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Comparison of visualization of optimal clustering using self-organizing map and growing hierarchical self-organizing map in cellular manufacturing system

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ABSTRACT

The present research deals with the cell formation problem (CFP) of cellular manufacturing system which is a NP-hard problem thus, the development of optimum machine-part cell formation algorithms has always been the primary attraction in the design of cellular manufacturing system. In this proposed work, the self-organizing map (SOM) approach has been used which is able to project data from a high-dimensional space to a low-dimensional space so it is considered a visualized approach for explaining a complicated CFP data set. However, for a large data set with a high dimensionality, a traditional flat SOM seems difficult to further explain the concepts inside the clusters. We propose one such possible solution for a large CFP data set by using the SOM in a hierarchical manner known as growing hierarchical self-organizing map (GHSOM). In the present work, the two novel contributions using GHSOM are: the choice of optimum architecture through the minimum pattern units extracted at layer 1 for the respective threshold values and selection. Furthermore, the experimental results clearly indicated that the machine-part visual clustering using GHSOM can be successfully applied in identifying a cohesive set of part family that is processed by a machine group. Computational experience specifically with the proposed GHSOM algorithm, on a set of 15 CFP problems from the literature, has shown that it performs remarkably well. The GHSOM algorithm obtained solutions that are at least as good as the ones found the literature. For 75% of the cell formation problems, the GHSOM algorithm improved the goodness of cell formation through GTE performance measure using SOM as well as best one from the literature, in some cases by as much as more than 12.81% (GTE). Thus, comparing the results of the experiment in this paper with the SOM and GHSOM using the paired *t*-test it has been revealed that the GHSOM approach performed better than the SOM approach so far the group technology efficiency (GTE) measures of performance of the goodness of cell formation is concerned.

1. Introduction

The cellular manufacturing system (CMS) is a relatively self-contained and self-regulated manufacturing approach that involves the grouping of machines and parts such that each part family is processed by machine cell. The benefits of CMS are to reduce lead time, setup time, material handling and work in process, and also to improve quality, machine utilization, simplified scheduling, space utilization, improved human relations, etc. The benefit of productivity improvement and lead time reductions to MRO operations has also been reported from the application of CMS [53].

The strategy of CMS is to process a family of parts through a dedicated cell, thereby gaining the advantages of a mass production system. The principal problem in designing a CM system is the cell formation problem (CFP) which is solved by decomposing the system into subsystems which are as autonomous as possible so that the relations of the machines and parts inside subsystems are maximized and the interactions among machines and parts of other subsystems are reduced to the extent that possible.

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The cell formation problem is an NP-hard problem [1,2], therefore, the development of optimum machine-part cell formation algorithms has been always the primary attraction in the design of cellular manufacturing system, and thus wide-ranging research has been existed in the literature. During the last few decades a large number of authors have reviewed extensively of the work on CMS [3–5,57,64].

Over the last decade, researchers have presented many cell formation methods to solve CF problem. These methods can be broadly classified as: Mathematical programming methods [6–9,61], Heuristic [10–12] and Metaheuristic algorithms [13–20,54–56], artificial intelligence methodologies [21–27].

Unsupervised learning techniques are a subset of neural network fields which enable the identification and grouping of machine-part clustering patterns without having seen that pattern before or having its key characteristics described; to do this a similarity measure is defined and the groups are clustered together into a lower dimensional space [28]. Self-organizing map (SOM) of unsupervised neural network are one such technique which enable mapping of data with a large feature set into 2D space [29,59]. SOM has been effectively used to solve CFP of CMS [28,30–34] by applying traditional SOM successfully through visual understanding of Part-Machine Incidence Matrix (PMI) based data structure related to various production factors. In the earlier work of [34] the quality of the trained SOM has been evaluated by the quantization error and topographic error calculated for various map sizes which has strong influence on the quality of machine-part cell formation. It is also evident from the literature that there is no definite rule for determining optimal SOM map size which is also one of the serious lacunas of traditional SOM [34,60]. In the context of the present work the following limitations of traditional SOM are being taken into account while applying to cell formation. The limitations are summarized as follows:

- Firstly, the size and arrangement of the maps have to be established prior to training.
- Secondly, they are not able to represent hierarchical relationships of the CFP data.
- Thirdly, it is quite difficult to comprehend the clustering of cell formation from a large size output SOM map applied to huge PMI matrices.

Therefore, the growing hierarchical self-organizing map (GHSOM) [35] was proposed to solve the above weaknesses. This type of SOM approach has a hierarchical architecture divided into layers consisting of different SOMs whose size is automatically determined during the unsupervised learning process.

The GHSOM approach was implemented successfully in creating a topology-preserving representation of the topical clusters of the machine-part cell formation by the present author for the first time [36]. But the proposed work will differ from the earlier ones by experimenting and analyzing the convergence criteria, computation time, quantization error for exploring a suitable GHSOM model applied to cell formation problems so that best optimal visual clustering of machine-part cell formation will be achieved.

The objectives of the proposed work are:

(1) to determine the impact of two parameters (depth and breadth) to obtain the best optimal GHSOM map orientation and topology preservation.
(2) to understand of the hierarchical clustering improved by applying different visualization techniques to the maps at each layer so that visual clustering information can be utilized by the manager in order to obtained optimum machine-part cell.
(3) to compare the network architecture and performance (both computational time and quantization error) of both SOM and GHSOM for visual clustering of machine-part cell formation.
(4) to analyze the criteria of choice of visual clustering of machine-part cell formation using traditional SOM and GHSOM that use the information on the sequence of operations of the different part types.
(5) to verify the efficacy of our work, we first conduct an experiment using the proposed SOM and GHSOM models. Then apply both models to selected CFPs from literature to calculate the goodness of cell formation and compare them with the available best results using other approaches from literature.

1.1. Cell formation problem

The present work has been considered one real life production factors, such as operation sequence in the problem formulation which is an ordering of the machines on which the part is sequentially processed [37]. In the machine-part incidence matrix (MPIM) the operation sequence is represented as the value, a_{ij}. Inside the matrix the operational sequence of part j to be processed by machine i otherwise zero.

Grouping of parts into families and machines into cells results in a transformed matrix with diagonal blocks where sequence of operations (ordinal numbers 1, 2, 3,. . .) occupy the diagonal blocks and zeros, the off-diagonal blocks. The output diagonal blocks represent the machine-part cells. An odd sequence number lying outside the diagonal blocks indicates processing of a part outside its cell, requiring inter-cell movement, which is undesirable. Preferably, the all the operations of the parts should be completed within the cell to which they belong. The objective of the cell formation problem is thus to rearrange the PMI to minimize the number of exceptional elements, provided a block-diagonal structure exists. Thus, in general, best result for a machine-part clustering is desired to satisfy the following two conditions:

(a) To minimize the number of 0s inside the diagonal blocks (i.e., voids);
(b) To minimize the number of ordinal numbers (sequence) outside the diagonal blocks (i.e., exceptional elements).

The remainder of this paper is organized as follows. In Section 2, we describe the visual clustering approach of both the proposed self-organizing map and growing hierarchical self-organizing map algorithms. The goodness of cell formation through a performance measure known as group technology efficiency has also been discussed in this Section 2. Section 3 presents an experiment with a numerical example using both SOM and GHSOM visual clustering models. In Section 4, we examines the computational results and findings based on structure of visual clustering maps of both the proposed applied models and show how they confirm the efficacy of this research. A detail discussion has been made in the next Section 5 and finally, we conclude this paper and describe our future work in Section 6.

2. Methodology

Visual cluster analysis, as the term implies, is a method of information visualization and cluster analysis techniques which is gaining significant relevance in many industrial and research areas for visualizing complex and high-dimensional data. It has been shown that visualization allows for verification of the clustering results [39]. The SOM maps are often proposed for this task since they generate a mapping from the high-dimensional input space to the low-dimensional structure used as network topology.