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Flexible Manufacturing by Application of RFID and Sensors in Robot Cell Manufacturing Systems

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Abstract: Cell production in which only a few human operators manufacture products by themselves is popular in Japan due to its flexibility. However, the decrease in the number of young persons in developed countries will make it difficult to do in the near future. Therefore, cell production using robots is going to be needed. A cell production system using a robot and automatic machines having special functions is developed. The robot transfers parts and tools for the automatic machines. A RFID is attached to each part, and the quick change in the functions of the automatic machines is executed as the kinds of products change. Adaptive tool setup scheduling for the change in operation times of the special function machines is executed and the improvement of product efficiency is analyzed. Many vision sensors are used for the adjustment of the position and orientation of the robot hand and parts, and distributed image processing for the hand and parts make rapid motion adjustment possible.

1. INTRODUCTION

Manufacturing in Japan in 1980's aimed at the efficient improvement of production according to the size and speed of mass production. However, this production method was not flexible enough to meet customer requirements. Therefore, flexible manufacturing systems (FMS) which used many robots, AGVs, conveyor systems and automatic storage were gradually developed. However, such systems require large investments, and their modification is not easy due to the rapid change of products. Such systems met with difficulty in global manufacturing competition.

Production fewer human operators called “cell production” saved manufacturing in Japan in 1990’s. The production system is called “cell production” in Japan. It can be done with small investment, and it is highly flexible to the change in economic environments and kinds of products. When an operator has the ability to assemble products by him/herself only, such a “cell production system” contributes to global competitiveness.

However, Japan is going to meet a new difficulty, with the decrease in the population of young people. One solution to this problem might be to adopt robots instead of human operators. We call these systems RCMS: Robot Cell Manufacturing Systems.

An approach to RCMS might be to develop high ability humanoid robots. Many researchers are working to do so, but it takes time to develop such robots.

The authors have adopted another way; Use an ordinary SCARA-type robot and automatic special machines having many functions. The functions of the automatic special machines can be changed by exchanging the tools used inside them. The robot carries the tools when a change of functions is required.

The robot also transfers parts of products from one automatic special machine to the next one. All parts are attached with RFIDs (Radio Frequency Identification) for the flexible preparation of tool changes to respond to the variation in operation times of the automatic special machines. In real production systems, three cell systems are connected in series. Products are assembled in lots of 20 – 50 pieces to obtain greater efficiency. When the operation of a certain kind of product is found from the information of RFID, a tool change in the automatic special machines is executed as soon as possible, and the improvement in the efficiency of productivity is analyzed.

Many vision sensors are also used in the system. A vision sensor is attached to the robot hand in order to adjust to mutual position and orientation errors between the robot hand and parts. Other visual sensors are attached to the frame of cells to measure the orientation of parts on part-feeders. As the part-feeders are vibrated, the orientation of parts gradually changes. When a part in proper orientation for robot-hand-grasping is found by vision analysis, the vibration stops. The vision analysis of the images from the robot hand camera becomes simple, and the tact time of the system becomes short when using these distributed image processing systems.

The precise concept of each function of the developed robot cell systems are introduced next.

2. THE CONCEPT OF RCMS

The objectives of the RCMS are; to have functions such as the adjustment of robot handling to fit the automatic machines; flexibility to the change in the kinds of products; processing with "Specialty & Flexibility with Intelligence"; and high efficiency in manufacturing.

2.1 System Configuration

Fig. 1 and Table 1 show the comparison of the new RCMS with an old automation system to produce sensors in a factory. The old system is large, using thirteen robots, but the new RCMS is compact using only three. Enlargement of the old system is difficult due to market changes. Its maintenance is also difficult due to its many robots even though the operations of the robots are simple.

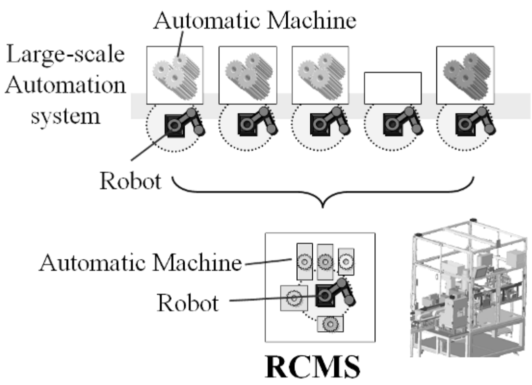


Fig.1. Old System and RCMS

Table 1. Comparison of the proposed RCMS with a large-scale automation system in OMRON Corporation.

Case in OMRON	Large-scale automation	RCMS
Kind of products as externals size	1 kind	8 kinds
Number of robots	13 systems	3 systems (Three cells)
Type of robots	6 axes	4 axes SCARA-type
Vision sensors	1 system	19 systems

On the other hand, RCMS, a medium type SCARA robot is set at the center of a cell, and automatic machines, part supply systems, and inspection systems are connected to the robot. Human operators, shown in the U station, are eliminated and replaced by the robot.

To improve space efficiency, the automatic machines are miniaturized and arranged in a three-dimensional way in the cell. Arbitrary and/or assembling processes are easily attained by the addition of automatic machines in the cell and/or the connection to other RCMSs.

Moreover, because this system configuration separates the area of the machine easily with the person, the installation of the safety sensor is facilitated.

The reason for building in medium SCARA is as follows.

(1) The easy concurrent design of products and manufacturing tools due to the rather simple structure and movement of the robot.
(2) The high rigidity, speed and accuracy of the robot,.
(3) The moderate length of the arm, and adaptation to the increase in the number of automatic machines.

2.2 Specialty & Flexibility

The feature of "cell production" is the use of fewer human operators because of the following:

(1) The person provides senses.
(2) The person's hand is the super-flexible.
(3) Both of the person's arms correspond to the eight axis robot arms.
(4) The person's brain provides the knowledge data base and the algorithm that can evolve infinitely.

The manufacturing processes of the sensor products deal with many materials of uncertain shapes, such as resin, solders, and wire rods that minutely connect parts of many varieties. Due to the complexity of this manufacturing process, "cell production" has evolved using a human operator's skill and flexibility to its maximum.

However, the population of young human operators is decreasing in developed countries today. Thus, "cell production" systems will have to evolve from person-working system, to robot cell-production systems, as shown in Fig.2. "Specialty" is the role of an automatic machine, and the base machine with a robot contributes to "Flexibility".

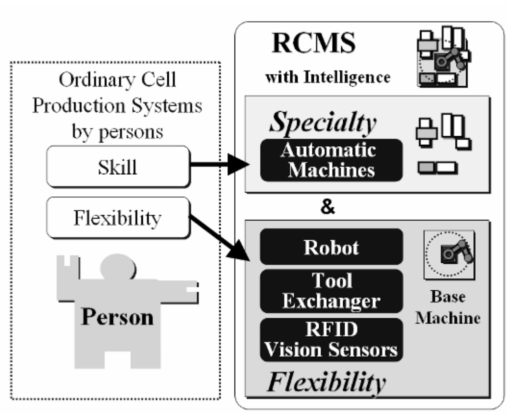


Fig.2. The Concept of a RCMS

An automatic machine has the mission of achieving human skill in mechanization and extreme specialty by aiming to rectify the inside and outside of the cell by processing and manufacturing supply. This can surpass the speed and precision of a person by miniaturization. The result is an industrial technology that can do what a person cannot do. The restrictor is measured by in-line sensing technology, and the causal relation is digitalized making the knowledge it controls. As a result, processing that surpasses that of a person became possible. It can do laser beam machining, rolling line processing and resin spreading, among others.

The base machine is composed of a SCARA robot, a tool exchanger system, RFID and vision systems. It contributes to flexibility by the adjustment of tools and the robot coordinate-correction for different types of parts with many varieties and variables.

2.3 The Relationship between Persons and Machines

The job of the person is non-stationary work, such as the replenishment of parts and the correction of abnormality in the machine, while the job of the robot is regular work, such as assembly. Moreover, the area of the robot is separated from that of the person with a safety sensor. HMI(Human Machine Interface) contributes to the safety system, the voice report system, the image monitor, and the progress management panel, and it supports the person aiming to maintain high quality and high Productive Time Ratio with safety. It is efficient due to the small number of persons.

3. DESIGN OF THE RCMS

3.1 Assembled Products

Products assembled by the RCMS are small electric proximity sensors of different 8 kinds of externals size as shown in Table 1. The diameters of sensors are from 8 mm to 30 mm. Now, the system produces about 40 kinds of sensors. The production processes include insertion, laser welding, soldering, coil-winding, injection of resin, measurement, and inspection.

It might not be easy to keep the Productive Time Ratio of the system high when such many kinds of products with small volume are required. The decrease of the Productive Time Ratio is caused by the interruption of set-up, machine adjustment, the generation of defective parts, and handling errors. Moreover, the waiting time of automatic machines or robots influences the cycle time of production.

Methods to solve these problems are proposed in Chapter 3.2 - 3.7.

3.2 Modeling

Fig.3 shows the model of the RCMS. A SCARA-type robot is placed at the center of the cell, and two or more automatic machines are placed around it. Arbitrary processing can be achieved by combining automatic machines in the cell. The connection of two or more robot cells is possible. The robot sequentially transports the work piece from Automatic Machine-#1 to Machine-#2-#3-#4-#5, and the system operation completes the five processes.

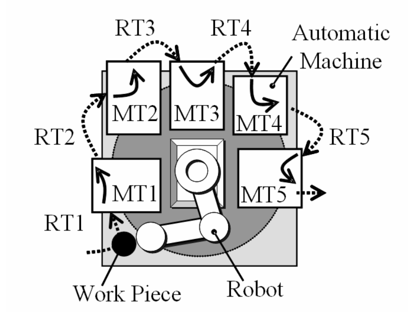
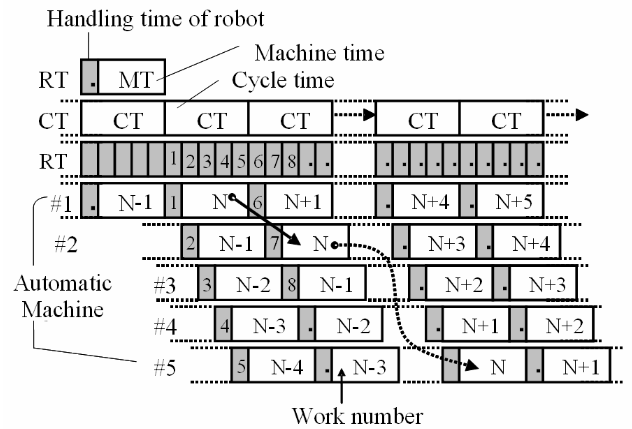


Fig.3. Arrangement of Robot Cell

After transporting the work piece to Automatic Machine-#1 in time-*RT*, the robot transports other work pieces to other each of four machines in time-*MT*. Each automatic machine has a time difference, as shown in Fig.4 and does side by side driving. Autonomy and the unit of the cell of an automatic machine increase the speed of the system resulting in high Productive Time Ratio.



$$CT > \max_{i} (RTi + MTi) \quad i=1,2,-----N \qquad (1)$$

$$CT > \sum_{i=1}^{N} RTi \qquad (2)$$

CT: Cycle time of production
RT: Handling time of robot
MT: Machine time of automatic machine
i: Number of automatic machine / cell

Fig.4. Time Chart of Operations

Time-*CT* reaches a large value by both of expression (1) and expression (2). Because time-*MT* and time-*RT* are different in each work piece, the cell controls autonomous so that time-*CT* may become small by the communication between main controller and automatic machines.

The mechanism transfers the exchange and the work to the tool. For instance, when a hand waiting signal is sent from an automatic machine by the main controller, if it is a winding process, the robot carries it to an automatic machine and exchanges the following work for the processed work according to the main controller's instruction.

An automatic machine selects processing programs, such as the rolling number and sending speed, etc. according to the kind of work and begins processing. On the other hand, the robot carries the received work to an automatic machine for the next process in the cell and directs the processing.

The automatic machine in the cell functions according to an autonomous decentralized control, and it can advance work when two or more automatic machines are placed side by side.

3.3 The Autonomy of the Cell by RFID

When two or more robot cells are connected, the information on work is transmitted to the robot cell in the next process with RFID systems. And, the cell automatically executes the set-up. When the number of processes exceeds five, the production system is composed of the connection of cells.

The one work piece is put on palette with built-in RFID, and transported to the following cell by the method of "One-Piece-At-a-Time Production", and the information (the kind of product) is transmitted to the following cell through this. Each cell self-judges the exchange of tools and the selection of the processing program based on work information from the arriving palette and does the set-up.

The timing shown in Fig.5 is an example of "3 cells in cascading connection". A, B1, and B2 are the kinds of the products in the manufacturing lot. And, they are sequentially transported from Cell-1 to Cell-2, Cell-3. The Production Lead Time in each cell is 7CT (Cycle Time). The time of 8CT is needed in the exchange of tools. The Loss Time can be minimized by the autonomy of each cell using RFID, and the Productive Time Ratio can be improved.

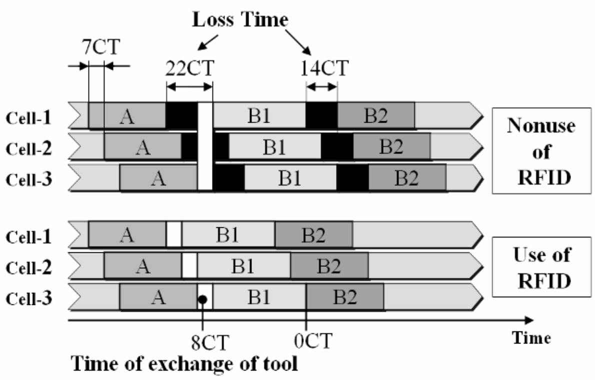


Fig.5. The Autonomy of the Cells

3.4 The Coordinate Transformation by Vision Sensors

Improving the accuracy of the relative coordinates in the intuition combination while handled the work of an automatic machine and work assembly are executed. This will raise the adjustment and the system reliability to a highly accurate assembly. The method increases the machine accuracy of the robot and the accumulation of size accuracy of work-positional accuracy in the machine's hand and the state of handling and work. The highly accurate designs of each and their correspondence is not necessarily desirable from the viewpoint of system reliability and cost. Therefore, the object of work is measured from the outside with work handled. Each time, an automatic correction of each work of the offset (robot coordinates) is executed. As a result, the improvement in the utilization rates by reduction in the adjustment time is achieved. The reliability of the system that does not receive different work and the influence of the wearing out of the machine has been easily achieved too, as shown in Fig.6.

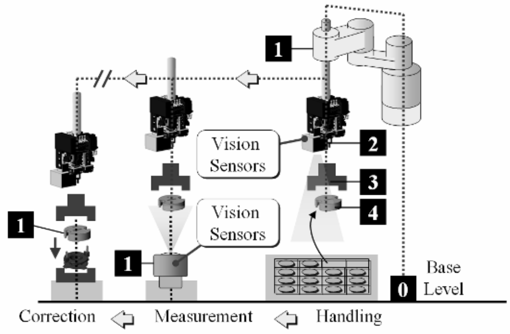


Fig.6. The Coordinate Transformation

3.5 The Inspection by Vision Sensors

The system down is reduced by improving the reliability of the automatic machine, and RCMS with a high Productive Time Ratio is achieved. Therefore, the processed measurement data is accumulated, and it uses it for preventive maintenance of the system. Fig.7 is a soldering inspection by "Pattern Matching".

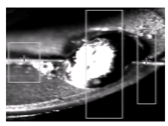


Fig.7. Inspection of Soldering

It is necessary to control for the stabilization of the spreading area of the resin with liquidity as shown in Fig.8. In this process, the measurement data is used for the feedback control, and the reliability of an automatic machine has been improved.

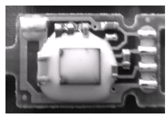


Fig.8. Measurement of Spreading Resin

3.6 The Speed-up of Handling by Vision Sensors

The robot is used in the other two methods to supply parts, and it adjusts to three methods (manufacturing supply, line supplies and random supplies). The raw material is supplied directly to the automatic machine. In this RCMS, a robot is not used for manufacturing supply. This is because the robot has the role of five automatic machines that correspond to the handling time that influences the production cycle time CT. In the supply line, work is handled by light, shade, and rotation search by the sight sensor installed in the robot hand shown in Fig.9 (a). After the part supply machine that uses the vision sensors executes the positional measurement shown in line and Fig.9 (b) by concurrent processing, the parts are handled in a random supply because the execution time cannot be shortened by the robot hand only. Production cycle time CT becomes expression (1) and (2) in the model shown in Fig.4. Shortening the action time of the robot (handle) can increase the number of the automatic machines that do the shortening, the cell of the production cycle time can be installed, and a highly effective system can be achieved.

(a) Vision sensor at hand (b) Parts Feeder

Fig.9. Handling

3.7 The Application of Other Sensors

The production system is completed, and the position of the work piece and the movement of the machine should always be sensed accurately to achieve highly effective stable operation and maximum control. Information is important because this system does autonomous, decentralized control in each process. The automatic machine, the minimization of loss at the hand, waiting time between cells, and the minimization of machine stoppage are prevented. The part supply report of the machine breakdown has been achieved from this information as a sensing target by the detection of the palette and parts in supply, the detection of the work's position in transportation, detection of work dropout, and operation position detection of the mechanism and tool.

4. EXPERIMENT BY COMPUTER

4.1 Case (A): Productive Time Ratio

The effect of the autonomy of the cell by RFID at chapter 3.3 is confirmed by the calculation. The Productive Time Ratio is calculated on the condition of looking like the production of the realities as the cells, the lot size, the products and the orders.

4.1.1 Condition Setting (A)

(1) The number of cells: 3 cells in cascading connection.
(2) Manufacturing lot size: 50/100/150/200 pieces.
(3) Kind of products: 16 kinds as specified (8 x 2).
(4) Exchange of tools: 8 specifications.
(5) Tools are not exchanged: 2 specifications.
(6) Manufacturing orders: 10000 cases
(7) Processing of orders: Consolidating* / Non-consolidating
* Use of the same tool within the range of two back and forth orders

4.1.2 Computational Method (A)

The manufacturing lot size, kind of product, and the manufacturing order are assumed to be random, and Productive Time Ratio by set-up method is calculated.

Productive Time Ratio: $Rpt = T / (T + To)$
T = Productive Time
To = Loss Time: waiting time, time to exchange tools.

4.1.3 Calculation Result (A)

There is an increase of about 9% in Productive Time Ratio by using RFID, as shown in Table 2.

Table 2. Productive Time Ratio

Processing of orders	Nonuse of RFID The set-up by batch of all cells	Use of RFID The set-up by single of each cell
Consolidation	86.2 %	95.3 %
Non-consolidation	85.7 %	94.7 %

4.2 Case (B): Cycle Time

Fig. 10 shows timing. The cell operates so that the cycle time may become velocity as autonomy, machine time, and handling time change in the automatic machines and in the cell. The effect on the production cycle time of the autonomy of the automatic machines is verified.

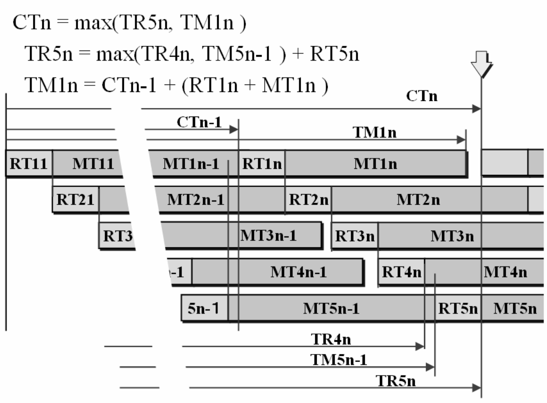


Fig.10. Cell Timing

4.2.1 Condition Setting (B)

(1) Number of cells: 3 cells in cascading connection
(2) The number of automatic machines: 5/cell
(3) Standard RT = 0.2 CT
(4) Standard MT = 0.8 CT
(5) Standard CT = 1

4.2.2 Computational Method (B)

(1) Change the speed of the machine: *RT* 、*MT* are random
(2) Maximum speed: Standard ±1%. / 2% / 5%
(3) Calculation frequency: 10000 cycles
(4) Cycle time *CT*: Average *CT* of each cell and the maximum value for three cells are calculated.

4.2.3 Calculation Result (B)

Table 3 shows the result of 10,000 cycles. There is advantage using an autonomous method.

Table 3. Production Cycle Time of a RCMS *

Change in random speed *RT, MT*	Synchronizing cells Fixed *CT* *	Autonomous cells Averaged *CT*
±1%	*CT*=1.010	*CT*=1.005
±2%	*CT*=1.020	*CT*=1.009
±5%	*CT*=1.050	*CT*=1.023

* Fixed *CT* = max (*RT*+*MT*)

In an actual production system, it depends in each work peace, and the machine time is different. The averaged CT shortens because it works so that an automatic machine may make each waiting time the shortest. The effect is large in the accumulation of a long term though the difference is a short time.

5. CONCLUSIONS

The modeling and the development of RCMS are done as a cell production system using a robot, and it actually is operated as a manufacturing system of the sensor products.

The cell is operated autonomously by using RFID, and as a result, the Productive Time Ratio of the RCMS increases. By the calculation, it is verified that the improvement of 9% in the Productive Time Ratio is shown.

Vision sensors were built into the RCMS for the coordinate transformation and the speed-up of handling. As a result, the ability and the reliability of the system have been improved.

The feature of RCMS is recorded as follows:

(1) An arbitrary manufacturing process can be made by arranging an automatic machine in the cell.

(2) Five processes can be executed at the same time in the cell.

(3) The cascading connection of an autonomous cell can be achieved.

(4) The reliability and the Productive Time Ratio of the systems are high because of the use of RFID, vision sensors and other sensors.

(5) The system is provided with a tool exchanging system of high flexibility.

The research in the future is evolution of “Speciality”. It means the production process in the cell increases by developing a new automatic machine. The basic machines are able to be standardized by this research.

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