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Recognition Index of Part and Unit by Discrimination Characteristics

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In this paper, we propose a recognition index to evaluate the complexity of discrimination among parts and units. The parts and units are classified into some groups (the number of groups is shown as n) by one characteristic, such as color, shape, size and so on. The recognition index of each group is denoted as $\log_2(n+1)$ by the information quantity formula. The recognition diagram shows the classification of parts and units into only one part and unit by the structure of a characteristic. Further we propose the line balancing method for assembly line based on the working time and the recognition index.

1. INTRODUCTION

Recently, the assembly line is required to correspond to multi item or one by one production style, in which many kinds of parts and units are handled by a worker or robot[1]. Then as similar parts are increased, selection of parts and units becomes the difficulty work. The difficulty of discrimination among many kinds of parts and units is not only influence to the productivity of the assembly line directly, but also to the design of the work of robot which has the recognition function by image processing.

In the field of information theory, the quantity of information that is needed to judge the suitable state from unknown state is evaluated by information quantity. We have proposed the method to calculate the entropy, that is, the average amount of information quantity of a logistics system in the production system and evaluate the logistics system numerically[2].

In this paper, we propose the recognition diagram and the recognition index to evaluate the complexity of discrimination among parts and units according to characteristics of them by information quantity formula. Further we propose the line balancing method in which a work is assigned to the work station based on working time and the recognition index.

2. PROPOSED METHOD

We propose the recognition diagram, the calculation method of recognition index, and some criterion for line balancing.

2.1 Definition of Symbols

Following symbols are used in this paper.

- M_i : The work station in the assembly line. $(i = 1, 2, \cdots, NM)$
- W_j : The assembling work element of the product. $(j = 1, 2, \cdots, NW)$
- SW_i : The set of work elements in station(M_i).
- t_j : The working time of a work(W_j).
- T_i : The working time of a station(M_i). This time is the sum of working times of which the set of work elements(SW_i) are assigned to the work station(M_i).
- PT : The cycle time of the assembly line.
- $SP(W)$: The set of partsa and units(P_k) that are assembled in a work(W). $(k = 1, 2, \cdots, NP(W))$

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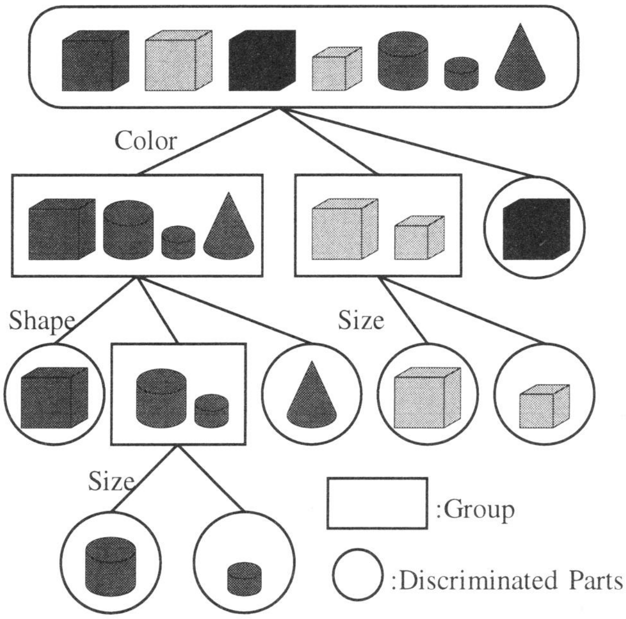

Fig. 1 Classification Procedure

$RI(X)$: The recognition index of X. X is a part/unit(P_k), a work element(W_j), or a work station(M_i).

2.1.1 Recognition Diagram

At the work station, the suitable part or unit is selected from all parts and units which are assembled in the process. The parts and units are discriminated according to many kinds of characteristics, such as color, shape, size and so on (see Fig.1).

Firstly, all parts and units are classified into some groups according to one characteristics($C_{q_1}, q_1 = 1, 2, \cdots, NC_1$) which has a great difference between groups, such as color. The group which is classified by a characteristics(C_{q_1}) is shown as $UP(C_{q_1})$, and $UP(C_{q_1})$ is defined as the eq.(1). $UP(C_{q_1})$ contains some kinds of parts/units. The number of parts and units in $UP(C_{q_1})$ is shown as $NUP(C_{q_1})$.

$$UP(C_{q_1}) \equiv \{P_k | \text{The part or unit is classified according to } C_{q_1}\} \tag{1}$$

where $k = 1, 2, \cdots, NUP(C_{q_1})$.

For example, UP(red) is the set of red parts and units, and other group on the same level are UP(yellow), UP(green), and so on. $UP(C_0)$ is the group of parts and units that don't belong to C_{q_1} ($q_1 = 1, 2, \cdots, NC_1$).

(1) Case of $NUP(C_{q_1}) = 1$

In this case, the group($UP(C_{q_1})$) contains only one part and unit, so that this one is distinguished from each other. This is shown by a circle in a recognition diagram.

(2) Case of $NUP(C_{q_2}) \geq 2$

In this case, the set contains more than two parts and units, so that they can not be discriminated from the other. This is shown by a rectangle in a recognition diagram. It is classified into subgroups according to other characteristic at level 2. The characteristic at level 2 is shown as C_{q_2} ($q_2 = 1, 2, \cdots, NC2$), and a subgroup is $UP(C_{q_1}, C_{q_2})$.

(3) Case of $UP(C_0)$

$UP(C_0)$ has more than two parts and units that don't belong to C_{q_1}, so that it is classified into $UP(C_0, C_{q_2})$ at level 2.

If the subgroup contains more than two parts and units, the same procedure is continued until all subgroup contains only one part and unit. Each group at level 2 has different characteristic C_{q_2}, so that a subgroup at level 2 is shown $UP(C_{q_1}, C_{q_2})$. The subgroup classified by a characteristic(C_{q_l}) at level l is shown as $UP(C_{q_1}, \cdots, C_{q_l})$ defined as the eq.(2).

$$UP(C_{q_1}, \cdots, C_{q_l}) \equiv \{P_k | \text{The part or unit is classified according to } C_{q_l}\} \tag{2}$$

where $k = 1, 2, \cdots, NP(C_{q_l})$.

The recognition diagram shows the classification system for parts and units by tree structure (see Fig.2). The important points of recognition diagram are the number of groups at each level and the relation between lower group and upper one.

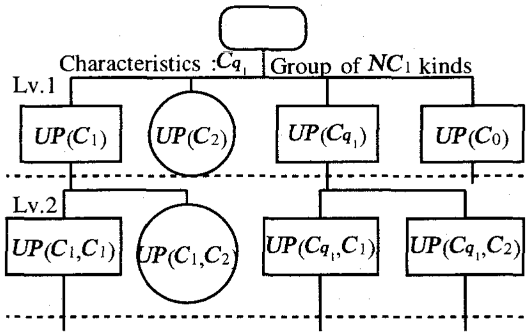

Fig. 2 Recognition Diagram

2.2 Calculation of Recognition Index

We calculate the recognition indexes for parts and units, work elements, and work stations. The calculation method for parts and units is similar to information quantity. The recognition index is calculated based on the recognition diagram's information.

2.2.1 Recognition index of parts and units

The recognition index is calculated based on the recognition diagram basically for the parts and units. The recognition index of work element and work station are calculated to sum up the recognition index of parts and units. If the recognition index of some parts and units become large, there are a similar parts and units to them. Selection of those parts is difficult.

(1) Case of part and unit discriminated at level 1

The number of states which are classified clearly at level 1 is the sum of the number of groups($UP(C_{q_1})$) and one($UP(C_0)$). If $P(C_{q_1})$ is discriminated at level 1, the recognition index($RI(P(C_{q_1}))$) is given by the eq.(3).

$$RI(P(C_{q_1})) = \log_2(NC_1 + 1) \tag{3}$$

And the recognition index of the group at level 1($UP(C_{q_1})$) which contains more than two parts and units is the same as $RI(P(C_{q_1}))$. This recognition index is used to calculated the recognition index of the part and unit discriminated at the lower level.

(2) Case of part and unit discriminated at level l

The part and unit discriminated at level $l(P(C_{q_1}, \cdots, C_{q_l}))$ is contained in the subgroup at level$(l-1)(UP(C_{q_1}, \cdots, C_{q_{l-1}}))$, so the recognition index $(RI(P(C_{q_1}, \cdots, C_{q_l})))$ contains the recognition index of level$(l-2)$ given by the eq.(4). $RI(P(C_{q_1}, \cdots, C_{q_{l-1}}))$ is the recognition index of the subgroup at level$(l-1)$.

$$RI(P(C_{q_1})) = RI(P(C_{q_1}, \cdots, C_{q_{l-1}})) + \log_2(NC_l + 1) \tag{4}$$

The subgroup at level$(l-1)(UP(C_{q_1}, \cdots, C_{q_{l-1}}))$ is contained in one at level$(l-2)(UP(C_{q_1}, \cdots, C_{q_{l-2}}))$. And the subgroup at upper level is contained in ever upper level, so that the eq.(4) is transformed as the eq.(5).

$$RI(P(C_{q_1}, \cdots, C_{q_l})) = \sum_{s=1}^{l} \log_2(NC_s + 1)) \tag{5}$$

If the recognition index of some parts and units is greater than others, there are a similar parts and units to them. They are difficulty in selecting.

2.2.2 Recognition index of work elements

The assembling part and unit is selected from all ones on work area before the worker begins to assemble. A set of parts and units in a work element(W) is shown as $SP(W)$, $SP(W)$ is defined as the eq. (6).

$$SP(W) = \{P_k | P_k \text{ is assembled in a work.}\} \tag{6}$$

where $k = 1, 2, \cdots, NP(W)$.

Then the recognition diagram which consists of parts and units of $SP(W)$ is made to show clearly the difference between them according to characteristics.

As the recognition indexes of each part and unit is calculated by the eq.(5), the recognition index of a work element($RI(W)$) is given by the eq.(7).

$$RI(W) = \sum_{k=1}^{NP(W)} RI(P_k) \tag{7}$$

If the recognition index of a work element becomes large, the selection of a part and unit becomes difficulty.

2.2.3 Recognition index of work stations

There are two supplying styles of parts and units to work station. One style is supply parts and units of all products. The other is supply parts and units of only one product to work station.

$MW_u(u = 1, 2, \cdots, NW(M))$ denotes the u-th work element assigned to the work station(M). The recognition diagram is made on each step to calculate the recognition index. If the recognition index of a work station becomes large, we should introduce the recognition machine or robot that can select the parts and units into an assembly line in order to reduce the worker's burden.

(1) Case of supply parts and units for all products

In this case, a suitable part and unit is selected among same condition of them. So we can meke samerecognition diagram on each step. The recognition index of each work element is calculated by the eq.(7). And $SP(W)$ is denoted the all assembling parts and units in the evaluated work station. The recognition index of work station($RI(M)$) is given by the sum of work elements' one by the eq.(8).

$$RI(W) = \sum_{u=1}^{NW(M)} \sum_{k=1}^{NP(MW_u)} RI(P_k) \tag{8}$$

This recognition index of a work station is same value regardless of work element's order.

(2) Case of supply parts and units of only one product

In this case, the number of parts and units in a work station is less than that of a product, so that the recognition diagram becomes small. So we should make different recognition diagram on each step. The recognition diagram is made each work element, and the recognition index is calculated by the eq.(7). The recognition index of work station($RI(M)$) is given by the eq. (8). If the order of work elements is changed, the recognition index of a work station becomes a different value.

2.3 Line Balancing Method Using Recognition Index

We propose the line balancing method based on the working time and recognition index. The line balancing criteria are almost based on the working time. Then we add the recognition index to the line balancing method in order to make the recognition of parts and units more easy.

Following symbols are used.

M : The work station.

$t(W)$: The working time of a work(W).

PT : The cycle time of the assembly line.

2.3.1 Possible work elements to assign

A set of possible work elements assigning to u-th at work station(M) is shown as $SW(M, u)$ in the eq.(9). W_s satisfies the following (1),(2),(3) conditions.

$$SW(M, u) \equiv \{W_s | \text{Conditions (1), (2) and (3)}\} \tag{9}$$

where $s = 1, 2, \cdots, NW(M, u)$ and the contents of conditions are as follows.

Where the contents of conditions are as follows.

(1) The work element(W_s) is not yet assigned to the work station.

(2) The preceded works of W_s have been assigned.

(3) The sum of working times of assigned work elements and W_s is less than the cycle time in the assembly line. If MW_{u-1} have assigned, the working time($t(W_s)$) of the work element(W_s) satisfies the eq.(10).

$$\sum_{r=1}^{u-1} t(MW_r) + t(W_s) \leq PT \tag{10}$$

2.3.2 Proposed criterion to select assigning work element

The criteria to select a work element among unassigned ones are almost based on the working time[3]. We attempt to use the recognition index in the assigning process. The proposed criteria using the recognition index are shown as follows.

(1) Minimum combination of work element's recognition index

The work element is always assigned based on the condition that the work station has the minimum recognition index.

(a) First step of selection

The recognition diagrams of a work element is made by parts and units, and the recognition index is calculated by the eq.(7). The work element which has the minimum recognition index is selected as the first step from possible work elements.

$$WM_1 = \min_{1 \leq s \leq NW(M,1)} (RI(W_s)) \tag{11}$$

(b) u-th step of selection

The recognition diagram for u-th step made by the parts and units of a possible work element and works' one. The recognition index of part and unit is calculated by the eq.(7) for the possible work element. The assigned work element is determining as one having the minimum recognition index in the eq.(12).

$$WM_u = \min_{1 \leq s \leq NW(M,u)} (RI(MW_1, \cdots, MW_{u-1}, M_s)) \tag{12}$$

(2) Distribution of work elements having large recognitino index of parts and units

According to the minimum combination of work element's recognition index criterion, the latter work stations are assigned the work elements of which the recognition index has a great value. If those work elements are assigned to the same work station, the recognition index becomes more large. So this criterion assigns the work element which includes the large recognition index of parts and units to the work station as the first work element. After 2nd step, this criterion is the same as the selection of the minimum combination of work element's recognition index.

(a) First step of selection of work element

The original recognition diagram shows clearly the difference among parts and units of a product consist. The recognition indexes of part and unit is calculated from the original recognition diagram of the product. At first step, a work element showing the maximum recognition index is selected from W_s which are able to assign by the eq.(13).

$$WM_1 = W_0, SP(W_0) \ni P_0, RI(P_0) = \max_{\substack{1 \leq s \leq NW(M,1) \\ 1 \leq k \leq NW(W_s)}} RI(P_k) \tag{13}$$

(b) u-th step of selection

This procedure is as same as the selection of the minimum recognition index criterion in (1)(b).

3. APPLICATION

We applied the proposed method to design the assembly line of the air filter. The air filter consists of 25 parts(P1 to P25). The air filter is assembled by 15 work elements(W1 to W15). Table 1 shows the assembled parts, predecessors and working time of each work element.

3.1 Recognition Diagram of Air Filter

Fig.3 shows the recognition diagram of the air filter. At level 1, 25 parts of the air filter are classified into 6 groups according to color. The silver parts is only P6 and the green parts is only P22, so P6 and P22 are discriminated from the other parts at level 1. The recognition indexes of P6 and P22 are calculated by the eq.(14).

$$RI(\text{P6}) = RI(\text{P22}) = log_2(6) = 2.58[bits] \tag{14}$$

Table 1 Work List

Work Element	Parts	Predecessors	Working Time
W1	P6, P8		2.7
W2	P2, P6		4.3
W3	P3, P4, P5		6.0
W4	P6, P7		15.7
W5	P1, P6	W2, W3 4.3	
W6	P8, P9, P10, P11, P12		13.7
W7	P17, P18, P19, P20		5.7
W8	P14, P15, P16		17.7
W9	P15, P20		3.7
W10	P12, P13		6.3
W11	P12, P23		2.7
W12	P6, P12, P21, P22	W10, W11	9.7
W13	P6, P20, P22		3.7
W14	P12, P24		2.7
W15	P12, P25		5.7

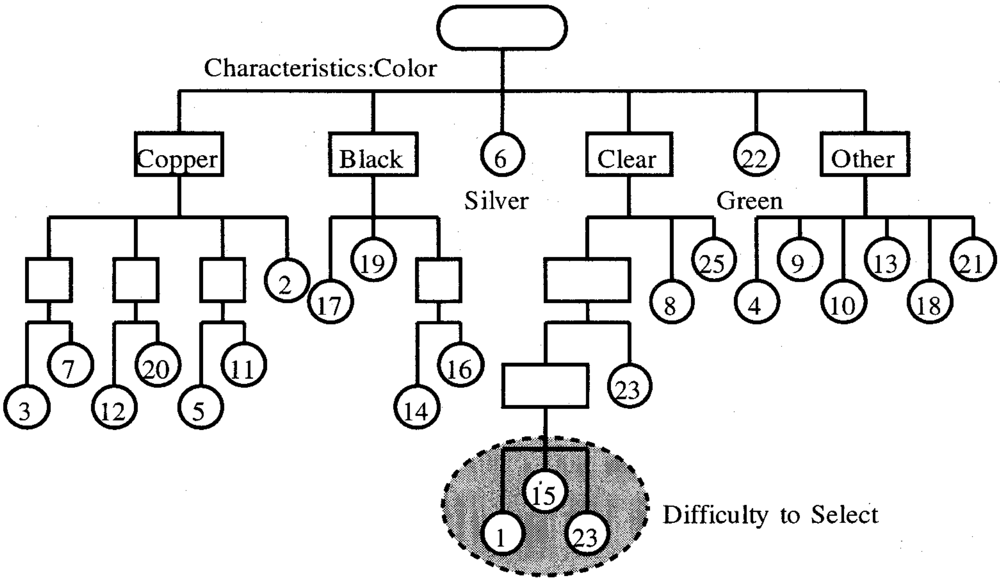

Fig. 3 Recognition Diagram of Air Filter

Table 2 Results

Maximum Working Time

	Assigned Works	Working Time	Recognition Index
1st station	W8, W10, W13	30.0	23.6
2nd station	W4, W6	29.4	19.6
3rd station	W7, W15, W2, W5, W9, W13	27.4.	40.6
4th station	W1, W11, W12, W14	17.8	23.4

Minimum Combination of Work Element's Recognition Index

	Assigned Works	Working Time	Recognition Index
1st station	W4, W1, W2, W10	29.0	12.0
2nd station	W15, W11, W14, W9, W13, W12	28.2	31.7
3rd station	W8, W3, W5	29.7	24.4
4th station	W6, W7	19.4	25.9

The groups of level 2 are classified according to size. P1, P15 and P24 are discriminated at level 4, so that parts are difficult to select. The recognition index of P1 is calculated by the eq.(15).

$$RI(\text{P1}) = log_2(6) + log_3(3) + log_2(2) + log_2(3) = 6.75[bits] \quad (15)$$

RI(P1) is larger than RI(P6), so that P1 is more difficult to select among all parts of the air filter. This assembly line has 4 work stations(1st to 4th station), and the cycle time is 30 second.

3.2 Result of Line Balancing

The assembly line is designed by the proposed method using the criterion of the working time and recognition index under conditions that the cycle time is put as 30 sec. And the number of stations as 4. Table 3.2 shows the results of line balancing using the criterion of maximum working time. 3rd station is constructed by 6 work elements and shows the large recognition index of work station. The worker should be made efforts to select parts in this work station. But using recognition index, 1st station is costructed by 4 work elements, and the recognition index of this station becomes the smallest of all stations. And 2nd station has 6 work element, but the recognition index is smaller than the resuluts of the maximum working time.

4. CONCLUSION

In this paper, we proposed the recognition index to evaluate the complexity of discriminating among parts and units. This index is applied to the criterion to assign the work elements in the line balancing for assembly line.

Firstly, the recognition diagram is propsed to show clearly the difference among parts and units according to characteristics.

Secondly, various recognition indexes are calculated based on the number of characeteristics that are shown in the recognition diagram.

Finally, the assembly line is designed by the proposed method based on the working time and the recognition index.

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