Adaptive Clustering Algorithm for Recycling Cell Formation : An Application of the Modified Fuzzy ART Neural Network

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Abstract

The recycling cell formation problem means that disposal products are classified into recycling part families using group technology in their end of life phase. Disposal products have the uncertainties of product status by usage influences during product use phase and recycling cells are formed design, process and usage attributes. In order to treat the uncertainties, fuzzy set theory and fuzzy logic-based neural network model are applied to recycling cell formation problem for disposal products.

In this paper, a heuristic approach for fuzzy ART neural network is suggested. The modified Fuzzy ART neural network is shown that it has a great efficiency and give an extension for systematically generating alternative solutions in the recycling cell formation problem. We present the results of this approach applied to disposal refrigerators and the comparison of performances between other algorithms.

This paper introduced a procedure which integrates economic and environmental factors into the disassembly of disposal products for recycling in recycling cells.

A qualitative method of disassembly analysis is developed and its aim is to improve the efficiency of the disassembly and to generated an optimal disassembly which maximize profits and minimize environmental impact. Three criteria established to reduce the search space and facilitate recycling opportunities.

Key Words

Fuzzy Theory, Fuzzy C-Mean Algorithm, Fuzzy ART neural network, Modified Fuzzy ART neural network, Recycling Cell Formation, Group Technology, Evaluation

1. Introduction

As the environmental regulations concerning the disposal of discard products are rapidly increasing to protect the natural environment, the planning of the end of life phase of products is becoming more important for manufacturers. The term recycling means reuse, further use or reutilization, of products or parts in life cycle. Within recycling, we distinguish between treatment and recycling process. The process of treatment includes refurbishing of subassemblies and components as well as reprocessing of materials. The recycling process involves shredding or disassembly of the product. Disassembly leads not only to the recovery of pure material fractions, but also to the isolation of hazardous substances and the separation of reusable components and subassemblies.

A disassembly-oriented recycling system is to collect material, labor, capital and knowledge needed for the disassembly of a product and for preparing the later treatment of its fraction. Recycling should deal with products usually not designed for recycling, and in general it can neither restricted itself to a special type, nor can it add much to the obsolete product value. To cope with these challenges, recycling system requires more efficiency and flexibility. Considering an adequate type of a system, cellular recycling system is favorable. Cellular recycling system could reduce recycling costs and increase productivity and flexibility by the classification of disposal products.

The recycling cell formation problem means that disposal products are classified into recycling part families using group technology in their end of life phase. Disposal products have the uncertainties of product status by usage influences. The existing clustering approach to group technology problem can be classified as matrix based methods, mathematical programming algorithms, graph theory based methods. Pattern recognition techniques, fuzzy logic approaches, expert system based methods, neural network, and genetic algorithm methods.(Gupta et al. 1996)

The recycling would justify uncertain product with the process characteristic by usage influence, as well as incomplete or erroneous information about various products. Therefore we consider the notion of design, process and usage attributes. Thus recycling cells are formed considering these attributes. In this paper, a novel approach to the design of cellular recycling system is proposed, which deals with the recycling cell formation and assignment of identical products concurrently. Fuzzy clustering algorithm and fuzzy-ART neural network are applied to describe the states of disposal product with the membership functions and to make recycling cell formation. The modified fuzzy ART neural network is suggested and applied to form the recycling cell. The performance of two algorithms are compared.

This paper is focused on the integration of product design and the disassembly and to generate an optimal disassembly which maximize economic profit and minimize environmental impacts. Four interrelated areas of disassembly and material recycling is focused on this paper :

1) Economic analysis

2) Environmental Analysis
3) Integration of economic and environmental factors
4) Disassembly sequence generation

In section 2, the characteristics of the recycling process is described. In section 3, the characteristics of group technology with grouping attributes and the generalized fuzzy c-mean algorithm, modified fuzzy-ART neural network and their solution procedures are presented. Application examples are illustrated by disposal refrigerators in section 4. The evaluations of clustering results are discussed in section 5. The generation of an optimal disassembly sequence in term of the economic and environmental consideration of material recycling and environmental impact at the end of the life cycle is introduced in section 6. Finally, the conclusions are presented.

2. Characteristics of the Recycling Process

Recycling deals with a huge variety of products from various producers and production years, as it usually cannot restrict itself to a spectrum of products from only one manufacturer. Uncertainty is caused by the varying product's life expectancies and generates a temporal dispersion of product abandonment. Arrival levels of each type of product and the product mix show non-deterministic properties. Products are usually distributed in many different places and so their deterioration degrees are different. Product attributes are not always affected by usage function. Two other factors, time and media, can serve as examples of influences that cause deterioration from the original condition of the product. While deterioration like wear and material fatigue can be predicted, the abuse of the product, i.e., using a product for the purpose other than the original one, generates deterioration that cannot be foreseen. This makes an additional level of uncertainty in recycling, which is unknown in planning manufacturing systems.

Alternate recycling plans for a product can be predicted by the original product design and the analysis of AND/OR graph. The plans mean all the enumeration of the disassembly options of a product. Assuming that the design attributes are known, and that information is complete, a preliminary plan can be done at the phase-out stage according to the product/subassemblies and parts condition. The grouping of products by preliminary data becomes an ineffective task. Considering all these aspects, recycling cells are formed.

3. The grouping Approach

In this section our aim is to present the grouping approaches for given disposal products. Considering design, process and usage attributes, we make cell formation with fuzzy C-means and fuzzy-ART algorithms which deal with the uncertainties by usage influences.

3.1 Grouping Attributes

At first, grouping is done by the nominal attributes of products, i.e., its design attributes. The design attributes, which are important for the recycling process include :

- country of origin(material parameters)
- year of production,
- size and weight,
- product type,
- material composition, parts and
- subassemblies,
- joining techniques,
- hazardous potential, etc.

A grouping based solely on the design attributes would be insufficient for the representation of the wide range of variant caused by usage influences. Furthermore, if we take into account the optional process attributes, it will lead to high computational complexity. Thus design, process and usage attributes are considered as recycling grouping attributes. Process and usage attributes reflect the following producer's phase-out conditions:

- Non-loosenable joint due to corrosion,
- missing/additional parts,
- deformation,
- breakage of parts, etc.

3.2 Fuzzy Clustering Approach

One common weakness with many conventional analytical method of cell formation is that they implicitly assume that the part families are mutually and collectively exclusive. In reality, it is clear that some products definitely belong to certain part families, but there exist parts whose lineages are much less evident. Thus the fuzzy cluster approach offers a special advantage over conventional clustering. It not only reveals the specific family to that a product belongs to, but also provides the degree or grade of each product family.

Assume that there are n products and p machines to grouped into c products families and corresponding recycling cells. Conventional clustering methods implicitly assume that disjoint part families exist in the data set; a part can only belong to one part family. The classification results can be expressed as a binary matrix. In many cases, part families are not completely disjoint; the separation of part families is fuzzy. Consequently, the concept of fuzzy subsets could offer an advantage over conventional clustering and could allow a representation of the degree or grade of membership of a part associated with each part family. In fuzzy clustering, the classification results can expressed as a matrix:

$$\mathbf{U} = \begin{bmatrix} u_{11} & u_{12} & \dots & u_{1n} \\ u_{21} & u_{22} & \dots & u_{2n} \\ \dots & \dots & \dots & \dots \\ u_{c1} & u_{c2} & \dots & u_{cn} \end{bmatrix} \quad (1)$$

such that

$$0 \le u_{ik} \le 1, i = 1,2,\dots,c; k = 1,2,\dots,n, \quad (2)$$

$$\sum_{i=1}^{c} u_{ik} = 1, k = 1,2,\dots,n \quad (3)$$

$$0 \le \sum_{i=1}^{c} u_{ik} \le n, i = 1,2,\dots,c. \quad (4)$$

Constraint (2) ensures that u_{ik} value can be fractional between 0 and 1, then kth part does not belong to ith part family. Therefore, a part could belong to several part families with different degree of membership. Constraint (3) ensures that each part will belong to one part family only. Constraint (4) ensures that each part family will consist of at least one part. Therefore, a part could belong to several part families with different degrees of membership.

3.2.1. Fuzzy C-mean Algorithm

The problem of fuzzy clustering has received much attention, and several algorithms for solving it have been proposed(Benzek 1981). In this paper, the generalized fuzzy c-mean(FCM) algorithm is applied to recycling cell formation. Since the number of possible U matrices that satisfy constraints (2) to (4) is infinite, an objective criterion to optimize the solution is required. The sum of square error function in any inner product form:

$$J_m(\mathbf{U}, \mathbf{v}) = \sum_{k=1}^{n}\sum_{i=1}^{c}(u_{ik})^m (d_{ik})^2 \quad (5)$$

In (5),

- $(d_{ik})^2 = \| \mathbf{x}_k - \mathbf{v}_i \|^2 = \sqrt{\sum_{j=1}^{p}(x_{kj} - v_{ij})^2}$ is the desired membership function:
- $\mathbf{x}_k \in \mathbf{X}$ where $\mathbf{X} = \{\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_n\}$ is a data set of n parts;
- $\mathbf{v} = \{\mathrm{v}_1, \mathrm{v}_2, ..., \mathrm{v}_c\}$ is the center of cluster u_i, i.e., the mean vector of the parts in the ith part family;
- $\mathbf{U} = [u_{ik}]$ is a matrix of fuzzy c-partition of $\mathbf{X}$;
- $\{u_{ik}\}^m = \{u_i(x_k)\}^m$

The solution procedure consists of eight steps:
(1) Choose the desired number of part family c, 1<c<n.
(2) Choose a value m, m>1, for the degree of fuzziness.
(3) Choose a membership function, $\|.\|$.
(4) Choose a value ξ for the stopping criterion.
(5) Choose an initial classification matrix, $U^{(0)}$.
(6) For iteration l=0,1,2,..., calculate the mean vector $\{v_i^{(l)}\}$ for the fuzzy cluster center

$$\mathbf{v}_i^{(l)} = \frac{\sum_{k=1}^{n}(u_{ik})^m \mathbf{x}_k}{\sum_{k=1}^{n}(u_{ik})^m}, 1 \le i \le c. \quad (6)$$

(7) Update $U^{(l)}$ using $\{v_i^{(l)}\}$ and:

$$u_{ik}(l) = \frac{1}{\sum_{j=1}^{c}\{\frac{dik}{djk}\}^{\frac{2}{(m-1)}}}, 1 \le k \le n. \quad (7)$$

(8) Compare $U^{(l)}$ to $U^{(l+1)}$. If $|u_{ik}^{(l+1)} - u_{ik}^{(l)}| \le m$, stop; otherwise, go back to step (6).

3.3. Fuzzy ART Algorithm

Fuzzy ART is an unsupervised category learning and pattern recognition network[5]. It incorporates computations from fuzzy set theory[6] into the Adaptive Resonance Theory(ART) based neural network. Fuzzy ART is capable of rapid, stable clustering of analog or binary input patterns. This network consists of two layers, the input(F1) and the output(F2) layers as shown in Fig.1. The number of possible categories can be chosen arbitrarily. At first step each category is said to be uncommitted. A category becomes committed after being selected to code an input pattern. Each input $\mathbf{I}$ is represented by an M-dimensional vector $\mathbf{I} = (I_1, ..., I_M)$, where each component I_i are in the interval [0, 1]. One set of weight vectors $\mathbf{W}_j = (w_{j1}, ..., w_{jM})$ is used to depict output category $\mathbf{j}$. Initially $w_{j1} = ... = w_{jM} = 1$, for all j. To categorize input patterns, the output nodes receive net input in the form of a choice function, T_j. The following function is used

$$T_k(\mathbf{I}) = \frac{|\mathbf{I} \wedge \mathbf{v}_j|}{\alpha + |\mathbf{v}_j|},$$

where is the choice parameter and is the fuzzy AND operator, defined as $(\mathbf{X} \wedge \mathbf{Y})_i = \min(x_i, y_i)$ and the definition of the norm of a vector $\mathbf{x}$

$$|\mathbf{X}| = \sum_{i=1}^{M} |x_i|.$$

The fuzzy AND operator is deduced from the Boolean AND operator. The category of output node with the highest value of T_j becomes nominated to claim the incoming pattern where

$$T_j = \max\{T_j : j = 1, ..., N\}$$

To accept the nomination of the category the match function should exceed the vigilance parameter; i.e.,

$$\frac{|\mathbf{I} \wedge \mathbf{W}_j|}{|\mathbf{I}|} \ge \rho$$

in the fast learning mode. If the first nominated category does not pass the similarity test, an uncommitted node should be committed to the input pattern.

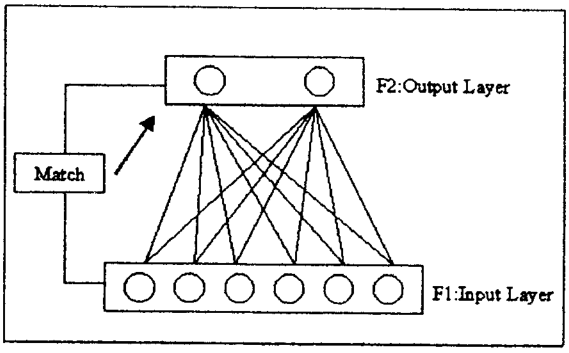

Fig 1. Simplified Representation of Fuzzy ART

The weight vector of winner category is updated as follow:

$$\mathbf{v}_j^{(new)} = \beta(\mathbf{I} \wedge \mathbf{v}_j^{(old)}) + (1-\beta)\mathbf{v}_j^{(old)}$$

Three parameters determine the dynamics of a Fuzzy ART network, 1)the choice parameter α> 0 2) the learning rate parameter, β∈ [0, 1] and 3) vigilance parameter, ρ∈ [0, 1].

3.3.1. The Modified Fuzzy ART Neural Network

The modified method uses fuzzy ART to generate a hierarchy of alternative clustering. Inputs are progressively merged until the fewest number of cells is formed or the desired number of cells is reached. The algorithm follows:

(0) Set k=0.

(1) For vigilance ρ_k and learning β_k group inputs by fuzzy ART. Call the resulting number of groups n_k and the elements of group i $\{e_{ji}\}$.

(2) Each cluster obtained in step 1 may have more than one member. So, form n_k new patterns (E_i, i=1,..,n_k) by merging scaling the numbers of each cluster, E_i = vector [sum(e_{ji})]. Rescale inputs.

(3) If either $n_k \leq N^*$ or n_k =1 stop. Otherwise, set k=k+1, Select vigilance $\rho_k \leq \rho_{k-1}$ and go to (1).(Notice that if we go back to step 1, we use a new fuzzy ART network in which $w_{j1}(0)=\ldots\ldots= w_{jM}(0)=1$.)
N^* = the desired number of clusters

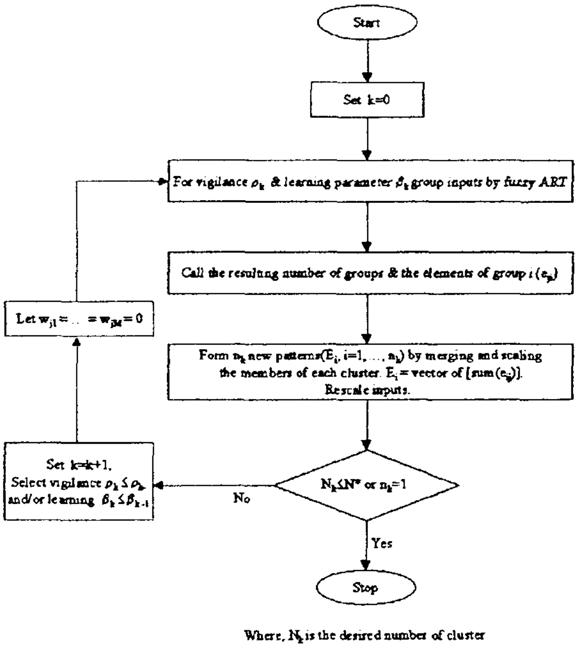

Fig 2. Modified Fuzzy ART Neural Network

In fuzzy ART, the number of clusters is determined by the values that the user chooses for parameter ρ and β, and the input matrix. This method uses fuzzy ART iteration.

4. A Case Study

We will show the application examples by disposal refrigerators, compared fuzzy clustering with fuzzy-ART performance in cell formation. A refrigerator consists of 8 modules : Cabinet, Base compressor, Motor, Louver, Box controller, Freeze door, Refresh door, others, and their components are one hundred approximately.

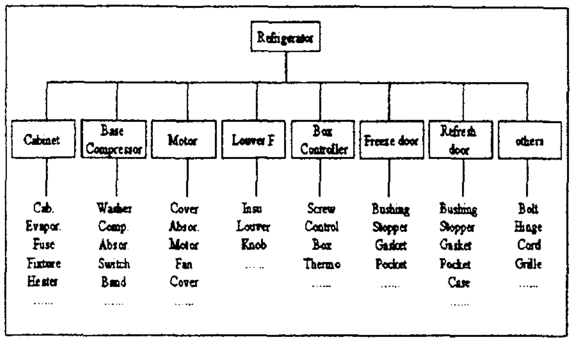

Fig 3. Structure of Refrigerator

For the purpose of protection against heat, CFC is injected to the refrigerator. Most countries regulate the CFC, because it is mainly caused of destroying ozone layer. In addition, certain materials of composing refrigerators pollute the ground and ground water, therefore hazardous materials are avoided to making refrigerator. New regulations prohibit the disposal of electronic appliances in landfill and adapt the "Take-back" concept. If they are disposed, they are deposited the special landfill and high disposal fees or forbidden disposal. Consequently, these regulations push companies to contribute themselves to new environmental conscious design and recycling of refrigerator in order to minimize the environment impact.

4.1. Recycling Selections

Recycling target is not a complete disassembly, but rather to find on optimum ; level which clearly benefits the recycling efforts. Disposal appliances will be reclaimed from the households by recycling center. The actual prehandling procedure basically consists of following stages.

- initial inspection, entry of item into the book keeping.
- separation, inspection, cleaning and repair of possibly reusable units and their redistribution through the recycling center etc.
- temporary storage and batching of appliances to be disassembled.
- drainage of CFC.
- disassembly of selected components to be reused as spare parts.
- disassembly and sorting of components made of materials which have a clearly defined individual recycling center.
- disassembly and sorting of potential hazardous elements and materials.
- crushing large steel, plastic structure
- storage and batching of appliances and disassembled fractions
- transportation to recycling companies, hazardous waste treatment plant, land fills etc.

There are five categories for recycling refrigerators. First, reuse of parts. Valuable parts like compressor, controller etc are reusable as many as possible. It needs use reliability using MTTF, MTTR, statistics and queuing etc. Second, reprocessing of parts and materials. Third, recycling of materials. Fourth, collecting CFC at liquid state and reprocessing. Fifth, waste treatment(landfill, incineration with special or regular).

4.2. Recycling Attributes

Owing to usage influences, the condition of disposal refrigerators varies in many influences, many uncertainties exist. In this paper, various recycling attributes are considered. For example, it is important whether CFC drainage or not. By the existence of CFC, the membership function of fuzzy characteristics is determined to 0 or 1. The next recycling attributes is the condition of outer case which is made from steel. It is seamed by rubber in order to prevent moisture and air from infiltrating into the outer case and not to rust . The condition of seam between outer case parts(both upper and lower) is determined to the degree of rust or cleanness of membership function. In addition to these recycling attributes, we consider twelve other attributes which are described by [0,1] states with fuzzy characteristics. (1) the condition of motor(cover, tapping, screw), (2) the condition of compressor(cover, tapping), (3) the condition of box controller(the condition of seal, housing joining, rubber cap), (4) the condition of gasket and rubber(R,F) (5) the condition of thermostat (6) the condition of screw tapping of each joining parts,(7) the condition of heater defrost, (8) the condition of evaporator (9) the condition of seal of heater defrost part(glass tube and silicon rubber), (10)the condition of fixture fuse part(leak test), (11)the condition of cabinet(leakage of rubber silicon, catalyst, refrigerant, water), (12)the condition of welding between parts.

4.3. An application Examples

As an illustration for the fuzzy C-mean and fuzzy-ART grouping procedure, we consider data collected by both a experiment of disassembly disposal refrigerators and a recycling center. These data is obtained twenty refrigerators from two companies. After carefully reviewing these data, and based on the experience of the expert, the twenty-one attributes were selected :

(1) length of life cycle(expected duration, year)
(2) take back(total cost and distance)
(3) type
(4) size(volume)
(5) total weight
(6) company
(7) the existence of CFC
(8) the degree of rust or cleanness of outer
(9) the condition of motor(cover, tapping, screw)
(10) the condition of compressor(cover, tapping)
(11) the condition of box controller(the condition of seal, housing joining, rubber cap)
(12) the condition of gasket & rubber of freezing door
(13) the condition of gasket & rubber of refreshing door
(14) the condition of thermostat
(15) the condition of screw tapping of each joining parts
(16) the condition of heater defrost
(17) the condition of evaporator
(18) the condition of seal of heater defrost part(glass tube and silicon rubber)
(19) the condition of fixture fuse part(leak test)
(20) the condition of cabinet(leakage of rubber silicon, catalyst, refrigerant, water)
(21) the condition of welding between parts.

4.4. Results of the application Examples

4.4.1. Fuzzy C-man Algorithm

The fuzzy c-mean algorithm was applied to these data set of c=3, m=2, |.|=Euclidean distance, and ξ=0.01. The $\mathbf{U}^{(0)}$ is obtained from the embodied heuristic. We get the final classification matrix is obtained by fourth iterations. Table 2 shows the clustered result.

Using final results, we can calculate the value of memberships for recycling cluster, and it means the degree of membership of each attributes associates with each part family. The larger the value, the higher the degree of the association.

This example illustrates how fuzzy c-mean clustering can help to design recycling cellular system. The final result could take into consideration the recycling workload balance, the material handling costs. Also, it is possible to evaluate the economic feasibility using the clustered result.

Products \ Attributes	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
1	0.6	0.5	1	0.3	0.4	1	1	0.2	0.8	0.7	0.5	1	1	0.8	0.7	1	0.7	1	1	0	0.8
2	0.7	0.8	0	0.2	0.3	0	1	0.5	0.0	0.5	0.7	1	1	0.0	0.6	1	0.0	1	1	1	0.6
3	0.5	0.6	1	0.6	0.7	0	0	0.3	0.8	0.7	0.6	0	1	0.8	0.5	0	0.8	0	0	0	0.2
4	0.8	0.4	0	0.5	0.6	1	1	0.5	0.8	0.0	0.3	1	0	0.7	0.6	0	0.7	0	1	1	0.9
5	0.7	0.5	1	0.4	0.5	0	1	0.2	0.0	0.7	0.5	0	0	0.8	0.7	1	0.8	1	0	1	0.8
6	1.0	0.3	0	0.5	0.6	1	1	0.5	0.8	0.8	0.2	1	1	0.6	0.5	1	0.6	0	1	1	0.7
7	0.9	0.7	1	0.5	0.6	1	0	0.4	0.7	0.6	0.0	1	1	0.7	0.3	1	0.7	1	1	1	0.9
8	0.6	0.5	1	0.6	0.7	1	1	0.1	0.8	0.0	0.5	0	0	0.0	0.2	0	0.0	0	0	0	0.3
9	0.7	0.6	0	0.3	0.4	1	1	0.2	0.7	0.7	0.3	1	0	0.7	0.3	1	0.7	1	1	1	1.0
10	0.8	0.5	1	0.5	0.6	0	0	0.2	0.8	0.8	0.3	1	1	0.8	0.8	1	0.8	1	1	0	0.8
11	0.7	0.7	0	0.4	0.5	1	0	0.4	0.9	0.7	0.5	0	0	0.0	0.2	0	0.0	1	1	1	1.0
12	0.9	0.4	1	0.6	0.7	1	1	0.5	0.0	0.5	0.5	1	1	0.8	0.7	1	0.8	0	0	0	0.2
13	0.9	0.4	0	0.4	0.5	1	0	0.2	0.8	0.9	0.4	0	0	0.5	0.1	0	0.5	0	1	1	0.8
14	0.7	0.5	0	0.5	0.6	1	1	0.3	0.0	0.7	0.0	1	0	0.6	0.5	1	0.6	1	1	0	0.9
15	0.8	0.6	1	0.4	0.5	0	1	0.2	0.7	0.0	0.5	1	1	0.8	0.7	1	0.7	1	0	1	0.6
16	0.7	0.7	1	0.5	0.4	0	1	0.0	0.8	0.6	0.3	0	0	0.0	0.3	0	0.0	0	0	0	0.1
17	0.8	0.6	0	0.3	0.4	1	1	0.1	0.0	0.6	0.5	0	1	0.5	0.4	1	0.7	1	1	1	1.0
18	0.7	0.5	1	0.2	0.3	1	0	0.0	0.6	0.0	0.5	1	1	0.8	0.8	1	0.8	1	1	1	0.9
19	0.6	0.6	0	0.3	0.4	0	0	0.2	0.5	0.9	0.4	0	0	0.0	0.1	0	0.0	0	0	0	0.2
20	1.0	0.5	0	0.4	0.5	1	1	0.1	0.0	0.7	0.5	1	1	0.9	0.8	1	0.7	1	1	1	1.0

(1) length of life cycle(expected duration, year),
(2) take back(total cost and distance),
(3) type,
(4) size(volume),
(5) total weight,
(6)company,
(7) the existence of CFC,
(8) the degree of rust or cleanness of outer,
(9) the condition of motor(cover, tapping, screw),
(10) the condition of compressor(cover, tapping)
(11) the condition of box controller(the condition of seal, housing joining, rubber cap),
(12) the condition of gasket and rubber of freezing door, (13) the condition of gasket and rubber of refreshing door
(14) the condition of thermostat, (15) the condition of screw tapping of each joining parts
(16) the condition of heater defrost, (17) the condition of evaporator
(18) the condition of seal of heater defrost part(glass tube and silicon rubber)
(19) the condition of fixture fuse part(leak test)
(20) the condition of cabinet(leakage of rubber silicon, catalyst, refrigerant, water)
(21)the condition of welding between parts

Table 1. Data for the numerical example

Recycling Cells	Products
Recycling Cell #1	1, 4, 6, 7, 9, 12, 20
Recycling Cell #2	2, 5, 11, 14, 15, 17, 18
Recycling Cell #3	3, 8, 10, 13, 16, 19

Table 2. Clustered result of numerical example

4.4.2. Fuzzy ART Algorithm

The fuzzy ART algorithm has several shortcomings of the original algorithm. First, it can suffer from category proliferation. Second, practical cell formation problem dictates the need of more flexible, scaling issue. In order to overcome these difficulties, the add method is used and choose the vigilance parameter(ρ) and learning parameter(β) properly.

Step 1 : Set $\beta = 0.5$, $\rho = 0.5$

Recycling Cells	Products
Recycling Cell #1	1, 4
Recycling Cell #2	2, 11, 14, 16
Recycling Cell #3	3, 10, 19
Recycling Cell #4	5, 9, 18
Recycling Cell #5	7, 8, 15
Recycling Cell #6	12, 13, 20
Recycling Cell #7	6, 7, 14

Table 3. Members of each recycling cell after first step

Step 2 : Set $\beta = 0.5$, $\rho = 0.3$

Recycling Cells	Products
Recycling Cell #1	1, 4, 9, 12, 20
Recycling Cell #2	6, 7, 14, 18
Recycling Cell #3	2, 5, 15,17
Recycling Cell #4	3, 10, 11, 13
Recycling Cell #5	8, 16, 19

Table 4. Members of each recycling cell after second step

Step 3 : Set $\beta = 0.5$, $\rho = 0.2$

Recycling Cells	Products
Recycling Cell #1	1, 4, 6, 7, 9, 12, 20
Recycling Cell #2	2, 5, 11, 14, 15, 17, 18
Recycling Cell #3	3, 8, 10, 13, 16, 19

Table 5. The final solution using fuzzy-ART

Here, we stop the process since the goal value equals to the solution to the fuzzy c-mean algorithm.

Analyzing these results, it is an option that a user wants to definitely have N* clusters. Otherwise, when the algorithm stop at step 3, the user can choose the best solution among all the generated clusters.

5. Evaluation

The performance of modified fuzzy ART algorithm is better than that of fuzzy c-mean algorithm compared to storage, processing time and other performance measures. Furthermore, the user can choose the best solution among the clusters generated by fuzzy ART. According to the results of experiments, the cellular recycling system is useful to make the part families of products grouped into a single disassembly line or machine cell and can evaluate the value at each cell of disposal products. The objectives for evaluation of worn-out products maximize the recycling, economic profits and minimize the environmental impacts. For these objectives, we apply two evaluation methods to recycling cells. The one is ABC evaluation method. Disposal refrigerators are grouped into three cells by fuzzy c-mean and fuzzy ART algorithms. From the final results, we could get the relation among cell, products and attributes. Thus it is possible to evaluate the recycling cells in consideration of value of attributes in each cell. The main idea of ABC evaluation method is to determine the rough identification for each clustering cell. Recycling cells are divided into three categories for reuse(category A), reprocessing(category B) and recycling(category C). Each category will be divided into three categories again. Now we can estimate the value of each clustering cell in detail. The other method is the estimation system based on database for disposal product. The most frequent and time consuming activities in recycling operation is to determine several things : recycling parameters of a part under process condition i.e., fatigue, damages, contamination etc., estimating the cost of reuse and reproducing the part. Database should involve all information i.e., materials, process constraints and parameters etc. about the objects. Each factor based database must be estimated in the system. This system can assess the value of each recycling cell and determine the recycling profitability. Eventually, these information are useful to make decision for recycling .

6. The Economic and Environmental Evaluation for Disassembly and Recycling

In this paper, recycling cells are formed using fuzzy C-Mean algorithm and modified fuzzy ART neural network. This section is illustrated that the integration of product design and the disassembly process to facilitate economical material recycling and to decrease environmental impact of products in recycling cells by economic-environmental evaluation analysis and disassembly sequence generation of products in recycling cells design for environment(DFE)

6.1. Economic-Environmental Index

In this paper, economic-environmental index model which can be considered economic and environmental respect simultaneously and same criteria are suggested.

6.1.1 Economic Index

Economic index provides an indicator of the profitability of material and component recycling compared to alternative options such as disposal or storage. Cost estimates are generated for recycling, reprocessing and reuse versus disposal of individual components. Unprofitable recycling attributes and disassembly operations are abandoned from further analysis. Material recycling value are maximized from the available material markets., so an optimal economic index is affixed to each recycling attributes and disassembly operation under consideration in the recycling process.

6.1.2 Environmental Index

Environmental index provides an indicator of the environmental impact of products(both material and component). There are some method for environmental impact assessment that are creating environmental metrics. The examples are followed :

1)Process-level metrics,

2)Facility-level metrics,

3)Ecological-level metrics

- Load-based Evaluation,
- Mass-based Evaluation,
- Effect-based Evaluation.

Environmental impact has to integration of environmental assessment with all manufacturing process. An optimal environmental index is affixed to each recycling attributes and disassembly operation under consideration in the recycling process. Environmental index which is a indicator of the environmental impact of products(both material and component) are converted to cost. Environmental value of hazardous emissions of all process(emissions through the three media - air, water and solid) are converted to cost by purification - catalyst, counteraction etc. All environmental potential are also converted to cost. Cost evaluation of purification stream in manufacturing process which is ranging from component making to product assembly. Eventually, environmental index is converted to cost, so environmental and economic index are comparable in same criteria.

6.3 Assumption of Economic-Environmental Index Model

The following method of economical-environmental analysis is most appropriate for improving the economic-environment associated with disassembly of products for recycling, reprocessing and reuse. The data are gained from recyclers, manufactures and environment experts, etc. The scope of economic-environment index analysis is bounded within these parameters which are recycling value, disassembly cost, disposal cost and environmental value etc. Therefore the calculated parameters which are material value, labor rates and disposal rates(landfill/incineration with regular or special), environmental value, uncertainty in data, hazardous potential, etc are known by recyclers and environmental experts.

6.4 The Economic-Environmental Evaluation Model

Disassembly process of product in recycling cells is recycled the component, eliminated hazardous component and disposal. The option of recycling is determined its cost and benefits and that of environment is decided its effect and cost. The present recycling values are disposal cost of the component and environmental burden. The possibility that disposal of the component is the best alternative but disassembly is still required that is the value of disassembly, disposal and environmental burden. Developing economic-environmental index is to assess the possible trade-off considerations between the above parameters.

The economic-environmental evaluation model is presented as following.

- $V_R = V_m \times W \times Deterioration\_factor[0,1] + C_{EB,R}$ (8)
- $C_{EB,P} = [C_{P,A} \times W] + [C_{P,B} \times W]$ (9)
  - · Process A : raw material → component process,
  - · Process B : component assembly process,
- $C_d = time \times C_L$ (10)
- $C_{dp} = C_{fee} \times W$ (11)
  - · landfill with regular / special,
  - · incineration with regular / special,
- $BL_{V_R} = V_R + C_{EB,P} - C_d + C_{dp}$ (12)
- $BL_{dp} = -C_{dp}(Disposal\_Cost\_Only)$ (13)
- $BL_{dp} = -C_{dp} - C_d(Disposal\_Cost + Disassembly\_Cost)$ (14)

where, V_R : Recycling Value
V_m : Material value($/mg)
W : Weight(mg)
$C_{EB,R}$: Environmental burden value of Recycling
$C_{EB,P}$: Environmental burden value of Process
$C_{P,A}$: Cost of Process A
$C_{P,B}$: Cost of Process B
C_d : Cost of Disassembly
C_L : Cost of Labor
C_{dp} : Cost of Disposal
C_{fee} : Cost of Disposal Fee
BL_{VR} : Benefit-Loss of Recycling Value
BL_{dp} : Benefit-Loss of Disposal Value

Equation (12), (13) and (14) are quantitative indices. The disassembly process of product in recycling cell may be optimized using three decision elements assess the trade- off between recycling, disposal and environment burden of individual components. Applied decision making for recycling, reprocessing and reuse of disposal products in recycling cell is focused on applying the use of the economic-environment indices to product-based disassembly analysis in recycling cells.

Equation (12), (13) and (14) are generated for each disassembly operation of disposal products to aid the design team in the decision of design for environment(DFE) such as recycling of its total cost and benefits, environmental burden of its effects and cost, disposal, disposal and disassembly. These three elements are assessed in a hierarchical manner.

Disassembly Profit is determined next equation.

- $V_R + C_{EB,P} + C_{dP} \geq C_d$ (15)

Generally, when equation (15) is satisfied, disassembly and recycling is beginning. Clustering for maximum recycling value and minimum environmental impact is made to maximize the gain from specific material markets and to minimize the environmental impact of materials. The cost-benefit analysis to recycling and disposal of disassembly is decided by cost-benefit analysis to environmental burden of products. The criterion of clustering for maximum recycling value and minimum environmental value is the most appropriate for improving the economic and environment associated with the disassembly process in recycling cells rather than being considered an element of design.

The economic-environmental index model is to optimal disassembly sequence generation of disposal products in each cell and to form evaluation matrix considering recycling, environment impact and disposal. Matrix is formed by cost of economic and environment factors according to disassembly operations. Formed matrix can be reduced the criteria for search space and be applied the example for optimal disassembly sequence generation by objective function and constraints.

7. Conclusions

An approach to the design of cellular recycling systems for disposal products has been presented.

Considering of uncertainties of disposal products, the part families were formed by design, process and usage attributes. Grouping is done by fuzzy C-mean and modified fuzzy-ART algorithms described by membership functions to what degree a special group belongs to a certain family.

Application examples were illustrated by disposal refrigerators, compared fuzzy clustering with modified fuzzy-ART performance in cell formation. It is shown that the performance of modified fuzzy-ART algorithm was better than that of fuzzy C-mean algorithm.

The two evaluation methods for recycling cell were applied. We could determine the rough identification for each clustering cell by ABC evaluation. The estimation system based on database could assess the value of each recycling cell and determine the recycling profitability.

It was suggested a systematic procedure for determining the most economical and environmental level of product disassembly and the corresponding sequence of disassembly operations which maximize profits and minimize environmental impacts of disposal products in recycling cells. The economic and environmental analysis evaluates the recycling and disposal components using a number of economic and environmental indicators.

Eventually, it has been shown that the proposed approach could deal with the recycling cell formation which was classified disposal products and evaluate the disposal products in each recycling cells considering economic and environmental factors in order to improving the disassembly process by reducing disassembly times, maximizing profitability and minimizing environmental impacts.

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