper proposes the configuration of an autonomous decentralized manufacturing system which is constructed based on an event driven system structure. In a manufacturing system, the occurrence of an event means that a workpiece for the product is input to the machining shop floor or that parts of the product are input to the assembly line. Then, a “product agent” is introduced as an actor for controlling the digital factory, and then the digital factory would be configured using this product agent.

2. CONFIGURATION OF A DIGITAL FACTORY BASED ON PRODUCT AGENTS

In the proposed digital factory, products such as workpieces, parts, and sub-assembled parts are configured as agents in addition to all factory elements such as machine tools, assembly machines and AGVs. The former one is called a product agent, and the latter a machine agent.

The machine agent can determine which process is to be performed by itself and can schedule its own operations for allocated jobs. The product agent is an intelligent and autonomous software unit attached to the product. The substance of the product changes the form from workpiece to complete product through parts or sub-assembled parts. In the manufacturing processes, the product agent plans the processes and allocates the machine for executing the manufacturing processes required to turn the workpiece into the target product. This means that the product agent takes an initiative in the manufacturing system by communicating with other product agents and machine agents. The conceptual structure of the autonomous decentralized manufacturing system based on product agents is shown in Figure 1.

In Figure 1 there are two components constituting the shop floor. One is the machining line, and the other is the assembly line. The machining line is structured by several agents corresponding to machine tools or machining cells, and AGVs. The assembly line is also structured by several agents corresponding to assembly machines or assembly cells, and AGVs. Usually, at first, a product agent is generated when a workpiece is introduced in the machining line. The product agent plans its own machining processes to output complete parts. One of the agents is placed on the assembly line as the main part of the product. This product agent leads the assembly processes for producing the complete product by associating with the other agents for sub-parts. Some of sub parts are manufactured outside of the factory.

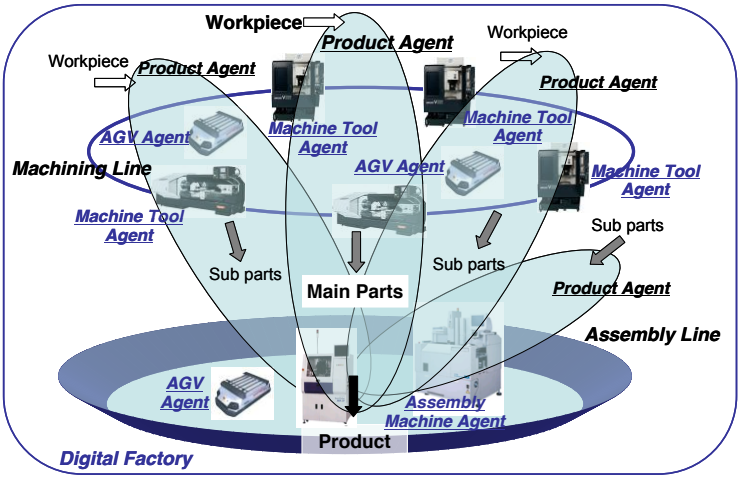

Figure 1. Conceptual structure of an agents based digital factory

3. TYPES OF AGENTS

3.1. Product Agents

The product agent autonomously plans and controls the entire process to evolve itself from workpiece to complete product. The product agent is a dynamic agent. It is created when the workpiece or part is input to the shop floor, and is deleted when the product is completed. Figure 2 shows the structure of a product agent. A product agent consists of a process planner, job allocator, and a transfer and machining requester. When a product agent is created, it has a product model which has the descriptions of the finished product. The process planner in the product agent performs machining process planning and assembly process planning by referring to manufacturing knowledge and machine data from a machine agent. The job allocator of the product agent schedules and allocates jobs according to each manufacturing machine's schedule. Once the job schedule is decided, the product agent requests an AGV to transfer itself and asks a manufacturing machine for execution of the operation.

The product agent is called a workpiece agent in the machining line of the factory and a main parts agent or sub parts agent in the assembly line. In the machining line, a workpiece changes the form of the parts. In the assembly line, parts are integrated into the product.

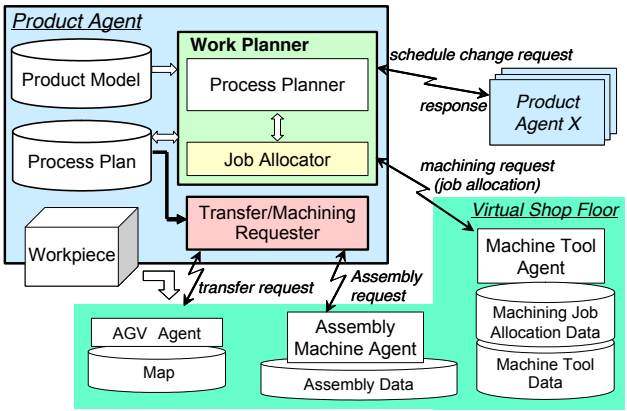

Figure 2. Structure of the product Agent

3.2. Machine Agents

Manufacturing machines in the factory are also agents which are called machine agents. The general structure of a machine agent is shown in Figure 3. A machine agent consists of operation planner, job scheduler, machine model and the machine itself. When the product agent asks whether a requested process can be performed by a machine, the machine agent determines which operations can be processed by the machine itself, generates its own schedule and replies with the possible operations and schedule to the product agent. Sometimes the product agent requests the machine agent to re-schedule the operation schedule because of an urgent job. Once a job is allocated, the machine agent schedules and controls the execution of this job. In this paper, there are two types of machine agents: machine tool agents and assembly agents.

The machine model is referred to by the operation planner and the job scheduler. In the machine model, the capability and specification of the machine is described. For example, the machine tool model consists of machine data and machining knowledge. The

machine data consists of specifications of the machine tool itself, specifications of the ATC (Automatic Tool Changer), jig and fixture which are prepared. Machining knowledge is described by means of a parametric operation plan with applicable tools corresponding to feature type and feature size. The tool models are described by means of tool data which the machine tool is holding. Tool types are mill, drill, ream, and so on. The machine tool model is implemented using XML.

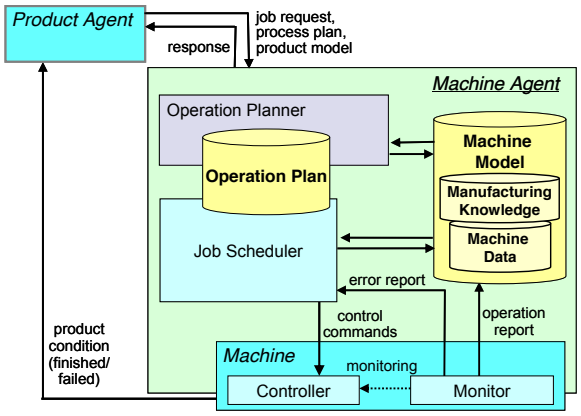

Figure 3. Structure of the machine agent

3.3. Other Agents in The Factory

The other elements of the factory are also agents. In the digital factory, all of the constituent elements are constructed as agents. For example, there are AGV agents, transfer machine agents and material handling tool agents.

4. AN AGENTS BASED DIGITAL FACTORY

4.1. Machining Line

The machining line in the digital factory consists of agents. Figure 4 is an UML sequence diagram which shows the sequence flow in the machining line. In this figure, only sequences for product agents and machine tool agents are drawn by omitting carrier devices such as AGV and transfer machine from a product agent view. A workpiece agent is a product agent in the machining line.

First in the sequence, several possible machining process plans are generated by the workpiece agent by referring to the product model and by communicating with machine tool agents to get machining knowledge and machine tool data. Second, the workpiece agent distributes some of the proposed process plans to all machine tool agents. Each machine tool agent makes an operation plan, schedules them if the plan is processed by itself and feeds back the results to the workpiece agent. Third, the workpiece agent selects the schedule from proposed plans and, if needed, negotiates with the other workpiece agents by requesting schedule changes according to the selected plan. After a successful negotiation, the workpiece agent modifies job allocation and scheduling status, and asks the machine tool agent to verify the machining job allocation schedule. Fourth, the workpiece agent requests an AGV for a transfer and asks the machine tool agent for execution of the machining. During machining job execution, the workpiece agent

deliberates the requests from newly input workpiece agents. When the workpiece agent accepts the schedule change request, the agent requests the AGVs and machine tools to follow the new plan.

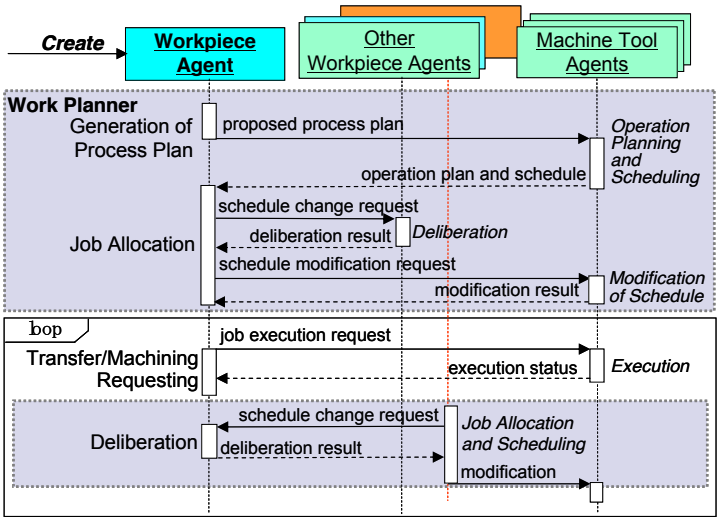

Figure 4. Sequence flow for the machining process

4.2. Assembly Line

The assembly line in the digital factory also consists of agents. Figure 5 is an UML sequence diagram which shows the sequence flow on the assembly line. In this figure, only sequences for product agents and assembly machine agents are drawn from a product agent view. The main parts agent and sub parts agents are product agents in the assembly line.

As in the machining line sequence, the main parts agent leads process planning and job allocation through communication with assembly machine agents. In this sequence, the main parts agents also confirms whether necessary sub parts are ready. Finally in the sequence, the main parts agent requests an AGV for a transfer of itself and any necessary sub parts and asks the assembly machine agent for execution of the assembly. During the execution, the main parts agent monitors the assembly process and asks for additional transfers of parts if necessary.

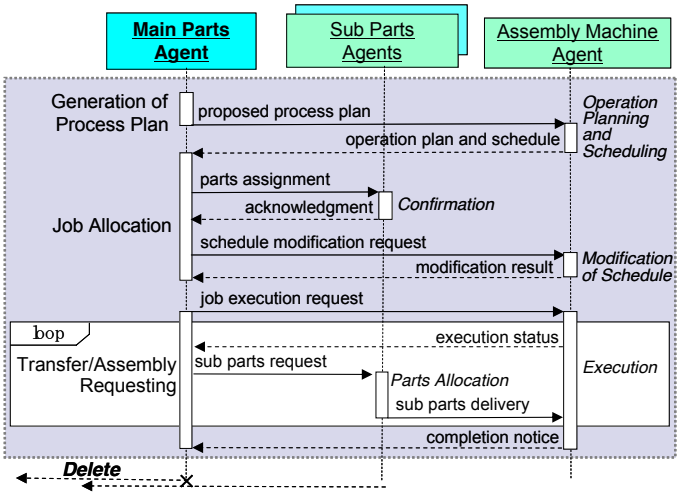

Figure 5. Sequence flow for the assembly process

5. TRIAL IMPLEMENTATION OF PLANNING SYSTEMS

5.1. Machine work planning using the workpiece agent

A machine tool agent for a machine work planning system was implemented. The machine tool model for the machine tool agent was installed using XML. The parametric process plans are listed for machining features in the model. The list of tools belonging to the machine tool and the specification of associated tools such as tool size, cutting speed and feed speed for material types are also described in the model using XML (Matsuda et al., 2006-1).

The machine work planning system using workpiece agents was virtually constructed and simulated on a computer. The workpiece agent is a product agent as mentioned above. The workpiece agent manager controls the timing of workpiece input to the shop floor in the trial system. When a workpiece is input, the corresponding product model is put on the blackboard model. Machine work scheduling is done by one-to-many workpiece agent negotiation after process planning. For example, Workpieces A, B and C are already on the shop floor. Workpiece D is input with some urgency. Machine A and B have the same specification. Before the negotiation, an optimized schedule is generated by applying a genetic algorism. According to this schedule, Workpiece Agent D negotiates with Workpiece Agent A, B and C at same time. If there is no delay in the turnaround time, the negotiation is successful. If the negotiation is not successful, another process plan for Workpiece D is selected and the procedure is repeated. The current schedule is also on the blackboard model. Figure 6 shows the display of this system. The display shows the detailed progress of the simulation. The left side of the window shows the job progress from the workpiece view. The right side of the window shows the job progress from the machine tool view (Matsuda et al., 2006-2) (Matsuda et al., 2007).

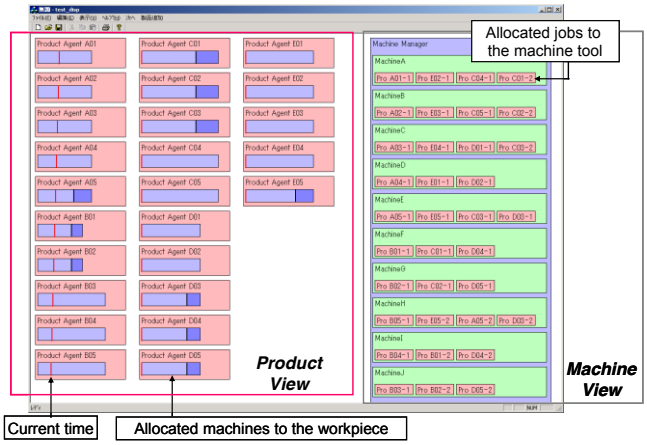

Figure 6. Display of the machining simulation

5.2. Assembly planning using the parts agent

The assembly planning system using parts agents was virtually constructed and simulated on a computer. The parts agent is also a product agent as mentioned above. In this system, assembly machine model in the machine agent and product model in the parts model are implemented using XML. Figure 7 shows the display of this system. In Figure 7, two kinds of cell phones are assembled. The main parts are electronic substrate. The main part agents of the substrate take the initiative in this assembly line. Machine 1 and 2 are for thread fastening. Machine 3 and 4 are adhesive machines. Two workers who supply parts to the machines are shown as Machine 5 and 6. Five lots of product are on the shop floor. The lower part of the display shows their current condition. The upper-left part of the display shows the planed work schedule from the product view and the machine view. The upper-right shows usage rate for each machine and completion rate for each of the products.

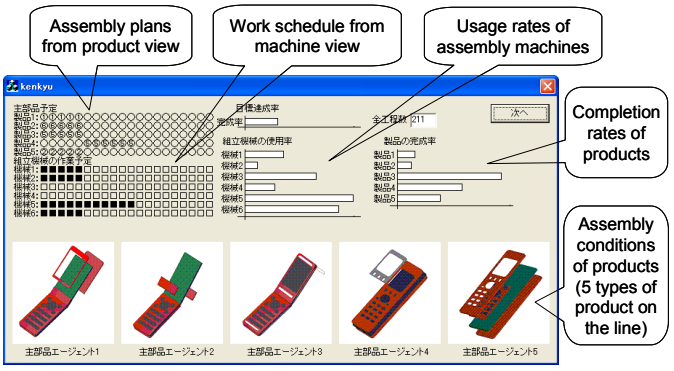

Figure 7. Display of the assembly simulation

6. CONCLUSIONS

An event driven configuration of the digital factory using agent technology is proposed in this paper. In this configuration, all elements of the factory including workpiece and parts are implemented as agents. The product agent which epitomizes workpiece and/or parts has the initiative in the manufacturing process and can autonomously decide on the

production process and the allocation of manufacturing machines. The method for structuring a product agent and machine agent were also shown. Trial implementation of the machine work planning simulation systems using machine agents and product agents have shown the possibility for the construction of a more autonomous and flexible virtual manufacturing system. This configuration has the possibility to provide efficient usage of manufacturing machines for environment-conscious manufacturing.

6.1. Acknowledgments

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