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Estimating the quality of process yield by fuzzy sets and systems

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ABSTRACT

Fuzzy grading is a multi-class problem, and is used for grading the product according to the degree of fitness for use, customer acceptance or commercial value. In this respect, the production system requires intelligent adjustments. Fuzzy set theory has a variety of applications in different fields. The most fruitful applications are in the field of modeling and control of production systems. Fuzzy logic may be used to control the key quality parameters, grade product quality to reduce the variations and adjust to the specification limits.

Fuzzy grading expresses the quality level of product by membership degrees in which belonging or not-belonging to a quality set is gradual. Similarly, the quality control charts are also focused on the reduction of variability and grading the key quality characteristics. The control limits are used to establish the natural spread or range of process so the controller will not signal changes in the process until the natural limits are exceeded. However, there is a logical inconsistency in control chart approaches, due to their crisp grading nature which are expressed as either conforming (good) or nonconforming (poor) to specifications. In this study, a new fuzzy grading approach was developed based on a fuzzy expert system. The outcomes of the fuzzy grading system were clearly proven to be more vigorous and flexible than the crisp control methods.

1. Introduction

For a product to pass inspection, its characteristics must fall within the manufacturing tolerances, and all product units that pass inspection are equally acceptable to the producer. Meanwhile, a product that is rejected because of failure to conform the specifications may be scrapped, or costly rework may be required (Wu & Liao, 2009). The percentage of processed products passing inspection is usually a standard crisp numerical quantitative measure of process performance in a manufacturing industry. Parchami and Mashinchi (2007) proposed the fuzzy attribute of quality, and a formula of fuzzy process capability index which can be defined as the probability of fuzzy up-to-standard products produced by production processes for dealing with fuzzy processes to reduce ambiguity. Hence, fuzzy sets and systems started to be employed in applications of quality assessment of food, powder and some similar industries. However, considerable work related to the quality of product has still been carried out manually in most industries. However, manual grading is difficult, stressful, unreliable, subjective, and time consuming. In high volume production powder, food, sinter and some other similar industries, manual grading leads to undesirable variation in assessment of product quality characteristics. Vanegas and Labib (2001) states the advantages of computer based continuous quality assessment systems to provide a strict and intelligent control on the main quality parameters to improve product utility, higher degree of consistency, productivity, defects detection, and efficiency. Moreover, intelligent control may reduce the response time in feedback of input parameters and provide online control of the output quality parameters. In this study, a fuzzy expert system for a granulator was developed. The fuzzy model is constituted from a set of fuzzy if–then linguistic rules which is the backbone of a fuzzy control system and behaves like the original human operator.

There is usually natural variability and some other unavoidable causes of variation in the production processes. In order to eliminate these variations, it is possible to deal with the quality characteristics of the products which usually necessitates monitoring both the mean value of the quality characteristic and its variability in the production process, regardless of how well and carefully designed and maintained the process is (DeVor, Chang, & Sutherland, 2009). A variable whose values are not crisp numbers but linguistic terms or sentences in nature or artificial language is a linguistic variable (Wang, 2009). In other words, for example, "input temperature" is a linguistic term (linguistic variable) whose values might be very low, low, medium, high, very high, etc. Linguistic values are usually presented by crisp values in real life, but can also be represented by fuzzy numbers. It is usually suitable to represent the degree of subjective judgment in a qualitative aspect than in crisp value. The concept of a linguistic variable is very useful in dealing with situations which are too complex or ill-defined to be reason-

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ably described by conventional quantitative expressions. The fuzzy linguistic approach represents qualitative aspects as linguistic values by means of linguistic variables. Most studies on measuring process yield are based on crisp estimates involving precise output process measurements (Chao & Lin, 2006). However, measurements of product quality sometimes cannot be precisely recorded or collected by precise numbers which have been considered the only feasible means of describing such data. Since measures of product quality often lack precision, a new trend has been inspired combining randomness and fuzziness in assessing process yield.

Feigenbaum (1991) uses linguistic terms for overall quality grading such as '*excellent*, *satisfactory*, *poor and unacceptable*'. Similarly, the quality of a product is measured by the customers through a list of qualitative terms which are called customer attributes such as '*good*, *not very good*, *easy to use*, *reliable*, *and durable, etc*.' These are the linguistic interpretations of quality characteristics and are linguistic terms rather than numerical values in real life. Juran and Gryna (2001) divide the quality specification limits into zones, such as, the zone within the control limits is the 'green zone', the zone between the specification limits is the 'yellow zone' and the zone outside the specification limits is the 'red zone.' As a general approach, when the process is statistically within the control limits, most of the product will fall between the upper and lower control limits (green zone). When the process is out of the control limits, a higher proportion of products will lie outside the limits (yellow zone). Yager (1995) stated that many aspects of different activities in a real world problem cannot be assessed in a quantitative form, but rather in a qualitative one, i.e., because of vague or imprecise knowledge. In real problems, evaluation techniques engage in handling cases like subjectivity, fuzziness and imprecise information. Application of the fuzzy set theory in evaluation systems can improve evaluation results. Whereas characteristics of the fuzziness and vagueness are inherent in various decision-making problems, a proper decision-making approach should be capable of dealing with vagueness or ambiguity. Fuzzy set theory is a very feasible method to handle the imprecise and uncertain information in a real world problem, especially, because it is a suitable technique for subjective judgment and qualitative assessment in the evaluation processes of decision making than other classical evaluation methods applying crisp values (Lin & Chen, 2004).

The aim of this study is to develop an expert assessment system based on fuzzy modeling outcomes. In fuzzy grading, linguistic terms were employed and the product is graded according to these linguistic terms to reduce the level of defects, and categorize products according to their quality level. However, in crisp (non fuzzy) grading, the powder has only two quality levels, it is either conforming to specifications or nonconforming. Conforming to specifications mean the product is within the predetermined specifications limits. However, a nonconforming product is out of control limits, so poor in quality. In crisp grading approach, conforming to specifications (belonging to a fuzzy set) is defined by 1 (within the control limits) and nonconforming to specifications (not belonging to a fuzzy set) is zero (out of control limits). Fig. 1 depicts the crisp quality grading of powder. Moisture content is the basic quality characteristic of powder of pharmacology and porcelain powder which is used to assess the quality of resulting products.

Powder industry requires consistently suitable powder for presses. Hence, customers desire receiving consistent quantities and qualities of powder particles which have 2.5 ± 0.5% moisture content. Every hour, a random sample of one kilogram of powder is taken from the production line manually, the moisture content of powder is measured and the relevant system parameters are recorded. The main quality characteristic of powder is the moisture content which requires checking the system parameters such as inlet temperature (IT), outlet temperature (OT), the pressure of the production system (P), the feed viscosity (V), the amount of chemicals used (AC), and solid content of slurry (LA). The three-dimensional relationship of some input quality characteristics and moisture content is given in Fig. 2. Careful control of parameters may enable the production of the improved granules, and improve the performance of overall process.

2. Literature review and research methodology

Filzmoser and Viertl (2004) presented an approach for testing hypotheses based on fuzzy data, by introducing the fuzzy p-value. Since the traditional crisp-based approaches can not be applied for precisely measuring the process yield, they are insufficient for assessment of product quality. Liu (2009) states that market economics has shortened the life cycles of products and has stimulated technological innovation. Fast-changing customer needs are a significant challenge to a company. New product development, which should meet various customer demands, is crucial, not only for the success of the product, but also for the company's survival. Büyüközkan, Feyzioğlu, and Ruan (2004) developed a fuzzy analytical network process method for computing the importance of engineering characteristics. Chen, Fung, and Tang (2006) proposed an integrated fuzzy expected value approach to calculate the importance of engineering characteristics. Bottani and Rizzi (2006) translated linguistic values of customer requirements into fuzzy numbers and computed the importance of engineering characteristics. Lyu, Chang, and Chen (2009) designed a quality assurance system (QAS) and used it to inspect product quality to determine causes of abnormality by collecting, analyzing and testing data from the product line, and then determining how an improvement plan should be conducted. Chen, Chen, and Lin (2003) incorporated the fuzzy inference system for processes with bigger-the-best type quality characteristics, and employed a concise score concept to represent the grade of process capability. Furthermore, Tsai and Chen (2006) considered the applications of index CP in the fuzzy environment, and formulated a pair of nonlinear functions to identify the approximate membership function. Additionally, Parchami and Mashinchi (2007) introduced fuzzy

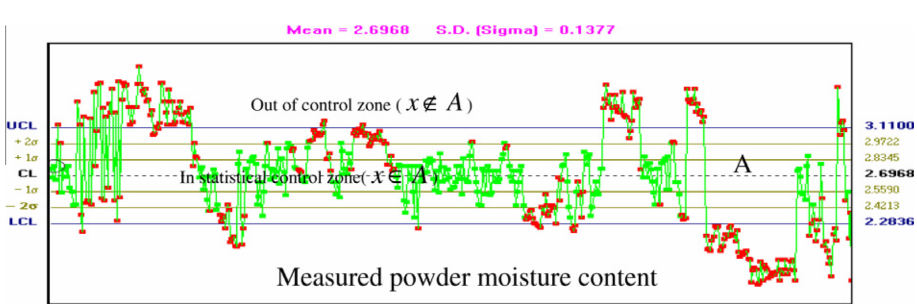

Fig. 1. Product grading based on crisp assessment.