A GREEN DECISION SUPPORT SYSTEM FOR INTEGRATED ASSEMBLY AND DISASSEMBLY SEQUENCE PLANNING USING A PSO APPROACH

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Abstract: A green decision support system is presented to integrate assembly and disassembly sequence planning and to evaluate the two costs in one integrated model. In a green product life cycle, it is important to determine how a product can be disassembled before the product is planned to be assembled. For an assembled product, an assembly sequence planning model is required for assembling the product at the start, whereas a disassembly sequence planning model is needed for disassembling the product at the end. In typical assembly and disassembly sequence planning approaches, the two sequences and costs are independently planned and evaluated. In this research, a new integrated model is presented to concurrently generate and evaluate the assembly and disassembly sequences. First, graph-based models are presented for representing feasible assembly sequences and disassembly sequences. Next, a particle swarm optimization (PSO) method with a new encoding scheme is developed. In the new PSO encoding scheme, a particle is represented by a position matrix defining an assembly sequence and a disassembly sequence. The assembly and disassembly sequences can be simultaneously planned with an objective of minimizing the total of assembly costs and disassembly costs. The test results show that the presented method is feasible and efficient for solving the integrated assembly and disassembly sequence planning problem. An example product is implemented and illustrated in this paper.

1 INTRODUCTION

In a complete product life cycle of an assembled product, both an assembly sequence and a disassembly sequence are required. An assembly sequence is required to locate and fix the components in an ordered sequence to construct the product at the start of the product life cycle. An assembly sequence can be defined as an ordered sequence of components and assembly operations required to produce the final product. The purpose of assembly sequence planning is to arrange the assembly sequences based on the assembly constraints and cost objectives.

On the other hand, a disassembly sequence is required to disconnect the components of the product at the end of the product life cycle. A disassembly sequence can be defined as an ordered sequence of components and disassembly operations with which the product can be decomposed into separated modules or components. The purpose of disassembly sequence planning to arrange the disassembly sequences based on the disassembly constraints and cost objectives.

In a green product life cycle, it is essential to plan how a product can be disassembled, reused, or recycled, before the product is actually assembled and produced. In a green product life cycle, although the disassembly operations occur at the end, it is important to plan in advance at the start. Therefore, a green decision support system is required in a green product life cycle management system to integrate assembly sequence planning and disassembly sequence planning.

In the traditional concept of sequential product life cycle activities, the assembly sequence planning and the disassembly sequence planning are considered as two independent tasks. As a result, the cost factors in the assembly sequence planning model may sometimes contradict the cost factors in

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the disassembly sequence planning model, or vice versa. Therefore, a good assembly sequence for constructing a product may result in adding more costs in the corresponding disassembly sequence. In this situation, if a product is assembled with an assembly sequence with a low cost, it may cost more to disassemble the product. Therefore, the assembly and disassembly sequences must be concurrently planned with an integrated model.

In this research, a green decision system is proposed. The assembly and disassembly sequences can be analyzed and evaluated with an integrated planning model. A new PSO encoding scheme is developed by defining the position of a particle using a position matrix. The position matrix of a particle defines an assembly sequence and a disassembly sequence. In this way, the assembly sequence and disassembly sequence can be simultaneously planned by optimizing the position matrix of a particle. The major contributions lie in the new concept of integrated assembly and disassembly sequence planning model and the new PSO encoding and solution scheme to optimize the two costs.

In this paper, Section 2 presents a literature review Section 3 presents the graph-based representation models for representing the assembly and disassembly sequences. Section 4 presents the PSO method for finding the solutions. Section 5 discusses the test results with an example. Finally, section 6 concludes this study.

2 LITERATURE REVIEW

In the related research in assembly planning, it can be summarized that assembly planning can be performed in three stages: (1) assembly modelling and representation, (2) assembly sequence generation, and (3) assembly evaluation and optimization. A recent review can be found in Abdullah et al. (2003). The previous research in assembly planning can be classified into three categories. The first category uses rules or knowledge bases to perform generation of different assembly sequences. The second category presents automatic generation of feasible assembly sequences using graph representation forms including the research presented in de Mello and Sanderson (1991), Lin and Chang (1993), and Choi *et al*. (1998). The third category focuses on assembly analysis and evaluation for searching the better or the optimal assembly sequence. The research in this class includes Laperriere and ElMaraghy (1996), Gottipolu and Ghosh (1997), and Chen *et al*. (2004).

The recent research by Su (2007) introduced a geometric constraint analysis method to generate assembly precedence relations and evaluate feasible assembly sequences. Dong *et al.* (2007) presented a connection-semantics-based assembly tree hierarchy to analyze geometric and non-geometric information.

In the related research in disassembly sequence planning, a review has been presented by Lambert (2003). The concept of disassembly precedence matrix has been applied by Huang and Huang (2002) and Gungor and Gupta (2001) to evaluate precedence relationships between components and to generate disassembly sequences. Torre *et al.* (2003) presented disassembly sequence planning based on precedence relations among components, sub-assemblies, and product. Kongar and Gupta (2006) presented a disassembly sequence planning method using GA.

The PSO has been successfully applied to many continuous and discrete optimizations (Kennedy and Eberhart, 1997). Banks *et al*. (2008) reviewed and summarized the related PSO research in the areas of hybridization, combinatorial problems, multiple objectives and constrained optimization areas.

In this research, a green decision support system for a complete life cycle management by integrating assembly and disassembly planning is presented. A PSO method is developed for finding the solutions with an objective of minimizing the cost functions.

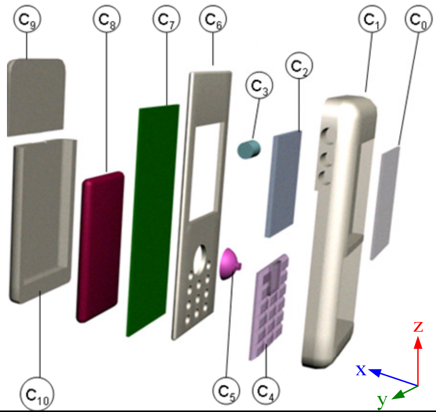
3 REPRESENTATION MODELS

Two graph-based models are presented to represent the integrated assembly and disassembly sequences.

(1) Assembly precedence diagram (APD),

(2) Disassembly precedence diagram (DPD).

An assembly precedence diagram (APD) is a directed graph showing the precedence of the components and the associated assembly operations. In this research, the concept of APD is applied to represent the spatial connectivity relationship and precedence between two components. The concept is expanded for use in disassembly planning by defining the disassembly precedence diagram (DPD). An example product A is shown in Figure 1. The APD and DPD of the product A are shown in Figure 2.



Component	Name
0	Screen cover plate
1	Top case
2	LCD panel
3	Side button
4	Keyboard
5	Front button
6	Frame
7	Printed circuit board
8	Battery
9	Bottom case
10	Battery case

Figure 1: Illustration of the example product A.

Two new matrices forms, assembly precedence matrix (APM) and disassembly precedence matrix (DPM), are developed for integrated assembly planning and disassembly planning. The two matrix models are shown as follows.

$$APM = \begin{array}{c} \\ p_{i=1} \\ p_{i=2} \\ \vdots \\ p_{i=n} \end{array} \begin{array}{c} \begin{array}{cccc} p_{j=1} & p_{j=2} & \cdots & p_{j=n} \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \\ \vdots & \vdots & a_{ij} & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \end{array} \quad (1)$$

where p_i and p_j are components, and n is the number of components, a value of $a_{ij} = 0$ represents that there is no precedence between two the components p_i and p_j, a value of $a_{ij} = 1$ indicates that component p_j must be assembled before component p_i.

$$DPM = \begin{array}{c} \\ p_{i=1} \\ p_{i=2} \\ \vdots \\ p_{i=n} \end{array} \begin{array}{c} \begin{array}{cccc} p_{j=1} & p_{j=2} & \cdots & p_{j=n} \end{array} \\ \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & \\ \vdots & \vdots & d_{ij} & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nn} \end{bmatrix} \end{array} \quad (2)$$

where p_i and p_j are components, and n is the number of components, a value of $d_{ij} = 0$ represents that there is no precedence between two components p_i and p_j, a value of $d_{ij} = 1$ indicates that component p_j must be disassembled before component p_i.

4 SOLUTION USING PARTICLE SWARM OPTIMIZATION (PSO)

The overall flow of the PSO method is illustrated in Figure 2. The PSO algorithm is an evolutionary computation method introduced by Kennedy and Eberhard (1997). In PSO, each particle moves around in the multi-dimensional space with a position and a velocity. The velocity and position are constantly updated by the particle's own experience and the experience of the whole swarm. Given a problem, a particle can be encoded to represent a solution. Each solution, called a particle, flies in the search space towards the optimal position.

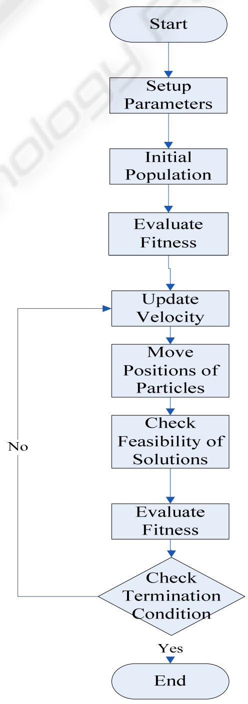


Figure 2: The overall flowchart of the PSO method.

In a general form, a particle is defined by its position and velocity. The position of a particle i in the D-dimension search space can be represented as $X_i=[x_{i1}, x_{i2}, \ldots, x_{id}, \ldots, x_{iD}]$. The velocity of the particle i in the D-dimension search space can be represented as $V_i=[v_{i1}, v_{i2}, \ldots, v_{id}, \ldots, v_{iD}]$. Each particle has its own best position $P_i=[p_{i1}, p_{i2}, \ldots, p_{id}, \ldots, p_{iD}]$ representing the particle's personal best objective (*pbest*) at time t. The global best particle is denoted as p_g and the best position of the entire swarm (*gbest*) is denoted as P_g=[p_{g1}, p_{g2}, …, p_{gd}, …, p_{gD}] at tie t. To search for the optimal solution, each particle adjusts its velocity according to the velocity updating equation and position updating equation.

$$v_{id}^{new}=w_i\cdot v_{id}^{old}+c_1\cdot r_1\cdot(p_{id}-x_{id})+c_2\cdot r_2\cdot(p_{gd}-x_{id}), \quad (3)$$

where d =1, …, D, i =1, …, E (number of particles),
v_{id}^{new}: the new velocity of i in the current iteration t,
v_{id}^{old}: the velocity of i in the previous iteration (t - 1),
c_1 and c_2: constants called acceleration coefficients,
w_i: the inertia weight,
r_1 and r_2: two independent random numbers with a uniform distribution [0, 1],
p_{id}: the best position of each individual particle i,
p_{gd}: the best position of the entire swarm.

$$x_{id}^{new}=x_{id}^{old}+v_{id}^{new}, \quad (4)$$

where x_{id}^{new} is the new position in the current iteration t, x_{id}^{old} is in the previous iteration (t - 1).

4.1 Cost Function

A cost function by integrating the assembly costs and disassembly costs is formulated and used as an objective function. The cost items are described as follows.

(1) Assembly and disassembly operation cost (*AOC* and *DOC*).

(2) Assembly and disassembly instability cost (*AIC* and *DIC*).

(3) Assembly and disassembly directional accessibility cost (*ADC* and *DDC*).

(4) Assembly and disassembly tool setup cost (*ATC* and *DTC*).

(5) Assembly and disassembly weight effect cost (*AWC* and *DWC*).

The value of each of the cost functions is measured on a consistent scale with a unit in dollars. The total cost function (*TC*) is the sum of all the operation cost functions and can be described using the following equation:

$$TC = (AOC+AIC+ADC+ATC+AWC) + (DOC+DIC+DDC+DTC+DWC) \quad (5)$$

4.2 Encoding

In the developed encoding scheme, a particle is represented by a position matrix. A position matrix presents an integrated assembly and a disassembly sequence. The position of particle i, i = 1, …, E, is represented by a position matrix, denoted as X_{ijk}, j = 1, 2, and k = 1, …, N, where N is the number of components.

The first row, where j = 1, represents an assembly sequence. In the heuristic sequencing rule, the values in the first row represent the ranked order values of the N components in an assembly sequence. The second row, where j = 2, represents a disassembly sequence. In the heuristic sequencing rule, the values in the second row represent the ranked order values of the N components in an assembly sequence.

$$X_{ijk} = \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \end{bmatrix}, \quad (6)$$

where i = 1, …, E, j =1, 2, and , k =1, …, N.

In the heuristic rule for decoding an assembly sequence, the values in the first row [X_{11}, X_{12}, …, X_{1n}] are sorted in an ascending order. The ranked order values represent the ordered position of the component in the assembly sequence. For example, if the ranked order values of row 1 of (C_1, C_2, C_3, C_4, C_5) are [4.5 1.1 3.2 7.6 5.3], then the ordered positions of (C_1, C_2, C_3, C_4, C_5) are (third, first, second, fifth, fourth). The assembly sequence is decoded as (C_2, C_3, C_1, C_5, C_4). The heuristic rule for decoding a disassembly sequence can be interpreted in the same way.

4.3 The PSO Method for Integrated Assembly and Disassembly Planning

The flowchart the PSO method is shown in Figure 3.

Step 1. Setup parameters.
(1) Set iteration t = 0.
(2) T_{Number}: the iteration (generation) number.
(3) P_{Size}: the number of particles.

Step 2. Initialize a population of particles i = 1, …, E,with random positions and velocities.
(1) A particle i is defined by a multi-dimensional position matrix of (2)*(N).
(2) The position of particle i is defined by X_{ijk}.
(3) The velocity of particle i is defined by V_{ijk}.

Step 3. Evaluate the fitness function.
(1) $t = t + 1$.

(2) *Fitness* = *TC*.

Step 4. Update the velocity of each particle *i*.

$$v_{id}^{new} = w_i \cdot v_{id}^{old} + c_1 \cdot r_1 \cdot (p_{id} - x_{id}) + c_2 \cdot r_2 \cdot (p_{gd} - x_{id}),$$

v_{id}^{new} is the new velocity in the current iteration *t*,

v_{id}^{old} is the velocity in the previous iteration (*t*-1),

Step 5. Move the position of each particle *i*.

$$x_{id}^{new} = x_{id}^{old} + v_{id}^{new},$$

where x_{id}^{new} is the new position in the iteration *t*,

x_{id}^{old} is the position in the iteration (*t* - 1).

Step 6. Check the feasibility of the solution and the number of iteration *t*.

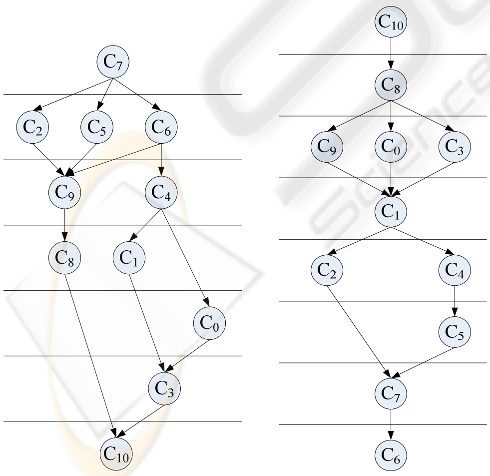
(1) The precedence is checked by APM and DPM.

(2) If ($t > T_{Number}$), then go to Step 7, else go to Step 2.

Step 7. Decode the best particle position and interpret the solution.

5 IMPLEMENTATION AND TEST RESULTS

In the presented green decision support system, the models were implemented and tested by developing software on a personal computer. The example product A is illustrated in Figure 1. There are 11 components, C_0, C_1, …, C_{10}. The APD and DPD are shown in Figure 3.



(a) APD (b) DPD

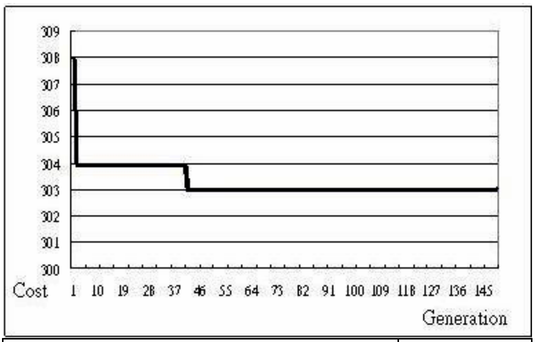
Figure 3: The APD and DPD of the example product A.

The APM and DPM are shown in the following forms.

$$APM = \begin{array}{c} \\ C_0 \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccccccccc} C_0 & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 0&0&0&0&1&0&1&1&0&0&0 \\ 0&0&0&0&1&0&1&1&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0&0 \\ 1&1&0&0&1&0&1&1&0&0&0 \\ 0&0&0&0&0&0&1&1&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&0&0&1&0&0&0 \\ 0&0&0&0&0&0&0&0&0&0&0 \\ 0&0&1&0&0&1&1&1&0&1&0 \\ 0&0&1&0&0&1&1&1&0&0&0 \\ 1&1&1&1&1&1&1&1&1&1&0 \end{bmatrix} \end{array}$$

$$DPM = \begin{array}{c} \\ C_0 \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccccccccc} C_0 & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 0&0&0&0&0&0&0&0&1&0&1 \\ 1&0&0&1&0&0&0&0&1&1&1 \\ 1&1&0&1&0&0&0&0&1&1&1 \\ 0&0&0&0&0&0&0&0&1&0&1 \\ 1&1&0&1&0&0&0&0&1&1&1 \\ 1&1&0&1&1&0&0&0&1&1&1 \\ 1&1&1&1&1&1&0&1&1&1&1 \\ 1&1&1&1&1&1&0&0&1&1&1 \\ 0&0&0&0&0&0&0&0&0&0&1 \\ 0&0&0&0&0&0&0&0&1&0&1 \\ 0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix} \end{array}$$

Finally, the PSO method is applied for finding the solutions. The test result is shown in Figure 4. Figure 4 shows that the computation converges after 40 generations. After 150 generations, a solution with the near optimized low cost of \$302.968 can be obtained. The numerical values of the position matrix of the solution are shown in Figure 5. The position matrix can be decoded to show the integrated assembly and disassembly sequence. Figure 6 describes the assembly and disassembly sequence. The 11 components can be assembled and disassembled with a near optimized low cost.



Cost (dollars)	302
Iterations (Generations)	150
Computer time (seconds)	1.281

Figure 4: The test result of the cost and generation number of the PSO method.

$$PM=\begin{array}{c} \\ \end{array}\begin{array}{ccccccccccc} C_{00} & C_{01} & C_{02} & C_{03} & C_{04} & C_{05} & C_{06} & C_{07} & C_{08} & C_{09} & C_{10} \end{array}$$

$$PM=\begin{bmatrix} 1.44 & 1.85 & 1.64 & 3.71 & 0.58 & 2.76 & 3.46 & 3.00 & 1.82 & 3.55 & 1.51 \\ 1.90 & 3.15 & 2.34 & 0.86 & 2.52 & 1.49 & 1.86 & 2.88 & 1.14 & 1.62 & 3.22 \end{bmatrix}$$

Figure 5: The Numerical values of the position matrix of the PSO solution.

Assembly sequence	1	2	3	4	5	6	7	8	9	10	11
Component	7	2	5	6	4	1	0	9	8	3	10

Disassembly sequence	1	2	3	4	5	6	7	8	9	10	11
Component	10	8	3	9	0	1	4	5	2	7	6

Figure 6: The final test results of the integrated assembly and disassembly sequences.

It is observed that the combinatorial number of sequences increases as the component number grows. It can be concluded in general, the PSO method can be considered an efficient and effective method for find the solutions of integrated assembly and disassembly sequences. Although the presented methods can be useful for generating and evaluating feasible sequences with good solutions, much remains to be done to manage more complicated products with a large number of components. Further research on the complexity issues need to be conducted.

6 CONCLUSIONS

In this research, a green decision support system is presented to integrate assembly and disassembly sequence planning models. First, graph-based models are built by analyzing the spatial relationships of the components and the operations. Second, a solution method using a PSO approach is applied to search for the good assembly sequence and disassembly sequence. A new encoding scheme of position matrix is developed for representing a particle. A cost function by integrating the assembly costs and disassembly costs is formulated. An example product is illustrated in this paper. The test results show that the PSO method converges within a small number of generations with a near optimized low cost. It can be generally concluded that the developed model in the decision support system is feasible and efficient for integrating assembly and disassembly sequence planning. The green decision support system is capable of finding complete assembly and disassembly sequences with a near optimized low cost. In further research, more detailed assembly and disassembly cost functions can be further explored. The solution method can be refined to enhance the solution speed.

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