A 2-level Intelligent Sensory Evaluation System of Industrial Products in an Integrated Supply Chain

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Abstract

This paper presents a 2-level sensory evaluation system of industrial products permitting to describe, analyze and interpret sensory data provided by multiple panels. These sensory data constitute a very important component in the information flow of the integrated supply chain in textile/clothing/distribution. Intelligent techniques have been used in this system to process uncertainty and imprecision existing in sensory data. In this system, a criterion of dissimilarity between two sensory panels has been defined in order to characterize business conflicts between suppliers and customers. Based on this dissimilarity, we propose a procedure for transforming evaluation terms between different panels, which is useful for solving related business conflicts. The effectiveness of this system has been validated using a practical example of fabric hand evaluation.

Keywords: Sensory evaluation, intelligent techniques, integrated supply chain, textile/clothing/distribution.

1. Introduction

In many industrial sectors such as food, cosmetic, medical, chemical, and textile, sensory evaluation is widely used for determining the quality of end products, solving conflicts between customers and suppliers, developing new products, and exploiting new markets adapted to the consumer's preference. Sensory evaluation is defined as a scientific discipline used to evoke, measure, analyze, and interpret reactions to the characteristics of products as they are perceived by the senses of sight, smell, taste, touch, and hearing [1]. In industry, sensory evaluation can be done at two levels: (1) design-oriented sensory evaluation (DOSE); and (2) market-oriented sensory evaluation (MOSE). DOSE is done by a trained panel composed of experienced experts or technicians inside the enterprise for judging industrial products using a number of neutral linguistic descriptors. It aims at obtaining basic sensory attributes of products to improve the quality of product design and development. MOSE is given by untrained consumers using hedonic descriptors according to their preference on the products to be evaluated. It aims at identifying consumers' preference in order to forecast market behavior.

In real applications, sensory evaluation plays an important role in the information flow of the related integrated supply chain. As a result, we give in Section 2 the structure of the 2-level sensory evaluation system in the supply chain of the textile/clothing/ distribution. In this structure, we explicitly describe the information flow in both DOSE and MOSE levels. In Section 3, we present a procedure for analyzing business conflicts at DOSE level. One solution to solve these conflicts is presented in Section 4. Section 5 shows a real example of fabric hand evaluation.

2. 2-level Sensory Evaluation in the supply chain of textile/ clothing/ distribution

Under the challenging economic pressure, there is a strong need to develop new methods in order to enhance communications between all related companies in the textile/clothing/distribution supply chain and between these companies and consumers.

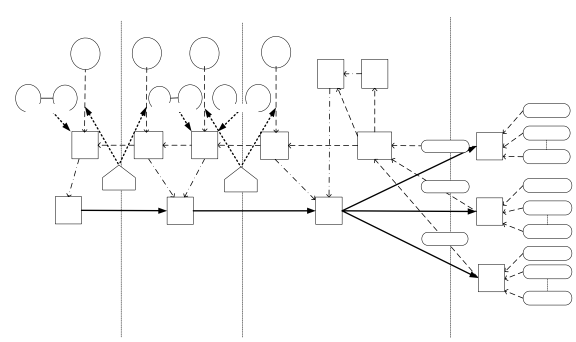

Fig. 1: Sensory evaluation in the supply chain of textile / clothing /distribution (one example).

In general, the structure of this supply chain should be optimized by exploiting relevant information on product quality, product design and marketing obtained from different companies. In this background, the introduction of a 2-level sensory evaluation system in this supply chain can provide a normalized platform to the companies for designing and producing standard, flexible and market oriented products and decreasing business conflicts between suppliers and customers. An example of this system in the supply chain is illustrated in Figure 1.

Table 1: Description of the symbols used in Figure 1.

Symbol	Meaning
⟶	Product flow
–·–·–〉	order information flow
◯⊢◯	Model for relating A to B
DOSE XY	design-oriented sensory evaluation X: No. of enterprise doing the evaluation Y: No. of product to be evaluated No. of enterprise: 1 yarn producer 2 fabric producer 3 garment maker No. of product: 1 yarn 2 fabric 3 garment
PF	Produce Factory
DC	Design Center
DMC	Decision Marking Center
PP	Produce Parameter
– – –>	evaluation information flow
··········▶	decision support
Solve Conflict	Method for solving the conflict between supplier and customer
MOSE XY	market-oriented sensory evaluation X: No. of enterprise doing the evaluation Y: the target market No. of enterprise:1 yarn producer 2 fabric producer 3 garment maker No. of target Market:1 France 2 Belgium 3 China
QC	Quality Center
MAC	Market Analysis Center
TM	Target Market

In this example, a South-American yarn producer is the supplier of a Chinese weaving company, which provides woven fabrics to a Chinese garment making company. This garment maker only produces garments according to the design parameters and the purchasing orders given by a French company which maintains connection with a number of European design centers and delivers finished garment products to its distribution network in France and Belgium. An efficient market analysis center (MAC) constitutes the kernel of this company in order to conduct all the activities of its partners (design centers, producers at different levels, distributors) according to the consumer's preference. In this multi-national industrial cooperation network, the departments of design and marketing are located in France and the production site in China. The final garment collections are sold in France, Belgium and China respectively.

In this supply chain, the product flow or material flow is going from raw material suppliers to producers of higher levels, then to distributors and consumers while the evaluation information flow from distributors and consumers to the design center and the quality inspection centers associated with producers of different levels. The order information flow is going from the design centers and the quality inspection centers to their associated producers in order to produce new market oriented products and improve the quality of existing products according to the sensory evaluation results. The market oriented sensory evaluation (MOSE) is performed in MAC by filling a number of questionnaires by selected consumers in each target market. It analyzes sensory data and provides relevant information on consumer's preference related to finished products to design centers and quality centers through the evaluation information flow. The design oriented sensory evaluation (DOSE) is performed in the design centers (DCs) and the quality centers (QCs) of the supply chain. It analyzes sensory data and provides relevant normalized product quality criteria and design criteria to related partners through the evaluation information flow and the order information flow for producing satisfactory intermediate products and solving business conflicts between suppliers and customers. In this 2-level sensory evaluation system, a number of mathematical models have been developed for characterizing relations between process parameters and sensory quality criteria and sensory design criteria used by different producers as well as sensory evaluation of consumers. These models permit to transform quality and design criteria used by one producer into those of his partners and consumer's evaluation and preference into design parameters and production parameters.

3. Analysis of business conflicts at DOSE level

In the supply chain of textile/clothing/distribution, an important problem is to solve business conflicts between two companies (supplier and customer) related to a set of representative samples. These conflicts can be characterized using the dissimilarity between two panels representing the related companies.

For the panel P_i , its aggregated sensory evaluation data constitute an evaluation matrix denoted by $S_i=(s_i(k,l))$ with $k=1,\ldots,n$ and $l=1,\ldots,m(i)$, were n represents the number of samples to be evaluated and $m(i)$ the number of evaluation terms used by P_i. The matrix $S_i = (S_{i1}\ S_{i2}\ ...\ S_{i,n})^T$ includes n *m(i)*-dimensional vectors, each representing the evaluation results for one sample.

As the evaluation terms used by one panel is often quite different from others, the dissimilarity between two panels P_a and P_b cannot be defined using classical methods, which compute distances between vectors in the same space. So a new dissimilarity criterion between two panels P_a and P_b has been defined in [2].

In this definition, the dissimilarity criterion takes into account the degree of consistency of relative variations of two different sensory data sets. If the internal relative variations of these two data sets are close each other, and then the dissimilarity between the corresponding panels is small. Otherwise, this dissimilarity is great. Formally, this dissimilarity is defined by: $D_{ab} = \frac{2}{n(n-1)} \sum_{i<j} d_{ab}(i, j)$

It depends on the following elements:

1) The dissimilarity between P_a and P_b related to the relative variation between fabric samples t_i and t_j: $d_{ab}(i, j) = |vr_a(i, j) - vr_b(i, j)|$.

2) The relative variations between t_i and t_j for P_k (*k*=*a*, *b*): $vr_k(i, j) = \frac{1}{\sqrt{m(k)}} \left\| S_{ki} - S_{kj} \right\|$.

The definition of D_{ab} permits to compare between these two panels the relative variations in the set of all samples. The dissimilarity between two panels reaches its minimum only when the internal variations of their sensory data are identical.

In the same way, we also define the dissimilarity or distance between terms used by two different panels [2]. This criterion permits to study the business conflicts between two panels related to the understanding of some specific evaluation terms. For example, the distance between two panels on the term "soft" may be very large, which means that these two panels understand this term in different ways.

It is important to physically interpret numerical values of the above criteria of dissimilarity. So, we transform these numerical values into fuzzy numbers, whose membership functions are generated according to the probability density distributions of the corresponding random matrices. The detailed procedure is given as follows and, according to the above section, P_a and P_b denote two panels *a* and *b*:

Step 1: For fixed values *n*, *m(a)* and *m(b)*, generating two random matrices S_a (dimension: $n \times m(a)$) and S_b (dimension: $n \times m(b)$) whose elements obey the uniform distribution between lower and upper bounds of evaluation scores.

Step 2: Computing the values of dissimilarity D_{ab}.

Step 3: Repeat Step 1 and Step 2 several times in order to obtain the probability density distribution for D_{ab}.

Step 4: We then divide equally the area of this distribution into 5 parts. According to these divided areas, we generate 5 fuzzy sub-sets for D_{ab}: {*very small, small, medium, large, very large*}. The corresponding membership functions can be determined from these 5 fuzzy numbers.

Figure.2 gives the probability distribution for the dissimilarity D_{ab} between two panels P_a and P_b using 11 and 6 terms respectively. Next, this distribution is equally divided into 5 areas each corresponding to a fuzzy value. From their membership functions, we can see that the dissimilarity D_{ab} is sensitive only in the interval of [0.161, 0.207], in which three fuzzy values small (S), medium (M) and large (L) are asymmetrically distributed. A value of D_{ab} smaller than 0.161 is considered as very small (VS) and a value of D_{ab} larger than 0.207 as very large (VL).

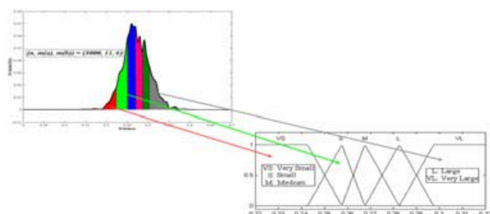

Figure.2: From a distance crisp number to a fuzzy distance number.

In this way, each numerical value of dissimilarity criteria can be transformed into a fuzzy number whose value includes the linguistic part taken from the previous 5 terms and the corresponding membership degree. This fuzzy number permits to interpret the dissimilarity with respect to the whole distribution of random values. The business conflicts between different panels can be effectively characterized from these fuzzy numbers.

4. Solving business conflicts by transforming evaluation terms between panels

For solving business conflicts between two companies related to the understanding of evaluation terms (product quality criteria or product design criteria), there exists a strong need for interpreting evaluation terms of one panel using those of another panel. In this section, we propose a genetic algorithm based procedure to do so. The details of this procedure are given as follows.

The sensory data of two panels P_a and P_b are obtained by evaluating the same set of representative samples denoted by *T*. The sets of terms of P_a and P_b are denoted by $A_a = \{a_{a1}, a_{a2}, ..., a_{a,m(a)}\}$ and $A_b = \{a_{b1}, a_{b2}, ..., a_{b,m(b)}\}$ respectively. For each term a_{ak} of P_a $(k \in \{1, \ldots, m(a)\}$, we try to find the optimal linear combination of the terms $a_{b1}, a_{b2}, ..., a_{b,m(b)}$ to generate a new term denoted by $a(P_a, P_b, k)$ which is the closest to a_{ak} in semantics, i.e. $a(P_a, P_b, k) = w_1^k \cdot a_{b1} + w_2^k \cdot a_{b2} + ... + w_{m(b)}^k \cdot a_{b,m(b)}$ with $\sum_{i=1}^{m(b)} w_i^k = 1$. The corresponding weights $\{w_1^k, w_2^k, ..., w_{m(b)}^k\}$ are determined using a genetic algorithm with penalty strategy [3] so that the distance between a_{ak} and $a(P_a, P_b, k)$ is minimal.

5. One Application in Fabric Hand Evaluation

At the level of DOSE, we apply our approach to sensory data on fabric hand evaluation provided by 2 sensory panels in France and 2 sensory panels in China, i.e. $\{FE, FTS, CE, CTS\}$ where FE, FTS, CE, CTS represent a panel of French fashion experts, a panel of trained French students, a panel of Chinese textile experts and a panel of trained Chinese students respectively. The set *T* is composed of 43 knitted cotton samples produced using 3 different spinning processes.

Based on the sensory data provided by these panels, we apply the method presented in Section 3 for computing distances between different panels and all of the fuzzy distances are "*VS*".

We can notice that the averaged distances between French and Chinese people and between professional experts and students are very small. It means that the general evaluation on fabric hand is related to neither the cultural background nor the professional background. In practice, business conflicts between suppliers and customers on general fabric hand are rather limited because their evaluation results for the same collection of products are generally very similar.

Using the method in Section 3, we can also calculate the crisp and fuzzy distances between evaluation terms used by different panels. The results of fuzzy distances between FE and FTS on the term "soft" are given in Table 3.

Table 3: The values of fuzzy distances between different panels (FE, FTS) on the common term "soft".

Process	Carded	Combed	Open-End
	VS: 0.81, S: 0.19	S: 0.42, M: 0.58	VS: 0.03, S: 0.97

Table 3 shows that the distances between different panels on the term "soft" are sometimes rather important although most of the fuzzy values of these distances are very small. The same phenomenon can be observed for the other terms such as "slippery" and "smooth". This means that one evaluation term is often semantically interpreted in different ways by different panels. In practice, this divergence in the understanding of linguistic quality criteria and design criteria constitutes a main source of business conflicts between suppliers and customers. A dictionary is then needed for the understanding of evaluation terms between different professional populations.

We use the method in Section 4 to interpret each term used by the panels of FTS, CE and CTS into those of FE. For simplicity, we only discuss the case of P_a =FTS and P_b =FE in this section. The 11 terms used by FE corresponds to $A_b = \{a_{b1}, a_{b2}, ..., a_{b,11}\}$ and the 4 terms of FTS to $A_a = \{a_{a1}, a_{a2}, a_{a3}, a_{a4}\}$. After applying the genetic algorithm with penalty strategy presented previously, we obtain the optimal linear combination of the terms of FE related to each term of FTS. For example, the term *"soft"* used by FTS can be approximately expressed as a linear combination of three terms of FE: *"soft"*, *"floppy" and "hollow"*, i.e.

$$soft\_FTS \approx 0.33 \cdot soft\_FE + 0.32 \cdot floppy\_FE + 0.35 \cdot hollow\_FE$$

6. Conclusion

This paper presents the structure of a 2-level sensory evaluation system in the background of the integrated supply chain of textile/clothing/distribution. In practice, this system can provide a normalized platform for optimizing relations between designers, producers of different levels and consumers. Under this structure, several procedures at DOSE level have been proposed in this paper in order to characterize and solve business conflicts between panels. Fuzzy techniques and genetic algorithms have been used in these procedures. This system has been successfully applied to the evaluation of fabric hand.

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