Product and machine agents for an autonomous assembly production system

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Abstract—In this paper, product parts and machine agents are proposed for the configuration of an autonomous flexible assembly system. Product parts are divided into two types. One is the main part that is a base of the assembled product and the other is for sub parts that are installed on the main part. These parts and assembly machines are implemented as software agents in a virtual assembly production line. The main part agent takes the initiative in this system. When a new main part is put on to the assembly line, the main part agent with the product model and sub part agents are dynamically generated. The main part agent plans the assembly process by itself and selects assembly machines that execute the assembly operations by communicating with assembly machine agents and other main part agents. The part agents are deleted when a product is completed. The assembly machine agent has a machine model of itself and can determine which operations can be processed by the machine itself. The product model and machine model are described using XML. Trial implementation of main part agents, sub part agents and assembly machine agents were done as was an assembly production simulation.

Index Terms—multi agent system, product parts agent, machine agent, product model, process model, autonomous assembly system

I. INTRODUCTION

In recent years, autonomous manufacturing systems tackling high-mix very-low-volume production have become known. 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 has recently been well applied to construct such a 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 [1][2][3][4][5]. If the manufacturing system doesn’t need the manager function that manages the entire factory by controlling each agent, it becomes a more flexible system. Such a system allows assembly machines to voluntarily decide on which workpiece to handle, and allows the workpiece more flexibility in its moves on the production line [6][7]. In this paper, we propose product parts agents and machine agents for an autonomous assembly system that has more flexibility.

II. AUTONOMOUS ASSEMBLING SYSTEM

In the proposed system, products such as workpieces, parts, and sub-assembled parts are configured as agents in addition to all factory elements such as assembly machines and AGVs. Parts that become the base for assembly operation such as the foundation of a cellular phone determine the operation to be performed on it, and determine the machine that receives the assembly request through communication with assembly machines. They call for other parts that have been assembled elsewhere, and are transferred to assembly machines with other parts that have been assembled elsewhere. The proposed system generates process planning that gains more flexibility through repetition of the aforementioned flow. Fig 1 shows the concept of the autonomous assembly system. The agents can be classified into main part agents that become the base for assembly operation, sub parts agents that are installed in main parts agents, and machine agents that perform the assembly operation. The main part’s agent decides on the operations required to complete itself. It also decides on an assembly machine from among machines that can perform such assembly and calls for sub parts agents that are necessary for the assembly operation. The main part agent and sub parts agents associate with the selected machine where they will be assembled. The main part agent takes the initiative in this system. It communicates with other agents as work progresses.

![Fig. 1. Concept of the autonomous assembly system](image-url)
III. PARTS AGENT

A. Main Part Agent and Sub Part Agent

The parts are categorized into main part that is based on assembly operation and sub parts that are assembled with the main part. The main part agent is the main operator of the assembly operation, so it must have five abilities as follows:
- communication capability with other agents
- computation of the necessary operations needed for completion
- deciding upon required assembly machines
- operation planning capability
- capability to call a sub part.

The main part agent must have complete knowledge of the technique and requirements of the assembly process. A sub part agent is a fictitious agent which is controlled by the main part agent. It receives an assembly request from the main part agent and schedules delivery timing of itself to the production line.

Fig 2 shows the structure of the main part’s agent. When a new main part is input to the production line, the main part’s agent is dynamically generated with the product model which indicates the structure of the complete product. The main part’s agent incorporates a Process Planner, Machine Determiner, Work Manager and Sub Parts Manager. The Process Planner plans the assembly operation schedule and generates a process model based on a product model. In a process model, assembly operation plans are described. The Machine Determiner allocates assembly operations to the assembly machine by referring to the process model and by asking the assembly machine agents which operation can be performed. The Work Manager controls the execution of operations according to the schedule. When sub parts are necessary during assembly processes, the Sub Parts Manager directs the sub part agents to input sub parts to the production line. Once sub parts are assembled with the main part, they become a part of the main part. When all sub parts are assembled with the main part, the main part agent disappears.

B. Product Model and Process Model

1. Product model

A product model is included in a main part agent. The product model provides complete product information such as shape and size of component parts. The product model is necessary to specify the main part agent’s work. The product model also has information on positioning and connecting relations of parts for the product. The product model is written in XML.

Fig 3 shows the structure of the product model. The product model contains the assembly scheme as a relationship among parts. A product has one main part. The relationship typically shows the connection between main part and sub parts. In the described relationship, positional information and connecting method of parts are provided. In the described parts, the total number of parts and their names are given.

Fig 4 shows a piece of the product model for a flip phone. In this example, Parts1, the foundation, is described as the main part. The next description is the relationship of sub parts such as Parts2, Parts4 and Parts15 to Parts1 that become the core of the assembly operation. The lower level description is information on parts such as total number of parts, Parts ID and name of the part. In this example, Parts1 is the foundation, Parts2 is the Lower Front Case and Parts15 is Lower Front cover. There are two connection method: screwing and bonding.

2. Process model

The process model contains the assembly sequence to complete the product, operations in each process and the required sub parts. Fig 5 shows the structure of the process model. The example of the detailed content written in XML is shown in Fig 6.
In Fig 5, the process model specifies the number of processes and proceeding order of processes, and for each such process it specifies the required part and its attachment position. The process model also contains the total number of parts and describes the necessary parts for each process.

3. The relationship between models

The main part agent generates a process model based on the product model. Fig 7 shows the relationship between product model and process model. The following can be understood from the description in the product model. The main part forms the foundation (Parts 1). The button (Parts 4) is placed above Parts1 and the Front case (Parts 2) and Front cover (Parts 5) are placed above Parts4. The Back case (Parts 3) is put underneath Parts 1. Using this information, the main parts agent generates process descriptions which are shown on the right side of Fig. 7.

Fig. 6. Example of the process model
the connection type of parts. Operation orders are also derived from these relationships. The results are described as the process model.

IV. ASSEMBLY MACHINE AGENT

The required capabilities for an assembly machine agent are the skill to communicate with other agents, a competency to judge if it is possible to perform the requested operation by the main part agent, and an ability to compute the start and finish times. Also required is a machine model in which specifications and capabilities of the assembly machine are described. Each assembly machine agent has its own machine model. Fig 8 shows the structure of an assembly machine agent. The assembly machine agent receives the request for assembly work estimation from the main part agent. By referring to the machine model, the machine agent determines whether the work that is required from the main part agent can be executed by the assembly machine itself. If the operations for the work can be executed, the assembly machine agent calculates the start and finish time for the work. The main part agent selects an assembly machine for executing the work depending on the above result determined by the machine agents. When the assembly machine agent receives the request, the machine agent adds the request into the operation schedule.

Fig. 8. Structure of the assembly machine agent

The flow of the feasibility determination process for the assembly work is shown in Fig. 9. At first, the main part agent distributes estimation requests for work to all active assembly machines in the production line. The assembly machine agent receives the work estimation request as the requested work name. An assembly machine agent refers to assembly machine model and compares the work name and executable operation type. If there is discord, the assembly machine agent returns the rejection notice to the main part agent. If there is accord, the assembly machine agent refers to its own schedule and calculates the starting and finishing time. Finally, the assembly machine agent returns an acceptance notice with the starting and finishing time to the main part agent.

Fig. 9. Feasibility determination of assembly work

Fig 10 shows a part of XML descriptions for a screw-driving machine model. In the machine model, there are descriptions for the assembly machine ID number, types of executable operations that the assembly machine can do, approach direction of the tool, calculation method for operation time, and precise steps for the operation. The machine model also contains mechanical specifications.

Fig. 10. Example of machine model

V. ASSEMBLING SIMULATION

A. Simulation System

Fig 11 shows the configuration of the assembly simulation system. The operator inputs the kind of products, numeric targets for the lot, and the timing for putting the main part on to the production line. According to the input data, the simulation manager requests a new main part to be put on to the production line.
The main part agent communicates with other agents and proceeds with the assembly jobs. The simulation manager displays the results of the simulation.

B. Flow of Assembly Simulation

In this simulation system, the main part agent, sub parts agents and machine agents are implemented. Fig 12 shows the sequence flow of agents for the virtual assembling.

As in the assembly line sequence, the main part 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 sub parts if necessary[8].

VI. EXAMPLE RESULT OF ASSEMBLING SIMULATION

The assembly simulation mimics the production of flip phones and cellular phones for example. Here, the flip phone is a clamshell type cell-phone and the cellular phone is a straight type cell-phone. At the first assembling step, the bottom front case, the bottom back case and buttons are screwed to the main part. In the next step, the center front case and the center back case are screwed to the newly assembled main part. The flip phone is completed by 13 further steps. Machine 1 and Machine 2 are fastening machines, Machine 3 and Machine 4 are bonding machines and Machine 5 and Machine 6 are workers.

Fig 13 shows an example of the planning simulation results. Fig 13 (a) is a job schedule for regular production. This presents the numeric targets for the lot. This example shows the situation of putting almost the same number of flip phone’s main parts and cellular phone’s main parts on to the production line at the start. The main parts that are put on to the production line are for cellular phones for which the sufficiency rating is lowest. But then new main parts are put on to the production line for a while for flip phones. There exists a difference in that flip phones require a longer process than cellular phones. Since the Simulation Manager put new main parts with low sufficiency rating on the production line, the flip phones are assembled first.

Fig 13 (b) shows the changed schedule due to the input of a new main part. When the flip phone order completes one lot, it can be seen that a new main part for cellular phones is put on the production line. The main parts with low sufficiency rating are put on to the production line because flip phones are assembled first. The main parts with the lowest sufficiency is put on to the production line. These examples show the decisions on which ordered operation should be performed through communication between agents. However, because an operation is allotted by the earliest starting time, results show big differences in a number of processes and availability ratios of the assembly machines.

VII. CONCLUSIONS

In this paper, the configuration of an autonomous assembly system using product part agents and machine agents is proposed. Trial implementation of main part agent and
assembly machine agents has been done. The assembly scheduling simulation was successful through use of these agents. This simulation shows that the agent based approach, especially the main part agent's initiative, is useful for the increase of autonomy and flexibility of the system. There is some future work such as to develop an effective negotiation procedure among agents and scheduling methodology, and to introduce a process planning function into the main part agent.

ACKNOWLEDGMENT

The authors are also grateful to Dr. Udo Graefe, retired from the National Research Council of Canada for his helpful assistance with the writing of this paper in English.

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