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Solution Space Generation for Disassembly Research on Liquid Crystal Displays Televisions

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***Abstract*—Waste Electrical and Electronic Equipment (WEEE) are one of the most significant waste products in modern societies, and disassembly is a critical step to reduce WEEE. In the past two decades, despite there are many research articles published for disassembly research of WEEE, those researches mainly focus on searching optimised disassembly sequences according to different considerations of stakeholders, while another important problem, i.e., the generation of solution space has received little attentions. However, before applying disassembly planning and optimisation techniques in real industrial cases such as Liquid Crystal Display (LCD) televisions, it cannot evade the issue of the solution space generation. In this paper, an effective approach was developed to generate the solution space for LCD televisions. Firstly, six space interference matrices are generated based on a CAD model, which can be used to represent the space relationship of each components in six directions in a Cartesian coordinate system. A matrix analysis algorithm is then developed to obtain all feasible disassembly sequences by analysing the obtained six space interference matrices in a 3D environment. The result can be used as a solution space to support a disassembly planning method to achieve better economic value and environmental protection requirements within an acceptable runtime. Finally, an industrial case on Changhong LCD television of the type LC24F4 is used to verify and demonstrate the performance of the developed research.**

***Keywords*—space interference matrix; matrix analysis algorithm; Liquid Crystal Display televisions**

I. INTRODUCTION

In recent years, paramount demands for Electrical and Electronic Equipment (EEE) have incurred more product development and manufacturing activities. Due to the short usage lifecycle of EEE, Waste Electrical and Electronic Equipment (WEEE) are becoming one of the major and challenging waste streams in terms of quantity and toxicity [1]. For instance, there are approximately 7 million tons of WEEE are generated in Europe per year [2].

In order to reuse and recycle WEEE, one key issue is how to choose a disassembly sequence fulfilling the regulation for recycling and recovery rates in an economical manner. In the past two decades, there are many research articles published for disassembly research of WEEE. In the literature [3-5], some detailed reviews on the research were made. Almost all those researches focused on the optimal disassembly solution search while another important problem, the generation of solution space, has received little attentions. However, before applying disassembly planning and optimisation techniques in real industrial cases such as Liquid Crystal Display (LCD) televisions, which is one of the main products of WEEE nowadays, it cannot evade the issue of feasible solution space generation for further search and optimisation [6]. There are two reasons: (1) In real practice, if the disassembly sequence is obtained by searching all the disassembly sequences instead of the solution space, the result could hardly be used as there are some geometrical or technical constraints to specify precedent relationships between disassembly operations; (2) LCD televisions are normally assembled by many components with complex shapes. For an assembly LCD television with N components, the total disassembly sequences could be as much as N!=N×(N-1)…2×1. It is too difficult to identify the best disassembly sequence within an acceptable runtime. In the last few years, despite some paper have reported researches on disassembly research for LCD televisions [7-12], the problem of solution space generation still received little attention, and it is still an important but a challenging research topic at present.

In this paper, an effective approach has been developed to address the issues of the solution space generation for LCD televisions. Firstly, based on a CAD model, space interference matrix in a Cartesian coordinate system is used to represent the space interference relationship between components in six directions (X+, X-, Y+, Y-, Z+, Z-). In the matrix, if space interference exists between two components in one direction, the element which is used to show the space relationship equals to ‘1’ in this direction. Otherwise, the element is ‘0’. By this way, all the space interference relationship between components of LCD television can be digitally recorded, and can be easily analysed in the next step. A matrix analysis algorithm is then developed to analyse the obtained six space interference matrices in a 3D environment. The algorithm is capable to find out all the feasible disassembly sequences of LCD television, and the obtained sequences result can be used as a solution space to support a selective disassembly planning method to achieve a better economic value for LCD televisions. In the end, case studies of front cover assembly part, base assembly part, and back over assembly part of LCD television is used to verify and demonstrate the performance of this research.

II. METHODOLOGY

As shown in Fig. 1, the developed research is carried out in two main phases. Phase 1 is to generate space interference matrix based on a CAD product model. It can be used to represent the space interference relationship between components of LCD television. Phase 2 is to obtain all the feasible disassembly sequence with the developed matrix analysis algorithm. The obtained all the feasible disassembly sequence can be used as a solution space to support a disassembly planning method to search optimised selective disassembly sequences for LCD televisions. The details of each phase are shown in following sections.

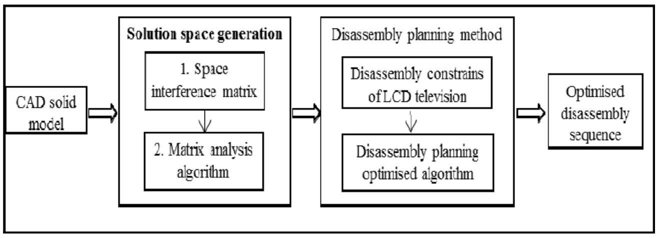

Fig. 1. A main flow of the developed approach.

A. Space Interference Matrix

Firstly, based on a CAD product model, six space interference matrices are generated in six directions separately in a 3D environment. It can be used to represent the space interference relationship of components of a product.

$$\begin{array}{cc} & \begin{array}{cccc} E_1 & E_2 & \cdots & E_n \end{array} \\ \begin{array}{c} E_1 \\ E_2 \\ \vdots \\ E_n \end{array} & \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & & \\ \vdots & \vdots & \ddots & \vdots \\ t_{n1} & t_{n2} & & t_{nn} \end{bmatrix} \end{array}$$

In the matrix, the element E_i in each row and column is one of the components in the product. The element t_{ij} shows the space interference relationship between components i and j in six directions (X+, X-, Y+, Y-, Z+, Z-) in a 3D environment. If space interference exists between components i and j in one direction, the element t_{ij} in the matrix is '1' in this direction. Otherwise, it is '0'. An example is used here to explain the space interference relationship between four components of a product. As the object 'A' is in X+ direction of the object 'B' to generate a geometric constraint when 'B' is moved along X-, and the object 'B' is in X- direction of the object 'A', the element r_{AB} in X+ direction matrix is '1', and the element r_{BA} in X- direction matrix is '1'. All the other results are also shown in the six matrices to represent the space interference relationship between each part (shown in Fig. 2).

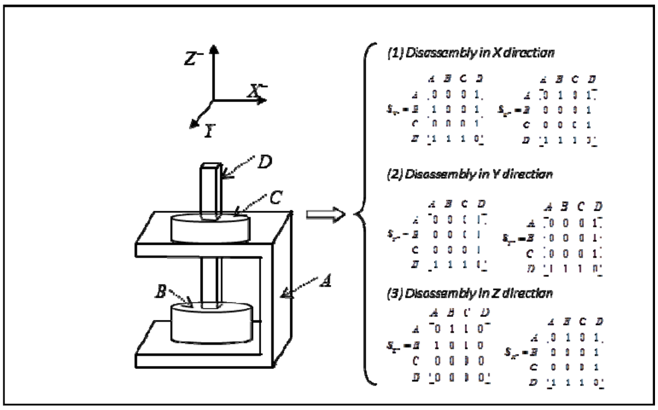

Fig. 2. Matrices to represent the space interference relationship of the product in six directions.

B. Matrix Analysis Algorithm

Based on the obtained space interference matrices in six directions in Phase 1, a matrix analysis algorithm is developed to find out all the feasible disassembly sequences of the product. Fig. 3 shows the flow of the algorithm.

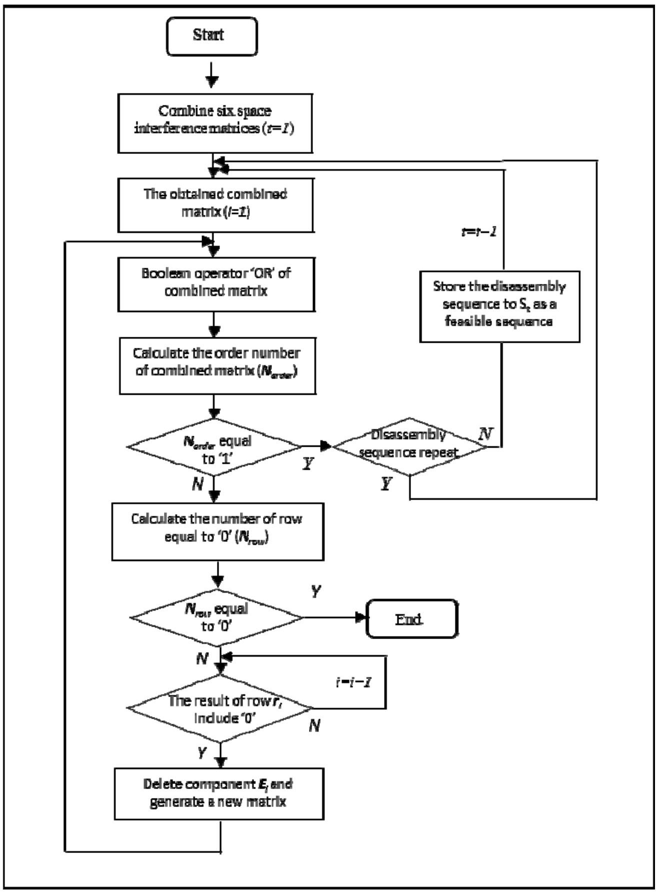

Fig. 3. Flowchart of the matrix analysis algorithm

An example is used here to explain the details of the developed matrix analysis algorithm. Firstly, the equation (1) is generated by combining the generated six space interference matrices of the product (shown in Fig. 2).

$$\boldsymbol{S} = \begin{array}{c} \\ A \\ B \\ C \\ D \end{array} \begin{array}{c} \begin{array}{cccc} A & B & C & D \end{array} \\ \begin{bmatrix} 000000 & 010011 & 000010 & 111100 \\ 100011 & 000000 & 000010 & 111100 \\ 000001 & 000001 & 000000 & 111100 \\ 111100 & 111100 & 111100 & 000000 \end{bmatrix} \end{array} \tag{1}$$

The Boolean operator ‘OR’ is used here for the above equation at any row to determine whether a component can be freely disassembled in a direction. The equation (2) is obtained below.

$$\boldsymbol{S} = \begin{array}{c} \\ A \\ B \\ C \\ D \end{array} \begin{array}{c} \begin{array}{cccc} A & B & C & D \end{array} \\ \begin{bmatrix} 000000 & 010011 & 000010 & 111100 \\ 100011 & 000000 & 000010 & 111100 \\ 000001 & 000001 & 000000 & 111100 \\ 111100 & 111100 & 111100 & 000000 \end{bmatrix} \end{array} \begin{array}{c} \text{Result} \\ 111111 \\ 111111 \\ 111101 \\ 111100 \end{array} \tag{2}$$

The result ‘111111’ represents the relationship between one component and all remaining components of the product in six directions (X+, X-, Y+, Y-, Z+, Z-). If the result is all ‘1’, it means the component could not be disassembled in any direction; if the result includes ‘0’, it means the component can be disassembled from that direction. For instance, in the equation (2), components ‘A’ and ‘B’ could not be disassembled in any direction as the result is all ‘1’; component ‘C’ can be disassembled in Z+ direction as the result is ‘0’ in this direction; and component ‘D’ can be disassembled in both Z+ and Z- directions.

Here, the component ‘C’ is disassembled in Z+ direction firstly, the remaining combined space interference matrix is shown below.

$$\boldsymbol{S} = \begin{array}{c} \\ A \\ B \\ D \end{array} \begin{array}{c} \begin{array}{ccc} A & B & D \end{array} \\ \begin{bmatrix} 000000 & 010011 & 111100 \\ 100011 & 000000 & 111100 \\ 111100 & 111100 & 000000 \end{bmatrix} \end{array} \begin{array}{c} \text{Result} \\ 111111 \\ 111111 \\ 111100 \end{array} \tag{3}$$

From the equation (3), only the component ‘D’ can be disassembled in both Z+ and Z- directions. Here, the component of ‘D’ is disassembled in Z+ direction, and the remaining combined space interference matrix is shown below.

$$\boldsymbol{S} = \begin{array}{c} \\ A \\ B \end{array} \begin{array}{c} \begin{array}{cc} A & B \end{array} \\ \begin{bmatrix} 000000 & 010011 \\ 100011 & 000000 \end{bmatrix} \end{array} \begin{array}{c} Result \\ 010011 \\ 100011 \end{array} \tag{4}$$

From the equation (4), the components ‘A’ and ‘B’ can be disassembled in three directions. After disassembling ‘A’ in X+ direction, the product has been disassembled completely. Loop the above analysis processing until all the feasible disassembly sequences of the product are obtained. Based on the above analysis and the developed matrix analysis algorithm, the total feasible disassembly sequences for the product is 192 (30+30+30+30+30+30+6+6) (shown in Fig. 4).

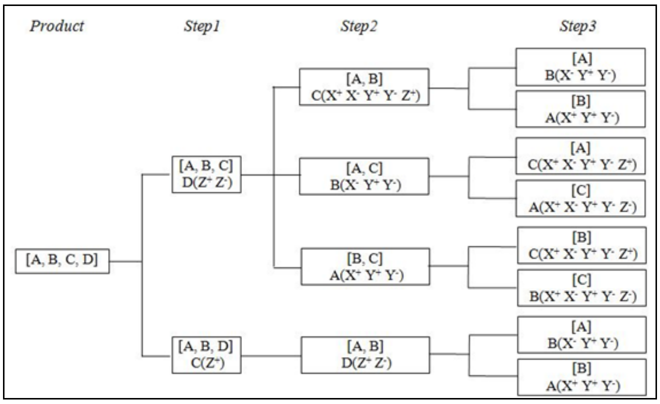

Fig. 4. All the feasible disassembly sequences for the product

The obtained result of all the feasible disassembly sequences for the product can be used as a solution space to support a disassembly planning method to achieve better economic value.

III. INDUSTRIAL CASES STUDY ON LCD TELEVISIONS

The LCD televisions have been developed quickly over the past decades and the outputs of LCD televisions are forecasted to surpass 200 million units in 2013 [13]. The LCD televisions studied here are produced by the Changhong Electronics Company, Ltd., which is the biggest television producer in China. The company provides information about LCD televisions of the type of LC24F4, such as the Bill of Materials, exploded view, mass of each part and the detailed assembly processes.

The structure of the LCD television is shown in Fig. 5(a) and (b). The typical exploded view of a LCD television is shown in Fig. 5(c). As shown in Fig. 5(d), a LCD television is typically assembled by three main parts: (1) base assembly part, (2) front cover assembly part and (3) back cover assembly part.

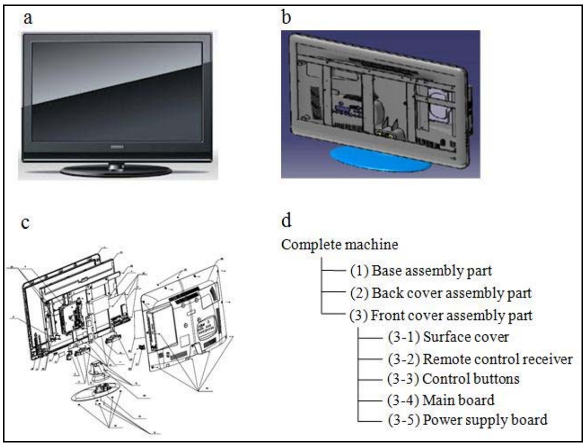

Fig. 5. The LCD televisions and its structures (a) LCD television; (b) LCD television CAD model; (c) exploded view of LCD television structure and (d) parts of LCD television

A. *Base Assembly Part*

The base assembly part of LCD television is shown in Fig. 7. It is composed by nine parts: (A) metal fixing plate, (B) metal washer 1, (C) metal washer 2, (D) top metal support, (E) cylindrical metal support 1, (F) cylindrical metal support 2, (G) toughened glass seat, (H) steel plate and (I) rubber gasket. The space interference matrices to represent the base assembly part in six directions are shown below.

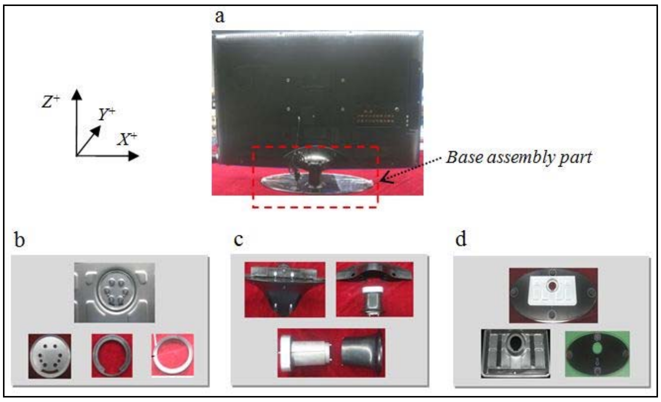

Fig. 7. The base assembly part of LCD television (a) base assembly part, (b) Components A,B,C (c) Components D,E,F (d) Components G,H,I.

$$\boldsymbol{S}_{X^+}=\left[\begin{array}{c|ccccccccc} & A & B & C & D & E & F & G & H & I \\ \hline A & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ B & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ C & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ D & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ E & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ F & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \\ G & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ H & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ I & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{array}\right] \quad \boldsymbol{S}_{X^-}=\left[\begin{array}{c|ccccccccc} & A & B & C & D & E & F & G & H & I \\ \hline A & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ B & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ C & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ D & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ E & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ F & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \\ G & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ H & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ I & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{array}\right]$$

$$\boldsymbol{S}_{Y^+}=\left[\begin{array}{c|ccccccccc} & A & B & C & D & E & F & G & H & I \\ \hline A & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ B & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ C & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ D & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ E & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ F & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \\ G & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ H & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ I & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{array}\right] \quad \boldsymbol{S}_{Y^-}=\left[\begin{array}{c|ccccccccc} & A & B & C & D & E & F & G & H & I \\ \hline A & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ B & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ C & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ D & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ E & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ F & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \\ G & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ H & 1 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ I & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{array}\right]$$

$$\boldsymbol{S}_{Z^+}=\left[\begin{array}{c|ccccccccc} & A & B & C & D & E & F & G & H & I \\ \hline A & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ B & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ C & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 \\ D & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ E & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ F & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 \\ G & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ H & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ I & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right] \quad \boldsymbol{S}_{Z^-}=\left[\begin{array}{c|ccccccccc} & A & B & C & D & E & F & G & H & I \\ \hline A & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ B & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ C & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ D & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 0 \\ E & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ F & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ G & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 \\ H & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ I & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}\right]$$

After combining the above six matrices and using Boolean operator ‘OR’ in rows, the obtained result is as follows:

$$\boldsymbol{S}=\begin{array}{c|ccccccccc|c} & A & B & C & D & E & F & G & H & I & \text{Result} \\ \hline A & 000000 & 000010 & 000010 & 000010 & 000010 & 000010 & 111110 & 111110 & 111100 & 111110 \\ B & 000001 & 000000 & 000010 & 000010 & 000010 & 000010 & 111110 & 111110 & 111100 & 111111 \\ C & 000001 & 000001 & 000000 & 000010 & 000010 & 000010 & 111110 & 111110 & 111100 & 111111 \\ D & 000001 & 000001 & 000001 & 000000 & 111101 & 111101 & 111101 & 111101 & 000000 & 111101 \\ E & 000001 & 000001 & 000001 & 111110 & 000000 & 111101 & 000001 & 000001 & 000000 & 111111 \\ F & 000001 & 000001 & 000001 & 111110 & 111110 & 000000 & 111110 & 111110 & 111100 & 111111 \\ G & 111101 & 111101 & 111101 & 000010 & 000010 & 000010 & 000000 & 111101 & 000001 & 111111 \\ H & 111101 & 111101 & 111101 & 000010 & 000010 & 000010 & 111110 & 000000 & 111100 & 111111 \\ I & 000000 & 000000 & 000000 & 000000 & 000000 & 000000 & 000010 & 111100 & 000000 & 111110 \end{array}$$

Based on the developed matrix analysis algorithm, there are total 450 feasible disassembly sequences for the base assembly part.

B. *Front Cover Assembly Part*

The front cover assembly part of LCD television is shown in Fig. 8. It is composed by 11 parts: (J) Control button, (K) Power switch, (L) Side loudspeaker, (M) Control receiver board, (N) Positive loudspeaker, (O) Power supply board, (P) Main board, (Q) Metal board, (R) Metal mounting plate, (S) Surface frame, (T) LCD screen.

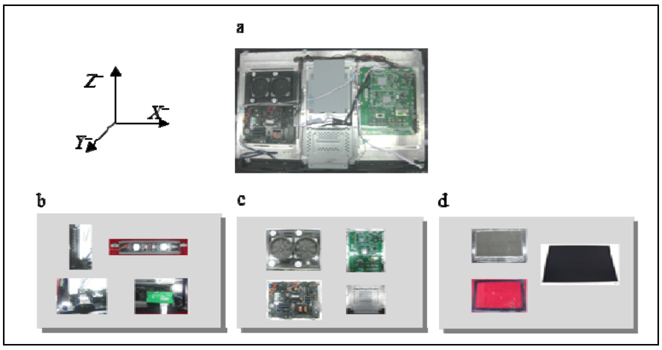

Fig. 8. The front assembly part of LCD television (a) Front assembly part, (b) Components J,K,L,M (c) Components N,O,P,Q (d) Components R,S,T

After combining the space interference matrices of the front assembly part and using Boolean operator ‘OR’ in any rows, the obtained result is shown below.

$$S=\begin{array}{ccc} & \begin{array}{ccccccccccc} J & K & L & M & N & O & P & Q & R & S & T \end{array} & \text{Result} \\ \begin{array}{c} J\\ K\\ L\\ M\\ N\\ O\\ P\\ Q\\ R\\ S\\ T \end{array} & \left[\begin{array}{ccccccccccc} 000000 & 100000 & 100000 & 100000 & 000000 & 000000 & 000000 & 000000 & 101111 & 000100 & 000100 \\ 010000 & 000000 & 100000 & 100000 & 000000 & 000000 & 000000 & 000000 & 111110 & 000100 & 000100 \\ 010000 & 010000 & 000000 & 100000 & 000000 & 001000 & 001000 & 000000 & 111110 & 000100 & 000100 \\ 010000 & 010000 & 010000 & 000000 & 000000 & 000000 & 000000 & 000000 & 111110 & 000100 & 000100 \\ 000000 & 000000 & 000000 & 000000 & 000000 & 000001 & 000000 & 000000 & 110111 & 000100 & 000100 \\ 000000 & 000000 & 000100 & 000000 & 000010 & 000000 & 100000 & 100000 & 110111 & 000100 & 000100 \\ 000000 & 000000 & 000000 & 000000 & 010000 & 010000 & 000000 & 010000 & 110111 & 000100 & 000100 \\ 000000 & 000000 & 000000 & 000000 & 000000 & 010000 & 100000 & 000000 & 110111 & 000100 & 000100 \\ 011011 & 111001 & 111001 & 111001 & 111011 & 111011 & 111011 & 111011 & 000000 & 110111 & 110111 \\ 001000 & 001000 & 001000 & 001000 & 001000 & 001000 & 001000 & 001000 & 111011 & 000000 & 111011 \\ 001000 & 001000 & 001000 & 001000 & 001000 & 001000 & 001000 & 001000 & 111011 & 110111 & 000000 \end{array}\right] & \begin{array}{c} 101111\\ 111110\\ 111110\\ 111110\\ 111111\\ 110111\\ 110111\\ 110111\\ 111111\\ 111011\\ 111111 \end{array} \end{array}$$

Based on the developed approach, there are total 2098 feasible disassembly sequences for the front assembly part.

C. Back Cover Assembly Part

The back cover assembly part of a LCD television is composed by three parts: (U) back cover, (V) cover plate, (W) support (shown in Fig. 9).

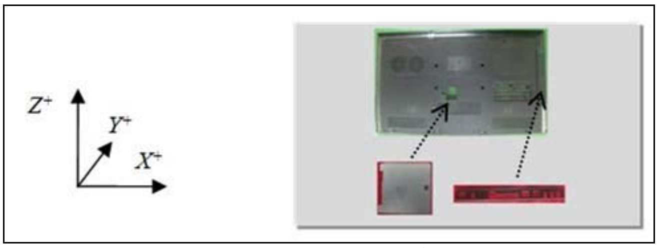

Fig. 9. The back cover assembly part of LCD television.

After combining the space interference matrices of the back cover part and using Boolean operator ‘OR’ in any rows, the result is as follows:

$$\boldsymbol{S}=\begin{array}{ccc} & \begin{array}{ccc} U & V & W \end{array} & \text{Result} \\ \begin{array}{c} U\\ V\\ W \end{array} & \left[\begin{array}{ccc} 000000 & 110111 & 101111 \\ 111011 & 000000 & 100000 \\ 011111 & 010000 & 000000 \end{array}\right] & \begin{array}{c} 111111\\ 111011\\ 011111 \end{array} \end{array}$$

Based on the developed approach, the feasible disassembly sequences for the back cover assembly part is 4.

Based on the above analysis, our developed approach can find out the all feasible disassembly sequence of LCD television of the type LC24F4 is **3776400**=450×2098×4(base assembly part × front cover assembly part × back over assembly part). Compared with the all disassembly sequences, which is 23!=23×22…2×1=**2.5852e+22**, the searching range for a disassembly planning algorithm to find the optimised disassembly sequence of LCD television is reduced about **6.8457e+15** times (shown in Table 1). All the results from the above have been generated using the algorithm in Matlab language. It is obvious that our developed approach can dramatically reduce the searching range and to support a disassembly planning method to achieve better economic value and environmental protection requirements within an acceptable runtime.

TABLE I. COMPARISON BETWEEN OUR DEVELOPED METHOD AND OTHERS

Our developed method:	450×2098×4=**3776400** (all feasible disassembly sequences)
Others:	23!=23×22…2×1=**$2.5852e^{+22}$** (all disassembly sequences)
Searching range reduce:	$2.5852e^{+22}$/3776400=**$6.8457e^{+15}$** times

IV. CONCLUSIONS

In order to reuse and recycle LCD televisions, one key issue is to search optimised disassembly sequences according to different considerations of stakeholders. However, before applying disassembly planning and optimisation techniques for LCD televisions, the generation of solution space is an essential step.

In this paper, an effective approach has been developed to generate feasible solution space of LCD television, which can be used to support a disassembly planning method in future to achieve better economic value and environmental protection requirements for LCD televisions within an acceptable runtime. The characteristics and contributions of the research include:

- Space interference matrix has been used to represent the space interference relationship of each components in six directions for LCD televisions. By this way, all the space interference relationship between components of LCD television can be digitally recorded, and can be easily analysed in next step.
- A matrix analysis algorithm has been developed to obtain all the feasible disassembly sequences of LCD television by analysing the six space interference matrices in a 3D environment. It is capable to obtain all the feasible disassembly sequences of LCD television, and the result can be used as a solution space to support a disassembly planning method to achieve better economic value for LCD televisions within an acceptable runtime.

Future work will include developing an intelligent automated selective disassembly system with industrial robotic manipulator, cameras and sensors for LCD televisions.

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