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Optimization of Assembly Processes of an Automobile Wire Harness

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ABSTRACT

To support design tasks of assembly processes of a wire harness, automotive parts suppliers developed CAD/CAM-based systems. However, even if these methods are used, engineers still need to look for efficient assembly processes by trial and error. In order to design efficient assembly processes without expertise of veteran engineers and trial and error, this paper proposes a new method to optimize assembly processes of a wire harness. The process in which a worker tapes routed cables is most important and hardest among the sequence of assembly processes and the difficulty of taping process depends largely on jigs layout on a workbench and taping route. Therefore, in the proposed method, jigs layout and taping route are modeled and optimized by using genetic algorithm. Working time of taping process derived from jigs layout and taping route is used as fitness function of GA. In the case study, to demonstrate the proposed method, design of assembly processes of the automobile wire harness installed in a certain actual compact car is carried out.

Keywords: automobile wire harness, optimization of assembly processes, optimization of jigs layout, optimization of taping route, genetic algorithm, travelling salesman problem.

1. INTRODUCTION

Since efficiency of manufacturing processes is always a matter of serious concern for every company, many researches have been done to support design of manufacturing processes for years. In this paper, we focus on assembly processes of an automobile wire harness because only a few researches focus on assembly process of an automobile wire harness.

A wire harness is an assembly of cables or wires which transmit signals or electrical power. To protect the cables and reduce time to install a harness to a product, the cables are bound together by tape, tube, sleeve or other ways. A wire harness is used in various kinds of products. Among them, an automobile is a major example. In automobile industries, a wire harness is manually manufactured by using a workbench with jigs in the form of a fork shown in Fig. 1 according to the following procedure. (1) Cables are cut to the desired length and the end of the cables is terminated. (2) The cables are routed through jigs. Jigs look like a fork and have a role in holding routed cables during assembly processes. (3) The end of the cables is inserted into connector housings. (4) Finally, cables are bound by tapes. Although automobile manufacturing processes are highly automated in these days, a wire harness still needs to be manufactured by hands. This is due to the many different processes involved and difficulty in their automation.

Recent CAD/CAM systems [5,10] have the function to support design of a wire harness. The dedicated software to support design of a wire harness [10,11] has also been developed. To support design of assembly processes of a wire harness, various kinds of methods / systems such as CAD/CAM based system [1,4,9] virtual reality based system [8,11], process planning [3] and expert system [6] have been developed. However, even if these methods are used, design of assembly processes still needs to be done by engineers by trial and error. Thus, the level of engineers has a large impact on efficiency of assembly processes and prolonged trial and error processes are required to explore efficient assembly processes. Therefore, in order to design efficient assembly processes without expertise of veteran engineers and trial and error, a design method based on optimization is required. The process in which a worker tapes routed

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cables is most important and hardest work among the sequence of assembly processes, so this paper focuses on this process. The difficulty of taping process depends on various factors, but it depends on heavily on a jigs layout on a workbench and a taping route. For example, if the angle between two branches of the wire harness is too small or two branches cross each other, it becomes difficult to tape each branch due to interference of branches. Therefore, in the proposed method, a jigs layout and a taping route are modeled and optimized by using genetic algorithm. As for fitness function of GA, since working time is most important, total working time is calculated from a jigs layout and a taping route and handled as fitness function.

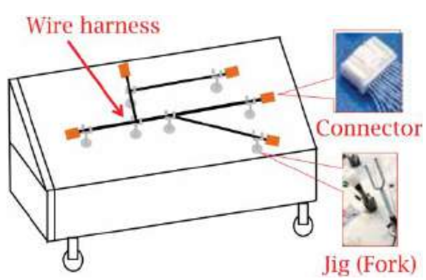

Fig. 1: A workbench for assembly of an automobile wire harness.

The rest of this paper is organized as follows. Section 2 describes the details of the proposed method. In Section 2, a layout of jigs and a wire harness on a workbench and a route of taping tasks are modeled and evaluated. And then, in order to optimize them using genetic algorithm, fitness function, individuals and constraint conditions are defined. Section 3 describes the case study. In the case study, the proposed method is applied to the emission harness installed in a certain actual car. Finally, Section 4 summarizes the results of this paper.

2. PROPOSED METHOD

2.1. Outline of the Proposed Method

Although a wire harness is assembled through the processes described in Section 1, this paper focuses on the process where a worker tapes the routed cables. This is why the process is the hardest work for a worker and the difficulty of its tasks seriously affects assembly time. The difficulty depends seriously on a jigs layout on a workbench and a taping route. As for a jigs layout, if the angle between two branches of a wire harness is too small or two branches cross each other, it becomes difficult to tape each branch due to interference of branches. Thus it is preferable that the angle between two branches is sufficiently large (ideally 90 degree or more) and intersection of branches must be avoided. However, since size of a workbench is limited and a wire harness used in a recent automobile tends to consist of many branches, it is difficult to ideally place every branch on a workbench. Therefore, the layout with minimum working time of taping processes needs to be explored. As for a taping route, there is little possibility that a taping route is traversable, so taping process consists of the task a worker actually tapes a branch and the task a worker moves his/her hands from the current branch to the next one without any task. The distance of the former task is constant with no relation to a taping route, while the distance of the latter task depends heavily on a taping route. Since the latter task is just a wasted work, the route that minimizes its distance needs to be explored. Moreover, the distance of the latter task depends on not only a taping route but also a jigs layout on a workbench because the distance between branches is based on the position of each branch derived from a jigs layout. If jigs layout can be optimized by evaluating not only the total taping time but also the moving distance without any task, there is a possibility that the moving distance without any task is further reduced. Therefore, in this paper, optimization of jigs layout and route of taping tasks are integrated and executed simultaneously.

To summarize the optimal design problem considered in the paper, a jigs layout on a workbench and a taping route tasks are handled as design variables whereas the time to tape every branch and the moving distance without any task are handled as valuation characteristics. Fitness function of the problem is based on them. To solve this optimal design problem, genetic algorithm is introduced.

The rest of Section 2 is organized as follows. A layout of jigs and a wire harness on a workbench is modeled and valuation characteristic of the layout is defined first. Then, a route of taping tasks is modeled and its valuation characteristic is defined. Finally, in order to optimize them using genetic algorithm, fitness function, individuals and constraint conditions are defined.

2.2. Model of Jigs and a Wire Harness on a Workbench

Fig. 2 shows the model of jigs and a wire harness on a workbench. An outer rectangle represents a workbench. Node N is a branch point or an end point of the harness. Jigs are placed at each node. In the figure, a node is represented by a circle. A connector is attached at the end of the harness and represented by a rectangle. A part of the harness between two nodes is named edge E. The length, the diameter and the angle of the edge E_j are l_j, d_j and θ_j respectively. θ_j is the angle between a horizontal line and the edge E_j in anticlockwise direction. The edge consisting of many cables is named “Main edge” whereas other edges are named “Branch edge”. A main edge is represented by a bold line whereas a branch edge is represented by a thin line. At the optimization stage, configuration of a wire harness and the length and the diameter of each edge are given conditions whereas the angle of each edge is used as a design variable.

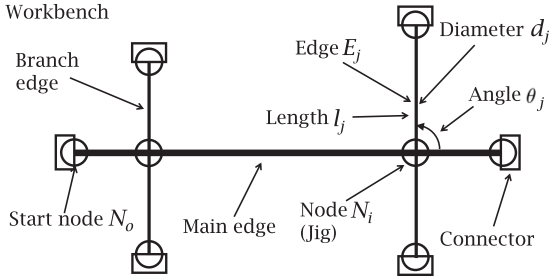

Fig. 2: Model of Jigs and a wire harness on a workbench.

2.3. Calculation of Total Taping Time

Total taping time T, the time it takes to tape every edge, is handled as the valuation characteristic of jigs layout on a workbench. Total taping time T is defined by the below equation.

$$T = \sum_{i=1}^{N} t_i \omega_i \tag{1}$$

Where, t_i is standard working time it takes to tape the edge E_i. t_i is the minimum time it takes to tape edge E_i in the case no obstacle such as other edges exists around the edge E_i. t_i is calculated by Table 1 using length l_i and diameter d_i. ω_i is the level of difficulty to tape edge E_i. As described above, if the angle between two edges is small, it becomes difficult to tape these edges. ω_i is calculated by Table 2 using the angle between neighborhood edges and diameter d_i. As shown in Fig. 3, the angles between the edge E_i and its neighborhood edges are calculated and the smaller one is selected. In the case of Fig. 3, $\theta_{i,k}$ is selected.

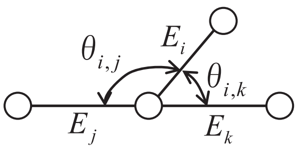

Fig. 3: Angle between the neighborhood edges and the edge.

2.4. Model of Order of Taping Tasks Based on a Travelling Salesman Problem

The entire route of taping tasks can be defined by the following information: the order of edges to be taped and the direction to be taped on each edge. To represent the order of edges to be taped, travelling salesman problem is used. As shown in Fig. 4, an edge corresponds to a city and the order of edges to be taped corresponds to the order that a salesman visits cities. The sequence of numbers that represents the order of edges to be taped is named P. In the case of Fig. 4, P is $\{1, 4, 6, 3, 8, 7, 2, 5\}$.

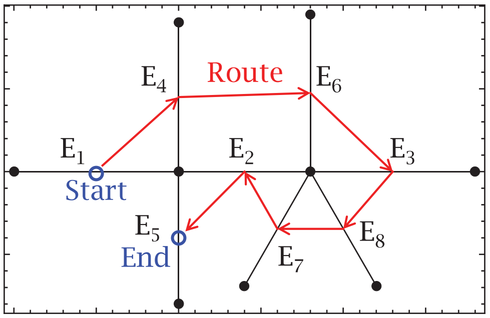

Fig. 4: The order of edges to be taped represented in the form of travelling salesman problem.

On the other side, the direction to be taped on each edge is represented by binary code. Each edge has two nodes at both ends. The node close to the node N_0 is named “Start point” and other node is named “End point”. If the direction is set to 0, a worker tapes the edge from the start point to the end point. If the direction is set to 1, a worker tapes the edge from the end point to start point. The list of binary codes that

	Diameter (mm)					
Length (mm)	9	10	11	12	13	...
20–39	1.5	1.5	1.7	1.7	1.7	...
40–59	2	2	2.2	2.2	2.2	...
70–79	2.5	2.5	2.7	2.7	2.7	...
80–99	3	3	3.2	3.2	3.2	...
100–119	3.5	3.5	3.7	3.7	3.7	...
...	...	...	...	...	...	...

	Diameter (mm)					
Angle (deg)	9	10	11	12	13	...
15	2.2	2.2	2.2	2.2	5	...
30	2	2	2	2	4	...
45	1.8	1.8	1.8	1.8	3	...
60	1.7	1.7	1.7	1.7	3	...
75	1.6	1.6	1.6	1.6	2.5	...
...	...	...	...	...	...	...

Tab. 1: (a) Table for calculating standard working time, (b) Table for calculating level of difficulty.

represents the directions on each edge is named D. Fig. 5 illustrates the direction to be taped.

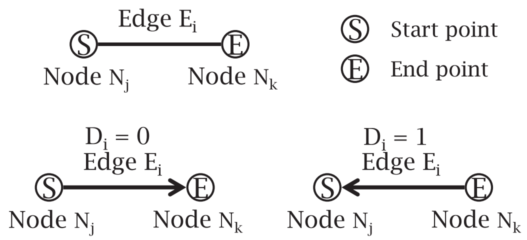

Fig. 5: Definition of taping direction.

When two types of information P and D are set, the entire route of taping process is identified. Fig. 6 illustrates the flow of identifying the route.

2.5. Calculation of the Distance a Worker Hand Movement without any Task

When the entire route of taping tasks is identified, the total distance a worker moves his/her hands during taping processes is obtained. As shown in Fig. 6, total moving distance consists of the distance a worker actually tapes edges and the distance a worker moves his/her hands without any tasks. The former is constant because the length of each edge is constant. The latter is based on the jigs layout and the route of taping tasks. Since movement of worker's hands without any tasks is just a wasted work, it's preferable to minimize the distance from the viewpoint of working efficiency. Therefore, the distance a worker moves his/her hands without any task is named L and handled as the valuation characteristic of a taping route. L is defined by the below equation.

$$L = \sum_{i=1}^{N-1} \| R_{P_i,k} - R_{P_{i+1},m} \| \tag{2}$$

$$\begin{cases} D_{P_i} = 0 \to k = 2 \\ D_{P_i} = 1 \to k = 1 \\ D_{P_{i+1}} = 0 \to m = 1 \\ D_{P_{i+1}} = 1 \to m = 2 \end{cases} \tag{3}$$

Where, R is the set of the start and end points of every edge. $R_{pi,1}$ and $R_{pi,2}$ show the coordination of the start and end point of edge E_{pi} respectively. If the end point of edge E_{pi} and the start point of edge E_{pi+1} are the same node, the moving distance is 0. If two points are not the same node, a worker needs to move his/her hands from the end point of the current edge to the start point of the nest edge.

2.6. Optimization of Total Taping Time T and Moving Distance without any Task L

To obtain the jigs layout and the route of taping tasks with minimum total taping time T and moving distance without taping tasks L, genetic algorithm is used in this paper.

As for optimization of jigs layout, the angle formed by a horizontal line and each edge in anticlockwise direction is handled as a design variable. In order to optimize the angle by using genetic algorithm, the angle can be discretized at 15 degree interval from 0 to 360 degree. As for optimization of the route of taping tasks, the order of edges to be taped and the taping direction on each edge are handled as design variables. Since the order of edges to be taped is represented in the form of travelling salesman problem, as described in Section 2.4, this paper adopts the coding method proposed by Grefenstette [7] to solve it by using genetic algorithm. Since the taping direction is simply represented by a binary code, it can be solve by using genetic algorithm with no operation. To wrap up, each individual has three chromosomes: the angle formed by a horizontal line and each edge in anticlockwise direction, the order of edges to be taped and taping direction on each edge.

As for fitness function, total working time T_{total} defined by the below equation is handled as the fitness function of genetic algorithm.

$$T_{total} = T + \frac{L}{400} \tag{4}$$

Where T is total taping time and L is moving distance without any task as described in Section 2.3 and Section 2.5. 400 [mm/s] is the moving speed a worker moves his/her hands on workbench without any task.

As for constraint conditions, several constraint conditions due to design requirements of a wire

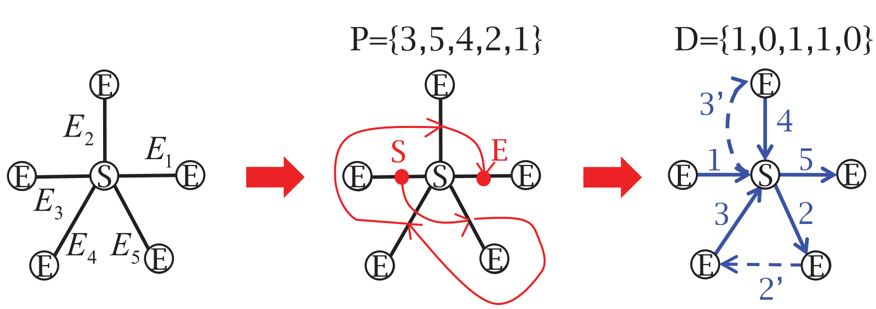

Fig. 6: Flow of identifying the route of taping process.

harness and workability of assembly processes are configured, as described below. If an individual violates these constraint conditions, its fitness function is charged a penalty.

- It is desirable that main edges are arranged linearly
- Edges should not cross each other
- Edges should not be beyond the area of the workbench
- Adjacency relationship among edges at each node is given in advance and should not be changed

3. CASE STUDY

To show the effectiveness of the proposed method, the proposed method is applied to the automobile wire harness manufactured and installed in a certain actual compact car. Fig. 7 shows the configuration of the harness. The harness is called the emission harness, which is installed around an engine. The harness consists of 35 edges and 36 nodes. The values described in the figure are length and diameter of each edge. As for parameters of GA, Population is 120, mutation rate is 0.01 and terminal generation is 400.

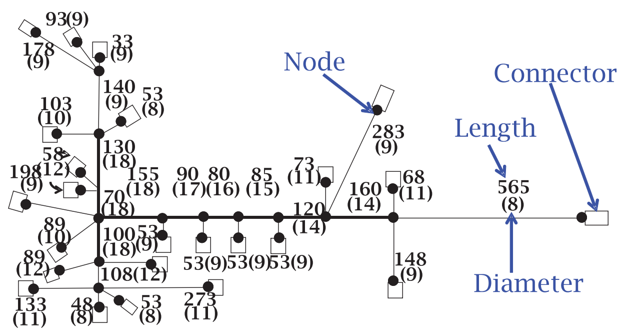

Fig. 7: Wire harness model.

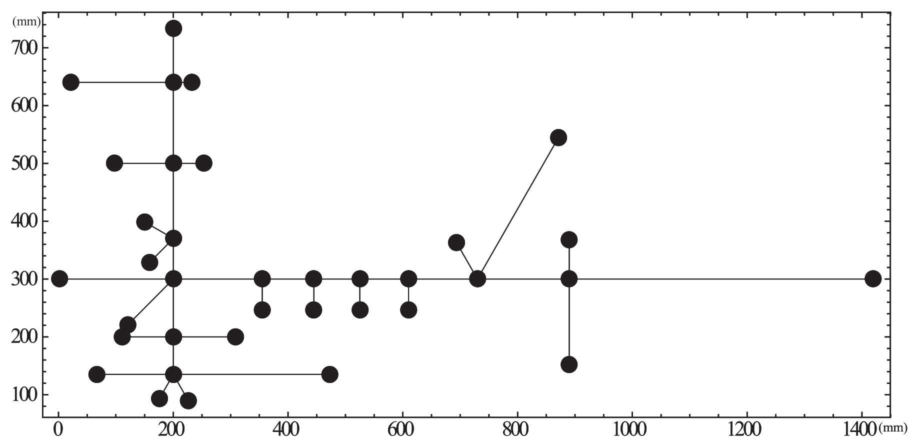

Fig. 8: Optimal layout.

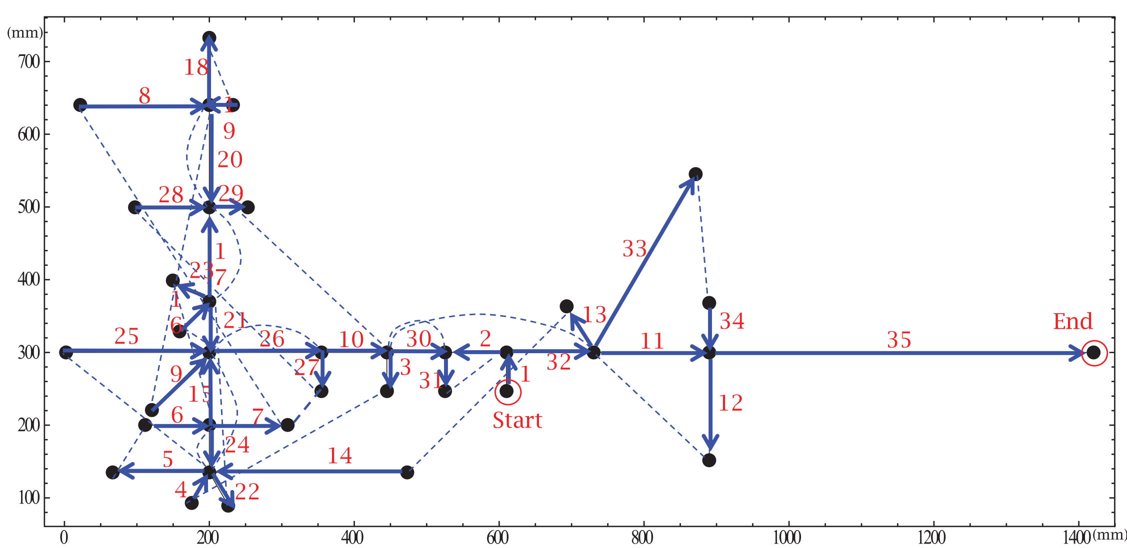

Fig. 9: Optimal route of taping tasks.

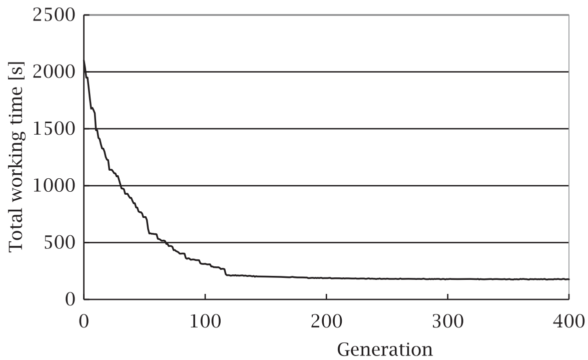

Fig. 10: History of total working time T_{total}.

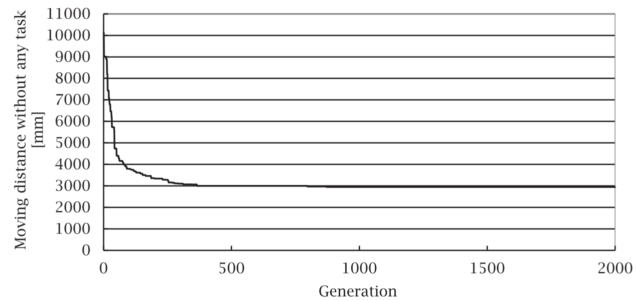

Fig. 12: History of moving distance without any task L.

Fig. 8 shows the optimal jigs layout. Comparison of Fig. 7 and Fig. 8 shows that adjacency relationship between edges at each node is not changed from the initial configuration. Fig. 9 shows the optimal route of taping tasks. Fig. 10 shows the history of the fitness function, i.e. total working time T_{total}. Fig. 11 shows the histories of total taping time T and moving distance without any task L. T_{total}, T and L of the optimal result are 177 s, 168 s and 3619 mm respectively. Histories of T and L show that optimization of jigs layout is converged whereas optimization of taping route seems to not be converged after 400 generations. The optimization program requires a lot of computation time, so terminal generation is limited to 400.

For comparison, optimization of jigs layout is independently executed first, and then optimization of the route of taping tasks is executed against the obtained optimal layout. . The total taping time T is 168 s, which is also the same as the time of integrated optimization. Fig. 12 shows the history of the fitness function of taping route optimization. The moving distance without any task L at the final generation is 2949 mm.

We expect that jigs layout is changed in order to reduce the moving distance without any task by using the integrated optimization (the proposed method), but these results show that jigs layout and route of taping tasks seem not to affect each other. This is why a worker can move his/hand hand very quickly without any task, so moving distance without any task L has a small impact on total working time T_{total}. Therefore, based on the configuration of the wire harness, a user should select the integrated optimization or the sequential optimization adequately.

4. CONCLUSION

To design efficient assembly processes of an automobile wire harness, this paper focuses on the process a worker tapes the cables and proposes integrated optimization of jigs layout on a work bench and route of taping tasks. To show the effectiveness of the proposed method, the proposed method is applied to the automobile wire harness installed in a certain actual car. The results show that although the proposed method can optimize jigs layout and route of taping tasks simultaneously, nearly equal results can be obtained by using two types of optimization independently and sequentially. Therefore, a user should select the integrated optimization or the sequential optimization adequately based on the configuration of the wire harness.

As for future works, we are planning to focus on not only design of assembly processes but also design of a wire harness itself. By designing a wire harness considering its assembly processes, it is expected that the efficiency of assembly processes can be further improved.

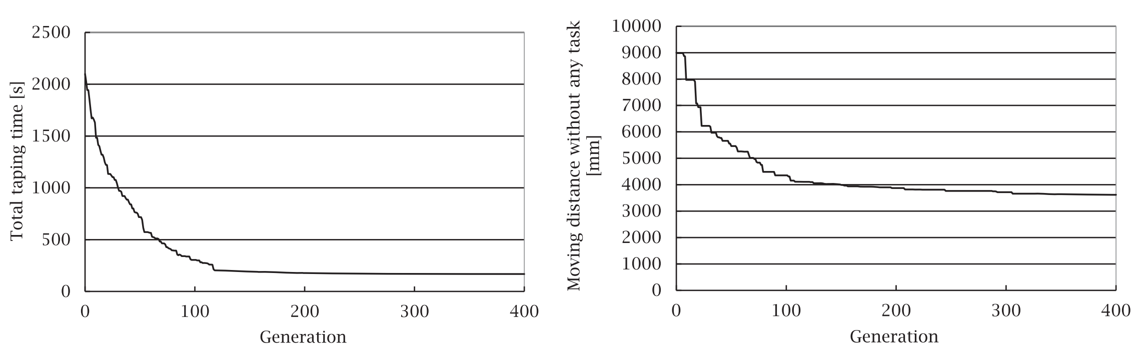

Fig. 11: Histories of total taping time T and moving distance without any task L.

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