APPLICATION OF ARTIFICIAL INTELLIGENCE TOOLS TO THE CLASSIFICATION OF STRUCTURAL MODULES

Galina Setlak, Tomasz Kożak

Abstract: *The purpose of this paper is to present the fundamental algorithms and procedures by which processes of clustering and classification of elements, assembly units and parts of installed product devices are carried out in the system of computer-aided design of modular technology of assembly.*

There will also be presented a basic tool that has been used for classification of structural modules - the self-organizing Kohonen network.

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ACM Classification Keywords: *I. Computing Methodologies, I.2 Artificial Intelligence, J. Computer Applications, J.6 Computer Aided Engineering*

Introduction

Modular technology of assembly can be defined as a set of technology modules that cover specific assembly operations, which are structurally enclosed part of technological process in the manufacture of some object (product or its component, structural element). The technological module of assembly is considered as a set of integral operations of major and minor assembly, which is carried out in a specific sequence at one position and is characterized by its use of a specific set of tools for combining surface, components, subassemblies, assemblies [Szabajkowicz, 2000].

Designing of modular technology is an appropriate choice of technological modules, their task is to work out an applicable structural module of the product. Therefore, the modular process combines the advantages of both the separate process which takes into account the characteristics of the specific unit, as well as features of group process. That enables connecting different units in the groups and makes the process flexible. In particular, it allows to minimize various technological means of the assembly, as well as avoiding duplication of work as regards the technological preparation of production [Szabajkowicz, 1998]

Currently, the modular technology is the basic and the most promising direction of development of modern assembly techniques, it is based on the principles of group technology manufacture. In recent years, the flexible module assembly design is the main problem of scientific research centres, as well as design offices of leading manufacturing companies. This design is performed on the basis of modular technology of assembly [Szabajkowicz, 2000].

The purpose of this paper is to present the fundamental algorithms and procedures by which processes of clustering and classification of elements, assembly units and parts of installed product devices are carried out in the system of computer-aided design of flexible, technological modules of assembly.

There will also be presented a basic tool that has been used for classification of structural modules - the self-organizing Kohonen network.

Classification and grouping issues of the modular technology of assembly

While designing products for assembly using modular technology, the principle of structural modularization of the product needs to be applied. This means that when designing assemblies, subassemblies and components, the following steps should be followed:

- specify and isolate parts as well as base areas,
- use the typical patterns and methods of assembly,
- strive to match the new product to such construction to be able to use existing structural modules and technological modules.

In the process of designing flexible assembly systems based on modular technology of assembly, operations for classification and clustering are performed repeatedly, at different stages, namely:

- classification of objects into groups and subgroups of elements,
- classification of assembly units, which are technologically similar
- extracting from the technological schemes, autonomous, integrated assembly actions, followed by grouping separate assembly units, depending on instrumentation equipment on which these actions could be performed;
- grouping of elementary modules and selection of appropriate, possible options of the technological modules and structural modules;
- classification of elementary, technological modules of the assembly [Setlak, 2003].

In order to classify and group the assembled components, apart from manufacturability other basic structural features are highlighted such as construction, ways of orienting and basing of parts. The projects concerning the planning technological processes of assembly present different methods of the parts classification of assembled products to develop a typical, unified, structural modules.

Among others, in the given study there will be used classification of the combined elements, taking into account their functional characteristics [Szabajkowicz, 2000] (isolating base parts, connected parts and fasteners) and classification of the part which takes into account the characteristics such as shape, variety of shapes, symmetry, way of orienting or arranging them in terms of the complexity of their automatic orienting.

Using the appropriate method of classification of installed products and components, it is possible to develop common technological modules of assembly and choose the typical technical equipment and assembly instrumentation [Rampersad, 1997].

For this purpose, the following classification criteria have been chosen:

- structural and technological use of elements (this criterion divides the assembled elements into groups),
- repeatability in the construction of objects (distinguishes typical and unique parts),
- shapes of the components of assembled product (division on types: shafts, wheels, bushings, brackets, etc.).

Similarity research methods

The main methods used to study the similarities of elements of the designed products and assembly units are classification and clustering [Setlak, 2003].

Classification is the assignment of an object to a standard class on the basis of selected characteristics. The process of classification may occur when classes will be defined before the division, to which set of input will be distributed. The classification also means assigning the input images to proper sets, defined as classes [Knosala, 2002].

Methods of classification:

- standard method,
- image recognition based on patterns of classes,
- image recognition based on sequence of learning,
- method of real characteristics.

The standard classification is characterized by the process of division into classes, implemented on the basis of the division of value of characteristic features. Before the classification, there should be selected those features that are used to attain the objectives of the classification process. This is an important aspect, because the wrong choice of features describing the tested items may result in erroneous classification outcomes, while very large number of them can demonstrate that some of them do not relate to the classification aim [Knosala, 2002]. The real characteristics method indicates only initial recognition, which determines to which (general) class the given item belongs.

It is also worth mentioning that in the case of image recognition, the concept of classification is defined as the relation describing a destruction of sets of items into the collection of equivalence classes corresponding to individual images. In the process of recognition, the most important issue is to calculate the membership function.

Checking the similarity of the structural modules can provide information that are relevant to the organization of industrial production. This information can be obtained by clustering similar items.

Clustering is the original action in relation to the classification, since it leads to the definition of classes. Clustering takes place when the number of groups is not specified and range of characteristics is not known before the division of the input set. Clustering means bringing together similar objects and separating different. Clustering is the process of splitting a set of elements into subsets without previous arrangement what will be the bands of characteristics and the number of these subsets.

In determining the subsets, called clusters, two basic conditions have to be accomplished:

- data which belongs to the same cluster should be most similar,
- data which belongs to different clusters should be most dissimilar (varies to the greatest extent).

For this purpose, the similarity research methods are used. Without the application of these methods, the full production cycle of element involves a design and construction process, preparation of production and manufacturing. In many cases, the method of studying the similarity can allow a simplification of these processes, or even eliminate some of them, when a new element is taken into account (one of these three cases may occur):

- eliminating the need to design a new element occurs in the case when the newly designed element is identical to that which has already been produced,
- situation where a few changes have to be made, while a new item is being produced, it happens when the newly designed element has common features with the one which was produced before,
- if the newly designed element does not have common features with the one produced before, then a complete structural and technological documentation has to be done.

This method allows to avoid certain limitations associated with the process of classification. It is not always possible to determine the values division of characteristics that describe the class, moreover, classification systems can be created in two directions, as a specialized tools for analyzing very small group or more universal systems, but of little opportunity to study similarity. The classification depends on the criteria, due to which it is maintained. Method of clustering is devoid of all these restrictions, because the criteria for division into groups take place automatically, on the basis of features detected in the analyzed element.

In order to fully demonstrate the methods of studying similarity, the exact duties of each of the methods ought to be specified (apart from the general presentation).

The study of similarity should consider such problems as:

- define the similarity between elements,
- find similarity of a given element to the set of classes,
- use the data to find similar elements [Knosala, 2002].

Currently, the methods of artificial intelligence are used to solve the tasks of classification and clustering, including artificial neural networks and fuzzy clustering algorithms [Setlak, 2000].

Application of Kohonen neural networks for clustering of structural elements

Kohonen networks are one of the basic types of self-organizing networks. The capacity of self-organization gives completely new opportunities - an adaptation to previously unidentified input data of which very little is known. This seems to be a natural way of learning. Kohonen networks are synonym of the entire network group in which learning takes place by a self-organizing competitive method. It involves giving the network input signals, and then selecting through the competition a victorious neuron that best corresponds to the input vector.

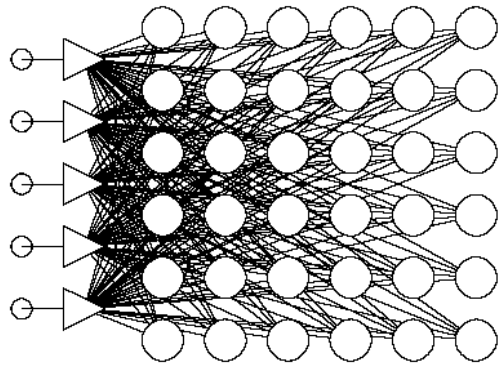

Figure. 1 Kohonen network
[Zurada, Barski, Jędruch, 1996]

The exact pattern of Kohonen neural network architecture presents the following figure (Fig. 1).

The structure of neural network is very important issue. A single neuron is very simple mechanism and thus able to do a little. Only a combination of many neurons enables to carry out any complicated actions [Zurada, Barski, Jędruch, 1996].

The aim of such networks is clustering or classification of input patterns. This is done in accordance with the principle that similar input signals raise the same output unit of neural networks. Algorithm, from which a whole class of networks was called are self-organizing Kohonen maps. The network copies the input in the form of one-dimensional or multidimensional vector of characteristics into the one-dimensional or multidimensional output [Kohonen T,1990].

$$w_{i^*j}(t+1)=w_{i^*j}(t)+\eta(t)(x_j^{\mu}-w_{i^*j}(t)), \tag{1}$$

where:

$\eta(t)$ - network learning factor,

t - iteration's number,

x_j^{μ} - j's value of this feature μ-this pattern of input,

w_{ij} - weight value of input connection of j node with i output neuron.

Kohonen proposed two types of neighborhood: rectangular and Gaussian.

$$\begin{cases} 1 \;\; for \quad d(i,j^*) \le \lambda \\ 0 \;\; for \quad d(i,j^*) > \lambda \end{cases} \tag{2}$$

$$\lambda(i,i^*) = exp\left(-\frac{d^2(i,i^*)}{2\sigma(t)^2}\right) \tag{3}$$

Gaussian function is the most often applied neighborhood function. It gives a good convergence of Kohonen algorithm [Knosala ,2002].

Distance d_j is calculated to the input signal for all neurons and the best neuron is selected on the basis of the formula:

$$j^* = \arg\min_j d_j = \arg\min_j \sum_{i=0}^{N-1}\left(x_i(t)-w_{ij}(t)\right)^2 \tag{4}$$

where x_i – i's input node in a time moment t,

$w_{ij}(t)$ — synaptic weight from i's input element to j's neuron in a time moment t.

Instruments must be standardized before neural network learning. For this purpose, input vectors are normalized as follows:

- redefinition of the input vector components:

$$x_j \leftarrow \frac{x_j}{\sqrt{\sum_{j=1}^{N} x_j^2}} \qquad (5)$$

- increase the input space size by one, i.e. RN → RN 1, where

$$\sum_{j=1}^{N+1} x_j^2 = 1 \qquad (6)$$

In the process of neural network learning, in accordance with the Kohonen algorithm, the adaptation of synaptic value weights of neural network is performed in such a way, that the error is minimized, it is given by the formula:

$$\delta\{w_{ij}\} = \frac{1}{2}\sum_{ijk} M_j^{\mu}(x_j - w_{ij})^2 = \frac{1}{2}\sum_{\mu}\left|x^{\mu} - w_{j^*}\right| \qquad (7)$$

where M_j^{μ} is a checking function, which checks whether pattern x^{μ} activates the neuron as the winning unit j* and is calculated by the formula:

$$M_j^{\mu} = \begin{cases} 1 & if \quad j = j_{\mu}^* \\ 0 & \end{cases} \qquad (8)$$

In order to increase the convergence of the basic Kohonen network learning algorithm, it was modified in the algorithm "winner takes most." In the weight algorithm, successful neurons and neighbouring neurons are updated according to the so-called neighbourhood function, which on the one hand, acts as arresting connections and on the other hand, activates the output of neighboring neurons.

Based on the relation that the Gaussian function is mostly used neighborhood function depending on η (t), Kohonen rule increases the function value in all dependencies, until it reaches the minimum. Therefore, the learning rate η (t) is very important:

$$\eta(t) = \eta_0 \left| e^{-\alpha t} cos(\frac{\pi}{2T_z} K(t)t) \right| \qquad (9)$$

To investigate the accuracy of networks learning, inequality coefficient of neurons was introduced, which is based on the nodes of input and output connection weights. This factor's task is to analyze changes of the vector weight in the vicinity of each of the output nodes in relation to the neighbouring vectors. When the coefficient value is less, then the input object is better recognized.

In order to improve the quality of the clustering process, modified learning algorithm can be applied, in which new forms of neighborhood function were used $\Lambda(t)$ radius of neighbourhood $\lambda(t)$ and learning rate $\eta(t)$. A function of an error is used for analysis of the speed dynamics of network learning $\varepsilon(t)$ and a measure of inequality of the network $\theta(t)$. The most important function of the learning process in the Kohonen algorithm is the neighbourhood function. It decides about the adaptation of winning node weights and nodes in the neighborhood. As it has already been mentioned, Kohonen algorithm has many limitations, such as:

- achieving local minimum by a network,
- occurrence of dead nodes,
- low speed of learning.

In order to analyze the behavior of the network through learning processes and to explore its optimal parameters, the principal criteria for evaluation need to be defined. The criteria for these neural networks are:

- the criterion of minimum error or maximum objective function,
- the criterion of maximum organization of the network or minimum not clear.

These criteria set the end of the learning process and optimization of the learning parameters, applied to the problem [Knosala, 2002].

Conclusion

The basis for the design of flexible assembly modules are the classification and clustering of components, assembly units and parts of assembled products. Selection of appropriate methods and tools for solving these tasks is particularly important in the design process.

The paper presents issues which are only a part of the carried out studies, they require additional testing and even wider range of experience, especially practical applications.

On the basis of the presented algorithm, it can be concluded that some artificial intelligence tools for grouping structural components - Kohonen neural networks give very promising results. In order to perform more detailed studies, there should be developed algorithms which automatically record geometric features of structural components in a form of input matrix of features for the neural network. It is also required to have tools and methods for the detailed interpretation of the results of neural network work.

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