Intelligent Assembly Planning System in Distributed Production Environment

Hidefumi Wakamatsu, Keiichi Shirase, and Eiji Arai
Dept. of Manufacturing Science, Graduate School of Eng., Osaka University
2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
{wakamatu, shirase, arai}@mapse.eng.osaka-u.ac.jp

Abstract. There still often occurs errors and failures on the actual factory floor, that require the modification of the process plan, operation plan and production scheduling. In order to reduce the vast amount of such re-calculation efforts and to increase the flexibility to the change, an intelligent and distributed production systems have been proposed. This paper deals with the CAD/CAM system for product assembly in the intelligent and distributed production systems. The roles of process planning and operation planning of product assembly will be changed there. The process plan is generated mainly from the product data and stored in an IC card that is used to realize the material/information combined flow in the factory. The operation plan is developed in the assembly cell controller with the functionality data of the cell facilities through the communication between the cell controller and the IC card. The process planning is executed based on the product oriented way and the operation planning is on the production facility oriented way, which enables more flexible counter planning on the factory floor against the errors and faults.

1 Introduction

Manufacturing activities generally consist of three areas, CAD/CAM (engineering), production planning (management) and flexible automation (production). CAD/CAM is deeply connected with product design and production planning is also connected with product marketing/planning. The flexible automation system requires the following functions generally[1].

(1) Offer of on-scene information of the actual assembly shop floor.

(2) Realization of flexible construction/form of assembly shop floor convenient for CAD/CAM and production planning.

(3) Information processing partially included in CAD/CAM and production planning in order to lighten their load.

The keywords in order to realize the general requirements to the flexible automation systems are "intelligent" and "distributed" information processing on the factory floor that integrates the total manufacturing activities[2][3].

The roles of process planning and operation planning of product assembly have not clearly been defined. The ability of computers and controllers of assembly robots and cells has increased. That permits the intelligent and distributed information processing on the factory floor, where the roles of controllers and the definition of process/operation planning have been changed.

There still often occurs faults and errors in the actual factory floor that frequently require the modification of operation plan. It is more efficient to generate the assembly operation plan in the floor computers/controllers referring to the facilities and functionalities according to the given assembly process plan generated in CAD/CAM systems.

Process planning and operation planning in the field of machining is clearly defined. This is successful because machine-tools are grouped by their functionalities such as machining centers, lathers, milling machines etc.

In the product assembly representative facilities are robots which are designed to aim at achieving general functions rather than specified functions peculiar to specified product. They are applied to all kinds of products and assembly processes in the mechanical product assembly.

In other words, the product assembly is suitable to the intelligent and distributed production systems where facilities are fitted to different types of assembly by small changes like robot hands. While the assembly facilities are flexible, the control software has problems to be hard in developing flexible software.

There are two fundamental kinds of information required for product assembly : information of parts and products, and information of facilities. The present assembly planning systems utilize these two kinds of information in a mixed way. That is one of the reasons that it is difficult to develop the flexible assembly software.

The process planning and the operation planning of product assembly have to be separated from the viewpoint of the using information of the above two kinds. The process planning uses mainly the parts and products information to generate the possible assembly process plan.

Operation planning develops the feasible and detailed assembly sequences for each cell or station, and generates the task program for each station by decomposing the process plan by referring to the facility information. The operation planning is to be executed in the factory floor computers/controllers when they get the intelligent and distributed capabilities.

2 Intelligent and Distributed Assembly System

The past job shop floor with many workers and operators was very flexible for the changes because human beings could change the process sequence and the operation plan, and also could carry tools, jigs, fixtures and parts freely[4].

The former was realized by the intelligent and distributed information processing ability, and the latter by ability of production facilities, both of which are to be introduced into the autonomous production systems.

Especially the moving ability of facilities enables the dynamic structure of the factory where the required jobs/tasks can be executed by the cells with changing the facilities, that increases the flexibility. The dynamic structure causes the variety of the facilities as shown in Fig.1. The same jobs/tasks can be executed by different cells, however, the process sequence and the operation sequence for the jobs/tasks may differ according to each cell's ability or facilities[6].

Figure 1 shows the "rich cell" that have various functions facility and the "poor cell" for special purpose, and also shows the "rich AGV" and "poor AGV".

The dynamic structure of production facilities allows the existence of rich and poor cells etc. in the factory floor where the data communication among controllers plays

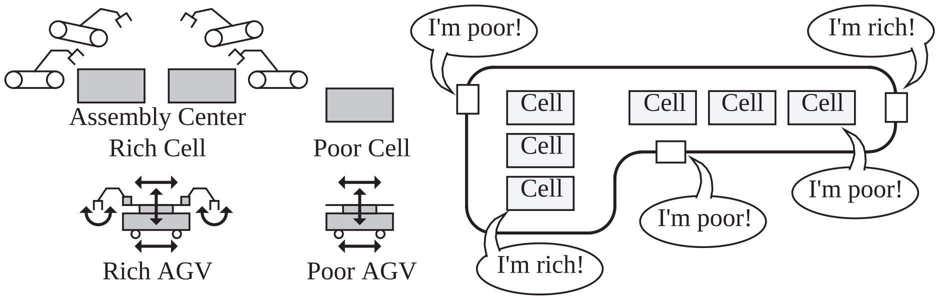


Figure 1: Dynamic Structured Factory with use of moving ability of factory facilities

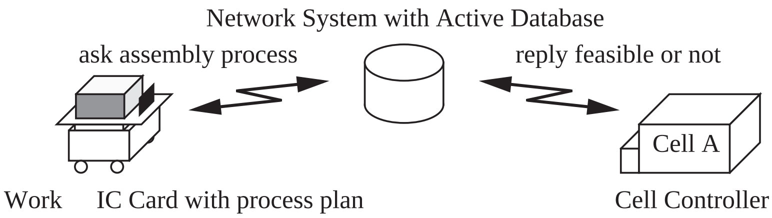


Figure 2: Communication between cell and work

the very important role to declare the functionality and the capability of each cell etc., and to describe the jobs and tasks to be executed.

The communication data includes the following items.

- product data
- production facility data
- process and operation description data
- order and monitoring data
- production knowledge which are stored in the distributed database

The flexible assignment of the jobs/tasks to the cells is realized with use of IC card attached to each work in order to integrate the material flow and the information flow. The process plan generated in the process planning system is described in each IC card. The cell controller communicate with IC card through network system using active database[5] to select the executable assembly processes like shown in Fig.2. The production process stored in IC cards does not specify the assembly cell sequence but describes the necessary sequence of assembly jobs/tasks with precedence constraint with use of the common description that is easy to understand by different controllers.

In other words, the process planning is prepared independently from the facility information of the factories. The input to process planning system is parts and product models that are constructed in the product design division, and the common sense to be used in product assembly.

The functions and capabilities of factory floor facilities and their operating conditions are considered within the operation planning system, not in the process planning system.

3 Assembly Process Planning

The process planning system in machining has been defined generally as to output the sequence of machine tools to finish the part from the material referring to the part information based on the geometric model, and to the machine tool capabilities. The detailed processing operation sequences for each machine tool are executed in the operation planning system that finally generates the CL data or NC programs.

When the factory is operated soundly with no faults by the given production schedule with no changes, this process/operation planning system concept is very effective. However, the actual factory has various kinds of changes. In order to fit the changes, it is too hard and time consuming to re-calculate the total process/operation plan.

Especially in product assembly planning, there has been no clear definition of process planning and operation planning but the detailed assembly operations have been calculated with use of the mixed information about parts/products and assembly facilities. In order to increase the flexibility in case of various changes on the factory floor, and to decrease the heavy load in CAD/CAM systems to re-calculate the total process/operation plan, it is effective to divide the assembly process planning and assembly operation planning by the information used in each process.

If the assembly process plan is executed by the product oriented way, it should be fixed even when there happens errors and faults in the factory facilities and only the operation plan that is calculated by the facility oriented way is to be re-calculated, that meets the above requirements. The process planning is executed in the CAD/CAM systems that are connected deeply with the product design division, and the operation planning is executed in the factory floor controllers that have enough capabilities in the intelligent and distributed assembly systems.

The total assembly planning flow is shown in Fig.3 where the roles of process planning and operation planning are clearly divided from the view of utilized information. The assembly process planning requires the parts and products information as the input data, and provides the following three functions.

- Judge the possibility of product assembly

  If we fail to assemble the product by moving parts only from the parts and product models without taking facility environment into consideration, we conclude the assembly is impossible, and the parts/products models are fed back to the product design division.

- Generate the local assembly sequences

  The local assembly sequences with assembly precedence conditions can be generated from the parts/product models with use of the kinematic simulation system which are send to the operation planning for the detailed assembly sequences.

- Generate possible assembly processes

  The process planning outputs possible assembly processes. Some assembly processes may not be feasible because the actual facility environment is not considered in this stage.

The assembly possibility is computed with use of kinematic simulation system[7] where the effect of gravity has to be considered to detect the necessities of jigs/fixtures.

The local assembly sequences are the most essential information to generate the task program for a particular assembly cell to assemble a particular product quickly in the operation planning.

There can be thought of several priorities among local assembly sequences from several different viewpoints with use of parts and product models in CAD systems.

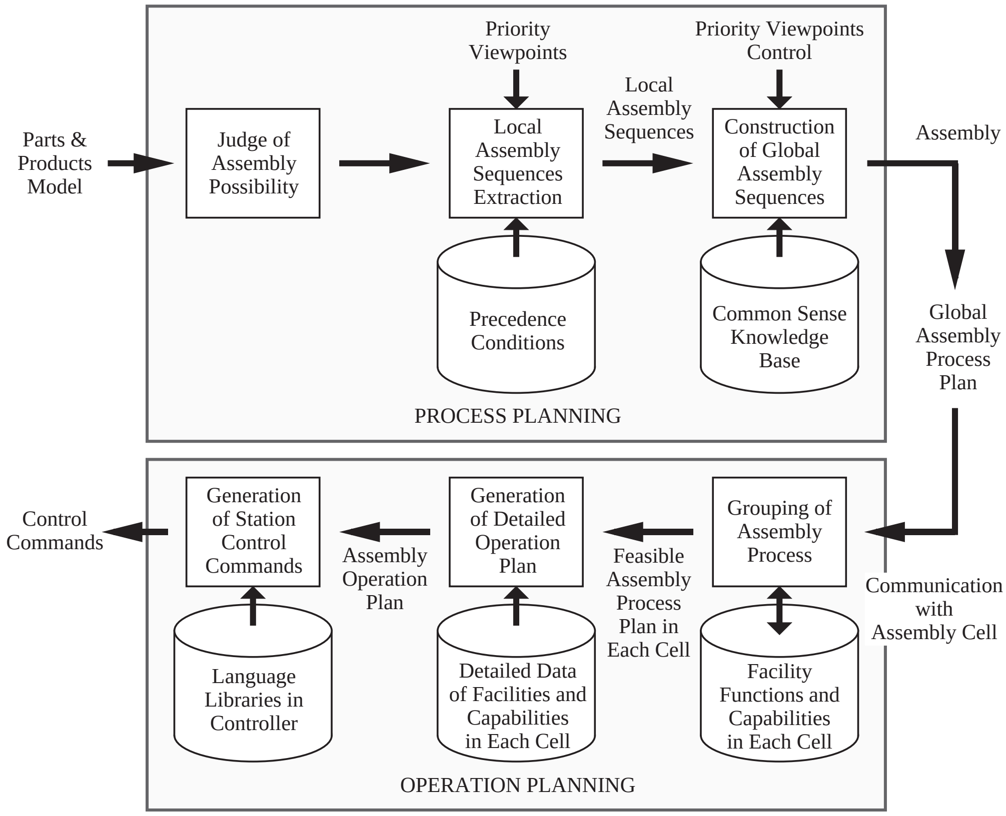


Figure 3: Production planning flow

One viewpoint is that geometrical interferences among parts are not allowed always throughout the assembly process, which leads the precedence constraints to assembly sequences.

Another viewpoint is the stability viewpoint of parts. It is preferable for assembly not to use jigs and fixtures to keep parts in some position in the space. The local assembly sequences are required to avoid from arranging parts where some parts fall down by the gravity force without jigs or fixtures.

One set of local assembly sequences is generated from one viewpoint, and described in a file. An example of the part/product data is shown in Fig.4. The CAD/CAM system processes the part/product data to generate the local assembly sequences.

The local assembly sequences are described by the binomial expressions where each variable shows the part and the relation shows the viewpoint. Figure 5 shows an example of local assembly sequences based on the viewpoint to avoid the geometrical interferences, and Fig.6 shows the local assembly sequences from the viewpoint of avoiding fall down of parts without jigs/fixtures by the gravity force.

These local assembly sequences can be computed in the CAD/CAM system automatically with use of the part/product models and the kinematic simulation systems.

The global assembly sequences are generated from the collection of several sets of local assembly sequences when the priority viewpoints are selected based on the factory facility information and the factory control principles taking the common sense and knowledge of product assembly process into consideration.

The assembly process plan consists of the global assembly sequences and the local assembly sequences with the priority viewpoints that are required in the operation planning when the assembly cell selects the different set of local assembly sequences

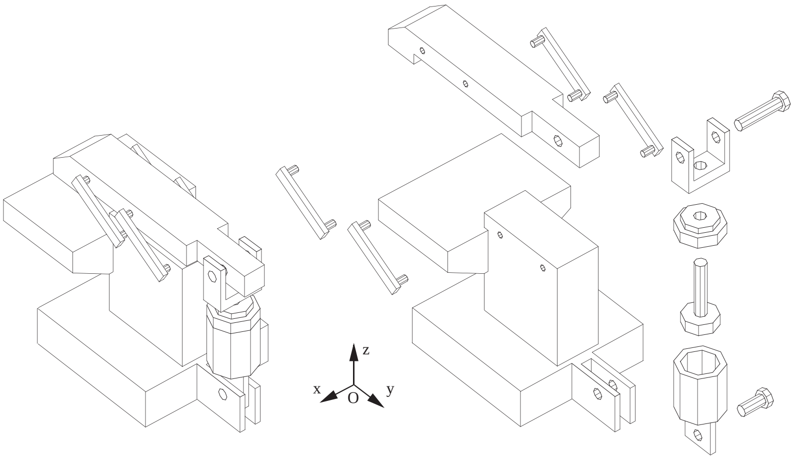
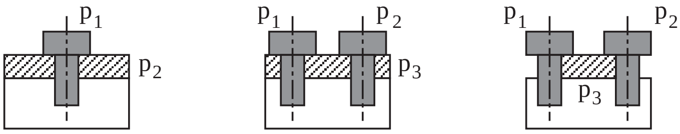


Figure 4: Product/part data described by solid model



$(p_1 \; p_2)$ $(p_1 \; p_3) \wedge (p_2 \; p_3)$ $(p_1 \; p_3) \vee (p_2 \; p_3)$

Figure 5: Local assembly sequences by geometrical interferences

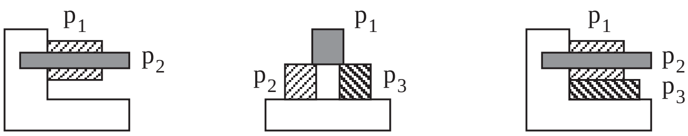
based on different priority viewpoints, and is stored in the IC card attached to the parts/subassemblies shown in Fig.7.

4 Assembly Operation Planning

The assembly operation planning is the process to generate the detailed assembly operation in each assembly cell or station from the input of both the result of the process planning and the assembly facility information that is given by geometric models of the facilities and the functions/capabilities of the assembly cells and stations.

The operation planning generates the actual assembly sequences referring to the actual assembly facility environment such as what kinds of robots are available, how many robots can be co-operated together in one cell and so on. The global assembly processes may be modified in the operation planning like shown in Fig.8 where the number of robots in a cell is taken into consideration, however, the local assembly sequences are kept.

The sequence of using cells or stations is decided by scheduling system. When a



$(p_1 \; p_2)$ $(p_1 \; p_2) \wedge (p_1 \; p_3)$ $(p_1 \; p_2) \vee (p_1 \; p_3)$

Figure 6: Local assembly sequences by gravity force

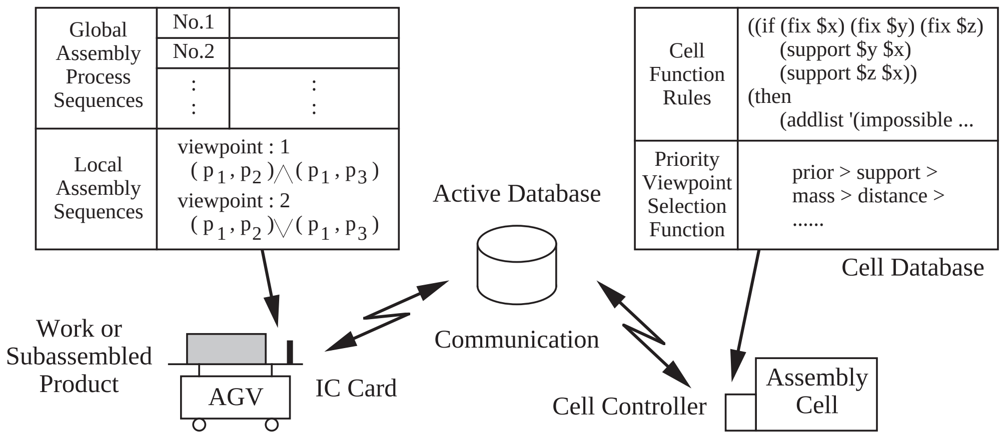


Figure 7: Assembly process plan stored in IC card

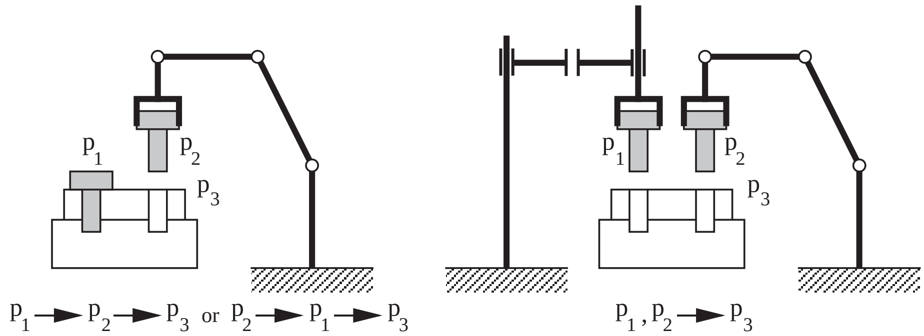


Figure 8: Modification of assembly sequences according to the number of robots

process planning is input, the operation planning system of each cell judges whether given assembly process is feasible in the cell or not referring to the cell functions and capabilities stored in the cell database. If it is feasible, the system generates the detailed operation plan that consists of two kinds of control data : hand positioning control data and arm movement control data, and reports it to active database. The scheduling system communicates with active database and decides the sequence of cells based on some rules.

In the generation of movements of the assembly facilities, the operation planning system utilizes the 3-D solid model based kinematic simulation system that ensures the realization of the computed movements so that parts and assembly facilities do not interfere with each other.

In order to assemble the product in Fig.4, it is required to support one part to assemble another part because of avoiding the part falling down by the gravity force. When the process plan is send to the cell with one robot, the cell controller replies that the given sequences are impossible, while the cell with two robots replies feasible.

The hand positioning control data is calculated automatically in the cell controller[8] [9][10]. On the other hand the generation of arm movement control data requires the co-operation between the operation planning system and the operation planner(or operator) referring to the kinematic simulation system except several simple examples[11]. The final output from the operation planning system is the station control command that requires the command language libraries and so on that are specified to the station controllers, some of which can be processed automatically.

5 Conclusion

The assembly process planning and the assembly operation planning are often connected together, and it takes vast amount of computation to change the operation plan to fit the change in the factory.

In the distributed and autonomous production systems, the roles of the two stages have to be separated.

The assembly process planning is executed in CAD/CAM system referring mainly to the parts/products data to generate the possible global assembly sequences and the local assembly sequences connecting with priority viewpoints.

The assembly operation planning is executed in the controllers on the factory floor to calculate the detailed assembly operation sequences in each assembly cell referring to the output from the process planning system and the assembly facility information of functions and capabilities. In this process, the global assembly sequences may be modified to fit the actual assembly cell functions and capabilities, however the local assembly sequences are to be maintained.

Both assembly process planning and operation planning systems are integrated through communication in the intelligent and distributed production systems.

References

[1] Arai, E. and Okada, S., 1990, A Feasible Study on Control Architecture of Autonomous Manufacturing Systems, Preprints of 1990 Japan-USA Symposium on Flexible Automation, Vol.1, pp.179-182.

[2] Bilberg, A. and Alting, L., 1990, A Flexible and Integrated Control Concept, Annals of the CIRP, Vol.39, No.1, pp.463-466.

[3] Kimura, F., et al., 1990, Product Feature Modeling for Integrated Product Design and Process Planning, Preprints of the 22nd CIRP International Seminar, pp.1-11.

[4] Bessant, J. and Chisholm, A. W. J., 1987, Human Factors in the Implementation of CIM, Manufacturing Systems, No.3, pp.231-240.

[5] Arai, E. et al., 1996, Auction Based Production System through Active Database System, proc. of the pacific conference on manufacturing '96, pp.371-376.

[6] Arai, E., et al., 1992, Manufacturing Software Environment for Future Flexible Automation, Proceedings of IMACS/SICE International Symposium on Robotics, Mechatronics and Manufacturing Systems '92 Kobe, Vol.2, pp.1119-1124.

[7] Arai, E. and Iwata, K., 1987, Development of Integrated Product Model for CIM, Manufacturing Systems, Vol.16, No.3, pp.187-199.

[8] Arai, E., et al., 1992, Hand Positioning in Operation Planning for Product Assembly Systems, Preprints of INCOM '92, pp.425-432.

[9] Jameson, I. W. and Leifer, L. I., 1987, Automatic Grasping : An Optimization Approach, IEEE Transactions on Systems, Man, and Cybernetics, Vol.SMC-17, No.15, pp.806-813.

[10] Phan, D. T. and Heginbothan, W. B., 1986, Robot Grippers, IFS Ltd.

[11] Lozano-Perez, T., 1981, Automatic Planning of Manipulator Transfer Movements, IEEE Transactions on Systems, Man, and Cybernetics, Vol.SMC-11, No.10, pp.681-698.