A Flexible Classification Method for Evaluating the Utility of Automated Workpiece Classification System

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In group technology, workpieces are categorised into families according to their similarity in design or manufacturing attributes. This categorisation can eliminate design duplication and facilitate the production of workpieces. Much effort has been focused on the development of automated workpiece classification systems. However, it is difficult to evaluate the utility of such systems. The objective of this study was to develop a benchmark classification system based on global shape information for use in evaluating the utility of workpiece classification systems. A classification system has a high level of utility if its classification scheme is consistent with users' perceptual judgement of the similarity between workpiece shapes. Hence, in the proposed method, the consistency between a classification system and users' perceptual judgements is used as an index of the utility of the system. The proposed benchmark classification has two salient characteristics:

1. It is user-oriented, because it is based on users' judgements concerning the similarity of the global shape of workpieces.
2. It is flexible, allowing users to adjust the criteria of similarity applied in the automated workpiece classification.

The development of this classification consisted of three steps:

1. Gathering row data on global shape similarity from a group of representative users and modelling the data by fuzzy numbers.
2. Developing benchmark classification for various similarity criteria by using fuzzy clustering analysis.
3. Developing indices for evaluating the appropriate number of workpiece categories and homogeneity within each group.

The applicability of the benchmark classification system in evaluating the utility of automated workpiece classification systems was examined.

Keywords: Automated workpiece classification; Benchmark classification; Flexible classification method; Group technology

1. Introduction

Workpiece coding schemes are widely used in the implementation of group technology (GT) to classify workpieces according to the similarity of their design and manufacturing attributes. The results of workpiece classification can be used to establish design and manufacturing databases, which facilitate the retrieval of similar designs and the standardisation of manufacturing processes and thus enhance design and manufacturing productivity.

The design and manufacturing attributes used in coding workpieces generally involve shape (i.e. geometric form and size), function, material, and other manufacturing characteristics. Among these attributes, in recent years shape-related attributes have drawn much attention from researchers because of the increasing demand for fully integrated CAD/CAM systems.

Manual coding of workpieces on the basis of their shape is a time-consuming and error-prone process. The operator has to memorise all the template-shapes and then match a particular template-shape with each workpiece. Few operators can perform such matching accurately and reliably, especially when a large number of workpieces are involved. To overcome this problem, researchers have developed several automated classification systems [1–4]. Most of these approaches use individual local geometric features as the descriptors for workpiece classification, and approaches of this type have been shown to be useful in the planning of manufacturing processes.

However, there are two shortcomings to using individual features as classification criteria:

1. As Fig. 1 shows, similarity of isolated individual features does not necessarily entail similarity in global shape.
2. Isolated individual features cannot be used for identification during the early stages of the design phase, because the designer's conceptual model evolves from an overall, global picture to individual details.
Thus the use of local features as workpiece classification criteria is generally limited to information retrieval and practical applications.

In more recent GT research, workpieces have been described and classified on the basis of the overall contour of the workpiece instead of local attributes [6–8]. This approach enhances performance in the design phase and increases efficiency on the manufacturing and assembly lines. One of the key criteria in choosing a practical automated classification system for design, manufacturing, and assembly is whether the classification results are compatible with the user’s own classification. To ensure that this criterion is met, benchmarks reflecting the user’s classification are needed to evaluate the performance of automated classification systems.

The purpose of this research was to establish a system for generating such benchmark classifications with which to measure the utility of automated workpiece classification systems. The utility of an automated classification system depends on the ease with which users can store and retrieve information and on the extent to which the classification system is consistent with the user’s intuitive judgement of the similarities and differences between different workpieces. In this work, a set of sample workpieces was selected and classified according to users’ intuitive perception of the workpieces’ global shapes.

A flexible system for generating benchmark classifications was then established, which allows users to adjust the similarity evaluation criteria to suit their particular requirements. If a user adopts a stringent criterion, so that only workpieces with a high degree of similarity are classified as belonging to the same group, then a benchmark classification will be obtained that includes more groups, each containing a small number of workpieces. On the other hand, if the user decides that for a particular application, even workpieces with a low degree of similarity can be grouped together, then a benchmark classification will be obtained that includes fewer groups, but each group will contain more workpieces. Since the criteria for forming the benchmark classification can be adjusted freely, we call the proposed benchmark classification system a “flexible classification method”. Each particular classification produced by the system is called a “benchmark classification”. A classification of the same set of workpieces generated by a particular automated classification system is called a “test classification”.

The utility of an automated classification system can be assessed by comparing the results of the test classification with one or more benchmark classifications.

After the benchmark classification is determined, two indices are used to measure the level of consistency between the test classification and the benchmark classification. The first is an index of the number of workpiece groups, which is used to check whether there are too many or too few groups. If there are too many groups, then the similarity criteria used in the test classification system are too stringent. On the other hand, if there are too few groups, then the similarity criteria are too loose. The second index is an index of the level of homogeneity within each group. This index can be used to compare the level of similarity between corresponding groups in the test classification and the benchmark classification. A one-to-one correspondence is found between groups in the benchmark classification and the test classification by working from the classification with fewer groups. For instance, if the benchmark classification has fewer groups, then a correspondence is assigned between the groups in the benchmark classification and the groups in the test classification that are most similar to them. The higher the level of similarity between each pair of corresponding groups, the more accurate the test classification is.

2. Establishing the Benchmark Workpiece Classification

The process of establishing the benchmark workpiece classification can be divided into two stages:

1. Collecting and aggregating information.
   (1) Selection of subjects.
   (2) Method of representing workpieces for comparison.
   (3) Definition of linguistic terms and membership functions.
   (4) Aggregation of membership functions and defuzzification.

2. Establishing the benchmark classifications.
   (1) Fuzzy clustering analysis.
   (2) Using aggregated comparison crisp numbers for workpieces clustering.

2.1 Collecting and Aggregating Information

The aim of this stage is to establish the benchmark workpiece classification. In this research, 30 subjects were asked to make pair comparisons of the global shape of the 36 sample workpieces shown in Fig. 2. When subjects are asked to compare the similarity of various objects, their judgements are often limited by their attention span, memory capacity, and previous experience. Their responses are generally fuzzy and cannot be expressed by crisp numbers from 0 to 9. To cope with the fuzziness inherent in human cognitive processes, we used linguistic variables for the similarity comparison and integrated the subjects’ responses by means of a fuzzy number operation. The fuzzy numbers were then changed into crisp numbers through a defuzzification process. The detailed procedures are described below.

2.1.1 Selection of Subjects

Since the aim of this project was to employ users’ intuitive classification of workpieces as criteria for evaluating the per-