VIRTUAL PCA LINE CONSTRUCTED FOR SIMULATION OF TIME SERIES CHANGES OF POWER CONSUMPTION CONSIDERING THE EFFECT OF PRODUCT FLOW

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Abstract
The Digital Eco-Factory proposed by the authors evaluates the production conditions including environmental indicators from an equipment and product view by executing a simulation using a virtual production line. In this paper, the Digital Eco-Factory for PCA (Printed Circuit Assembly) is discussed. The virtual PCA line is constructed by multi equipment agents which are generated based on equipment models. Production conditions are evaluated about power consumption of entire line from the product viewpoint. The equipment models include behaviour descriptions as states and their transitions. Each state is embedded with equations for calculating power consumption. The equipment agent includes communication functions with a PCB agent for controlling of product flow to manage the timing of the input of the product to each equipment on the virtual line. Experimental executions of a simulation using the constructed virtual PCA line show the effect of product flow.

Keywords: multi agent system, virtual production line, power consumption simulation, behaviour modelling

1 INTRODUCTION
Product life cycle engineering is an approach for considering the life cycle cost of a product, including the manufacturing process to the end of the life of the product, as well as for sustainability in the global environment[1-5]. A product at the end of its life would be reused by disassembling. These ideas bring about sustainability of the global environment and also the economic effect [6-10]. The product life cycle process as mentioned above is designed early in the design stage. However, the production process cannot be improved for more efficient production until the actual production at the factory. Wherefore, there will be a demand for reducing the difference in cost from the start of production to the improvement of the product flow. For reducing the difference, the thorough preview at the early stage is necessary. At the early stage of the preview, a simulation system is usually used.

The Digital Eco-Factory has been proposed by the authors for simulation of the production process[11]. The core of the Digital Eco-Factory is a virtual production line. The equipment on the production line is modelled through the e-catalogues which are used for implementing the virtual equipment. The equipment models include not only a static description but also a dynamic behaviour model. The behaviour model describes the states that the equipment can take and its transitions. For each state, there is embedded an equation for power consumption calculation including variables affected by external factors. The equipment model includes an embedded communication description to use for control of product flow. Controlling the product flow is to control the input timing of the product to each equipment. Therefore, it also affects the time series change of power consumption. Templates for each type of equipment are made by describing equipment models using a data description language. E-catalogues are generated by fulfilling a template by equipment specific data. By preparing an e-catalogue as a commonly usable equipment model, various operators can easily construct a virtual production line simply by selecting the model of the equipment. Equipment agent descriptions are automatically generated from e-catalogues. The description in the e-catalogue is converted into an equipment agent description suitable for a grammar of the simulation environment.

In this paper, the virtual PCA (Printed Circuit Assembly) line which is the core of the Digital Eco-Factory for PCA, has been constructed for the simulation of time series changes of power consumption considering the effect of product flow. In previous research, the authors focused on an equipment’s time series changes of power consumption. The Digital Eco-Factory can focus not only on time series changes of equipment but also a product’s power consumption without changing the structure of the virtual production line. Using the same virtual PCA line, it is shown that the result of the simulation of the time series changes of power consumption considering effect of product flow is confirmed.

2 CONSTRUCTION OF VIRTUAL PCA LINE FOR POWER CONSUMPTION SIMULATION
The equipment needed for the PCA line are a solder paste printer, several electronic part mounters, a reflow soldering oven, visual inspection machine and buffers. The construction procedure of the virtual PCA line in the Digital Eco-Factory is shown in Figure 1. The virtual production line is constructed as a multi agent system. Agent descriptions of equipment on the virtual PCA line are automatically generated from e-catalogues selected by an operator from library of e-catalogues. The production scenario is input to the Digital Eco-Factory. PCB agents that form target products of the PCA line are automatically generated based on the production scenario by the Digital Eco-Factory. A PCB agent communicates with equipment agents and completes itself by receiving a task. The PCA line has information about the structure and the connection of the equipment agents. As a result of the simulation, power consumption and productivity are output[12].

The contents of the production scenario which is input to the Digital Eco-Factory is shown in Figure 2. Production scenario include product data and input order data. Product data has information about the product, and input order data has information about the input sequence.
For example, there are the order of input to each line, input time and number of inputs. Using the constructed virtual PCA line, power consumption simulation can be executed from two viewpoints. An equipment agent monitors from the equipment view and a PCB agent monitors from the product view.

Table 1. Equations for calculation of power consumption at each state in printer.

<table>
<thead>
<tr>
<th>States</th>
<th>Equations for calculation of power consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting</td>
<td>Active Time Starting (h) X Controlled Equipment (kW)</td>
</tr>
<tr>
<td>Idling</td>
<td>Active Time Idling (h) X Controlled Equipment (kW)</td>
</tr>
<tr>
<td>Metal Mask Change</td>
<td>Active Time Metal Mask Change (h) X Controlled Equipment (kW)</td>
</tr>
<tr>
<td>PCB Set</td>
<td>Conveying Path Length (mm) X Board Width (mm) X PCB Conveying Motor (kW)</td>
</tr>
<tr>
<td>Metal Mask and Print</td>
<td>Conveying Path Length (mm) X Board Width (mm) X PCB Conveying Motor (kW)</td>
</tr>
<tr>
<td>Metal Mask Release</td>
<td>Conveying Path Length (mm) X Board Width (mm) X PCB Conveying Motor (kW)</td>
</tr>
<tr>
<td>Cleaning</td>
<td>Active Time Cleaning (h) X Cleaning Motor (kW)</td>
</tr>
</tbody>
</table>

To simulate time series changes of electric power consumption of each equipment on the PCA line, modelling of equipment behaviour is required. The behaviour model expresses state and state transition in the equipment. The behaviour model is described by the activity diagram using UML. Figure 3 shows the activity diagrams for each equipment on the PCA line. The activity diagram for the solder paste printer is shown in Figure 3 (a). After the printer start-up, the printer state transits to the idling state. If a PCB is input, the printer state transits to the PCB ID confirmation state. In this state, the printer confirms the PCB ID. After confirmation of the PCB ID, the printer judges whether it is necessary to change the metal mask. If necessary, the printer state transits to the cleaning state. In this state, the printer changes to the metal mask which is suitable for producing the PCB. If it is not necessary, the printer transits to the next state. After judging of the metal mask change, the printer judges whether it is necessary to clean the metal mask. If necessary, the printer state transits to the cleaning state. In this state the printer cleans the metal mask. If this is not
necessary, the printer state transits to the PCB set state. In this state, the printer conveys the PCB to the work space. After the PCB set state, the printer state transits to the metal mask set state. In this state, the printer covers the PCB with the metal mask. After the metal mask set state, the printer transits to the squeegee operation and printing state. In this state, the printer screen prints the solder paste to the PCB. After the squeegee operation and printing state, the printer transits to the metal mask release state. In this state, printer releases metal mask from PCB. After metal mask release state, printer transits to PCB output state. In this state, the printer outputs the PCB from the work space. After the PCB set state, if it has finished producing one lot, the printer state returns to the idling state, otherwise it returns to judge whether cleaning is necessary [12]. In the same way, Figure 3 (b) shows the activity diagram for an electronic part mounter, Figure 3 (c) is for a reflow soldering oven and (d) is for a buffer. For the calculation of time series changes of power consumption, each state in the activity diagram is associated with an equation for power consumption. Table 1 shows equations for the calculation of power consumption for each state in a solder paste printer. The
variables surrounded by squares are provided values from production scenario when the simulation is executed. These values are embedded into a PCB agent. In other word, different values are stored to an individual PCB agent which is generated according to the production scenario. Therefore, different power consumption can be calculated for each product produced.

A created equipment model including behaviour model and equations as discussed above are implemented as an e-catalogue using a data description language such as XML. An equipment agent whose description is generated based on a corresponding e-catalogue enables the calculation of the time series changes of power consumption of the equipment.

3.2 Time series of power consumption for each equipment

Virtual production is performed on the virtual PCA line constructed by equipment agents which are automatically generated from an e-catalogue created according to the above equipment model. The simulation of time series changes of power consumption of each equipment is executed using the virtual PCA line. Figure 4 shows the example simulation result of the time series of power consumption for each equipment. The structure of the virtual PCA line has the same structure as shown in Figure 1. Figure 4 shows six equipment's time series changes of power consumption, solder paste printer, buffer #1, electronic part mounter #1, electronic part mounter #2, buffer #2 and reflow soldering oven in order. In these graphs, the vertical axis represents power consumption about 1 product worked by each equipment. The power consumption line surrounded by leftmost squares shows time series changes of power consumption for buffer1. The line surrounded by third squares shows time series changes of power consumption for electronic part mounter1. The line surrounded by fifth squares shows time series changes of power consumption for buffer2. The line surrounded by sixth squares shows time series changes of power consumption for the reflow soldering oven.

At first the PCB agent communicates with the solder paste printer agent. If the printer agent says vacant, the PCB agent inputs itself to the printer agent with detailed product data. If the printer agent is occupied, the PCB agent keeps issuing requests until the printer agent becomes vacant. When the printer agent says that the work is finished, the electric power consumed until the completion of the work is provided by the printer agent and recorded in the PCB agent. Next, the PCB agent communicates with the buffer agent. If the buffer agent says vacant, the PCB agent requests to discharge from the printer and requests to store in the buffer. If the buffer agent says that its storage is fully occupied, PCB agent keeps itself in the printer until the buffer has a vacancy. The PCB agent completes itself by repeating the same communication as above with electronic part mounter and reflow soldering oven.

Figure 6 shows the data flow between the PCB agent and the equipment agents. PCB agent #1 sends data for PCB #1 width and PCB #1 Length to the solder paste printer agent. The printer agent calculates operation time for each state using these data. Power consumptions for each state of the printer are calculated based on calculated operation time. Power consumption incurred for each state are sent to PCB agent #1 sequentially. Next, at the stocking of PCB #1, PCB agent #1 sends PCB #1 Width, PCB #1 Length and PCB #1 ID which is used for controlling storage to buffer agent #1. Buffer agent #1 calculates operation time for each state. Power consumptions at each state of buffer #1 are calculated based on the calculated operation time. Power consumption incurred at each state are sent to PCB agent #1 sequentially. Next, at supplying of PCB #1, in the same way as stocking, power consumption for each state are provided to PCB agent #1. Based on that step, PCB agent #1 gathers power consumption data for each state from each equipment agent.

4 VIRTUAL PRODUCTION FROM PRODUCT VIEW

4.1 PCB agents

In the Digital Eco-Factory, the time series changes of power consumption from the product view point can be confirmed using the same virtual PCA line used in 3.2. PCB agents communicate with equipment agents. PCB agents provide product data to equipment agents and get simulation data from equipment agents. Figure 5 shows the production process in the PCB agent. A PCB agent which is automatically generated, based on product data and input order data, has the data necessary for production itself. The PCB agent gets an assignment of the PCA line to produce itself based on the input order data.
CONSIDERING PRODUCT FLOW

5.1 Simulation of power consumption using virtual production line

The simulation for observing the effect of product flow is executed using virtual PCA line. Figure 8 shows the display of power consumption simulation using the virtual PCA line. The upper right shows the graph of electric power consumed by the product currently being produced. The upper left shows how the product flows on the line. The lower shows power consumption of the entire line. Simulation using the PCA line is executed. Table 2 shows input order data for the experiments using the virtual PCA line. Figure 9 shows the example of power consumption simulation using input order data of Table 2 (a). Block 1 part of the power consumption of the entire line shows a dense waveform. This is because the capacity of the buffer is empty at the early stage of production, so that the product was continuously input. In block 2, the interval of the waveform is constant. This is because the product flow is controlled by the buffer.

5.2 Effect of the order of products input

Input order data is changed for confirm the effect of the order of products input. The total number of products to be manufactured is the same. 2 input order data are prepared. Table 2 (b) and (c) shows input order data for the experiment showing the effect of the order of product input. Figure 10 shows the example of power consumption simulation showing the effect of the order of product input. The upper graph shows power consumption when inputting every 10 PCBs. The lower graph shows power consumption when inputting every 5 PCBs. There is a dense waveform especially in the marked blocks. This is because the type of the product to be manufactured has been changed many times, so the difference of preparation time and operation time accumulated. Dense waveforms are appeared due to by overlap in the preparations. Also the power consumption may overlap locally and the total value may increase. So, there are many dense waveforms, the possibility of an instantaneous gain in power consumption increases.

5.3 Effect of interval of products input

Input order data are changed to confirm the effect of varying the interval of product inputs. The total number of products to be manufactured is the same. The order of products input is the same as in section 5.1. The interval of products input is changed. The input interval for each product to be produced is adjusted. Table 2 (d) and (e) shows input order data for the experiment showing the effect of changing of the interval of products input. Figure 11 shows the example of power consumption simulation showing the effect of changes of the interval of products input. Simulation with a 15 second interval is long until the product flow is controlled by the buffer. In other words, it is long until the buffer is full. If the interval until input is long, unevenness is occurred in the graph of power consumption especially in the marked block.

5.4 Effect of both the order and interval of product input

Input order data are changed for confirm the effect of both the order and interval of product inputs. The total number of products to be manufactured is the same. The order of products input is the same as section 5.2. The interval of products input is adjusted to have a certain interval every time the type of product to be produced is changed. Table 2 (f) and (g) shows input order data for the experiment showing the effect of both the order and interval of product input. Figure 12 shows the example of power consumption simulation showing the effect of changes in both the order and interval of product input.
The dense waveform that occurred in the experiment of section 5.2 is reduced. By reducing the size of one lot and adjusting the input interval, the waveform of the power consumption especially in the marked block shows a constant cycle.

5.5 Effect of multiple production lines

In the previous experiment, the number of production lines is 1. Therefore, the experiment is conducted to confirm the effect of using multiple production lines. Therefore simulations using 2 lines and 3 lines were also executed. Table 2 (h) and (i) shows input order data for the experiment showing the effect of using multiple production lines. Figure 13 shows simulation examples of power consumption showing the effect of using multiple production lines. Vertical bar in Figure 13 shows the end time of production at each line. In the experiment of using 2 production lines, although the number of production at each line is the same, the manufacturing end time is different. Because, Line #1 takes a longer time to complete work for 1 product, in order to produce a larger PCBs than Line #2. In the experiment using 3 production lines, although the number of production at each line differs by 5 PCBs each, the end time of production does not differ much, because, the similarity of the experiment using 2 production lines, the size of the PCB influenced the manufacturing end time.

6 CONCLUSION

The virtual PCA (Printed Circuit Assembly) line has been constructed for the simulation of time series changes of power consumption considering the effect of product flow. This focused not only on equipment's time series changes of power consumption but also a product's time series changes of power consumption without changing the configuration of the virtual production line. This is due to the fact that the product agent is configured so that the product agent can record and accumulate the time series data on power consumption received from each states at each equipment agent. In addition, the experiment in which the input order data is changed in order to observe the effect of the product flow throughout the production line is conducted. As a result, it is said that the proposed method of virtual production line is applicable to evaluate the production plan from the production line view, equipment view and product view.

7 ACKNOWLEDGMENTS

This work is supported by JKA and its promotion funds from KEIRIN RACE. The authors thank JKA. And also, the authors thank members of Technical Committee " DEcoF (Digital Eco Factory) " (2012. Oct. - ) by FAOP (FA Open Systems Promotion Forum) in MSTC (Manufacturing Science and Technology Centre), Japan for fruitful discussions and their supports. The authors are 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.

8 REFERENCES