Integration of Dependent Features on Sensory Evaluation Processes

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Abstract. The aim of a sensory evaluation process is to compute the global value of each evaluated product by means of an evaluator set, according to a set of sensory features. Several sensory evaluation models have been proposed which use classical aggregation operators to summary the sensory information, assuming independent sensory features, i.e, there is not interaction among them. However, the sensory information is perceived by the set of human senses and, depending on the evaluated product, its sensory features may be dependent and present interaction among them. In this contribution, we present the integration of dependent sensory features in sensory evaluation processes. To do so, we propose the use of the fuzzy measure in conjunction with the Choquet integral to deal with this dependence, extending a sensory evaluation model proposed in the literature. This sensory evaluation model has the advantage that offers linguistic terms to handle the uncertainty and imprecision involved in evaluation sensory processes. Finally, an illustrative example of a sensory evaluation process with dependent sensory features is shown.

Keywords: Sensory evaluation, decision analysis, sensory information, linguistic information, interaction, dependence.

1 Introduction

Evaluation processes are key in quality inspection, marketing and other fields in industrial companies. In these processes, it is very common that a group of evaluators assess a set of evaluated product, according to a set of criteria in order to obtain a global value of each evaluated product. To achieve this aim, some evaluation models are based on decision analysis methods due to the fact that these methods offer a simple and rational analysis that can be adapted in the evaluation context.

The sensory evaluation is an evaluation discipline that is carried out to evoke, measure, analyze, and interpret reactions of the sensory features of products [3]. This evaluation discipline has an important impact on many industrial areas such as comestibles, cosmetic and textile [16].

In the literature, several sensory evaluation models [6, 11–13, 15] have been proposed. These evaluation models assume that the multiple sensory features are completely independent, without presenting interaction among them. However, sensory features are perceived by the set of human senses *sight, smell, taste, touch* and *hearing* and, depending on the evaluated product, its sensory features may not be independent. For

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example, the *texture* and *appearance* are sensory features that are evaluated in clothing fabrics and there is a dependence between them. Another example are fruits where, usually, the sensory feature of *taste* can interact with other sensory features [16].

Therefore, in each sensory evaluation process is necessary to analyze each sensory feature and its relationships or dependence among them, i.e., to consider the interaction among sensory features. Furthermore, this interaction should be managed when the set of assessments is aggregated [10, 16] to obtain successful results that model the reality of sensory evaluation processes. Thereby, in order to manage the interaction among sensory features, sensory evaluation models should be extended.

In this contribution, we propose the use of fuzzy measures [18] in conjunction with fuzzy integrals [17] to capture the interaction among sensory features and to manage this interaction to compute the global value of each evaluated product in the sensory evaluation process. To do so, we propose the use of the Choquet integral [1] that is a fuzzy integral as well as a useful tool to model the dependence or interaction of criteria in several applications [4].

The information involved in sensory processes is perceived by the human senses and always involves imprecision and uncertainty that has a non-probabilistic nature [11]. For this reason, we propose to extend a sensory evaluation model that uses the fuzzy linguistic approach [21] to model and manage such an uncertainty by means of linguistic variables. The use of linguistic information in sensory evaluation processes involves Computing with Words (CWW) processes in which the objects of computation are words or sentences from a natural language and the results are also expressed in a linguistic expression domain [8]. Therefore, CWW processes are carried out in our proposal, considering the interaction among aggregated arguments. Finally, we show a case study to illustrate the usefulness and effectiveness of the fuzzy measures with the Choquet integral in a sensory evaluation process with linguistic information for fruit jam samples.

The rest of the contribution is organized as follows: Section 2 reviews the CWW processes in the context of dependent aggregation as well as the linguistic sensory evaluation model that will be extended. In Section 3, the integration of dependent features in the linguistic sensory evaluation model is presented. In Section 4, an illustrative example of the extended linguistic evaluation model is shown. In the last section, we give the conclusions.

2 Preliminaries

In this section, CWW processes with dependent arguments are reviewed by means of the 2-tuple linguistic model, which is used to represent the linguistic information in the linguistic sensory evaluation model that will be reviewed later.

2.1 CWW with Presence of Dependence

In this section, we review the 2-tuple linguistic model and dependent aggregation operators for linguistic 2-tuples, these will be used in our proposal to capture the interaction among sensory features and to carry out CWW processes, considering such interaction.

2-Tuple Linguistic Model. The 2-tuple linguistic model has been successfully applied in different fields such as sustainable energy [5], recommender systems [14], quality of service [7], performance appraisal [4], etc. This model represents the information by means of a pair of values (s, α), where s is a linguistic term with syntax and semantics and α is a numerical value that represents the value of the *symbolic translation*. The symbolic translation is a numerical value assessed in $[-0.5, 0.5)$ that supports the difference of information between a counting of information β assessed in the interval of granularity $[0, g]$ of the linguistic term set S and the closest value in $S = \{s_0, \ldots, s_g\}$ which indicates the index of the closest linguistic term in S.

This model defined a set of functions to facilitate the computational processes with linguistic 2-tuples [9].

Definition 1 *[9]. Let $S = \{s_0, \ldots, s_g\}$ be a set of linguistic terms. The 2-tuple set associated with S is defined as $\langle S \rangle = S \times [-0.5, 0.5)$. The function $\Delta_S : [0, g] \longrightarrow \langle S \rangle$ is given by,*

$$\Delta_S(\beta) = (s_i, \alpha), \quad with \quad \begin{cases} i = round\,(\beta), \\ \alpha = \beta - i, \end{cases} \tag{1}$$

where $round(\cdot)$ assigns to β the integer number $i \in \{0, 1, \ldots, g\}$ closest to β.

Proposition 1 *Let $S = \{s_0, \ldots, s_g\}$ be a linguistic term set and (s_i, α) be a linguistic 2-tuple. There is always a function $\Delta_S^{-1} = i + \alpha$ such that, from a linguistic 2-tuple, it returns its equivalent numerical value $\beta \in [0, g]$.*

Remark 1 *The conversion of a linguistic term into linguistic 2-tuple consists of adding a value 0 as symbolic translation. $H : S \rightarrow \langle S \rangle$ that allows us to transform a linguistic term s_i into a linguistic 2-tuple $(s_i, 0)$.*

The 2-tuple linguistic representation model has a linguistic computational model associated based on Δ_S^{-1} and Δ_S that accomplishes CWW processes in a precise way. Different 2-tuple linguistic aggregation operators have been proposed [9] that consist of obtaining a linguistic 2-tuple value that summarizes a set of linguistic 2-tuples. The 2-tuple ordered weighted averaging (OWA) aggregation operator that will be used in our case study is defined as follows:

Definition 2 *[9] Let $S = \{(s_1, \alpha_1), (s_2, \alpha_2), ..., (s_n, \alpha_n)\}$ be a set of 2-tuples and $w = (w_1, w_2, ..., w_n) \in [0, 1]^n$ be the weighting vector of S such that $\sum_{i=1}^{n} w_i = 1$. The 2-tuple ordered weighted averaging aggregation operators for linguistic 2-tuples is defined as:*

$$2TOWA_w(S) = \Delta_S\left(\sum_{i=1}^{n} w_i \Delta_S^{-1}(s_{\sigma(i)}, \alpha_{\sigma(i)})\right),$$

with σ a permutation on $\{1, ..., n\}$ such that $(s_{\sigma(1)}, \alpha_{\sigma(1)}) \geq \ldots \geq (s_{\sigma(n)}, \alpha_{\sigma(n)})$.

Dependent Aggregation Operators. Choquet integral-based aggregation operators [1] consider the dependence of the aggregated arguments in order to deal with the interaction among them. These aggregation operators require fuzzy measures [18] in order to represent the interaction among arguments. Following, the fuzzy measures and the Choquet integral for linguistic 2-tuples are defined.

Definition 3 *[18]. Let $N = \{1, \ldots, m\}$ be a set of m arguments. A* fuzzy measure *is a set function $\mu : 2^N \rightarrow [0,1]$ that satisfies the following conditions: $\mu(\emptyset) = 0$, $\mu(N) = 1$ and $\mu(S) \leq \mu(T)$ whenever $S \subseteq T$ (μ is monotonic)*

To represent set functions, for a small m, it is convenient to arrange their values into an array. For example, the fuzzy measure for $m = 3$ is represented as follows:

$$\begin{array}{ccc} & \mu(f_1, f_2, f_3) & \\ \mu(f_1, f_2) & \mu(f_1, f_3) & \mu(f_2, f_3) \\ \mu(f_1) & \mu(f_2) & \mu(f_3) \\ & \mu(\emptyset) & \end{array} \qquad (2)$$

Definition 4 *[20]. Let μ be a fuzzy measures on $X = \{x_1, x_2, ..., x_n\}$ and a set of linguistic 2-tuples $S = \{(s_1, \alpha_1), (s_2, \alpha_2), ..., (s_n, \alpha_n)\}$. The 2-tuple Choquet integral ($2TCI$) for linguistic 2-tuples is defined as:*

$$2TCI_\mu(S) = \Delta_S \left(\sum_{i=1}^{n} w_i \Delta_S^{-1}(s_{\sigma(i)}, \alpha_{\sigma(i)}) \right)$$

where $w_i = \mu(H_{\sigma(i)}) - \mu(H_{\sigma(i-1)})$, with σ a permutation on $\{1, ..., n\}$ such that $(s_{\sigma(1)}, \alpha_{\sigma(1)}) \geq (s_{\sigma(2)}, \alpha_{\sigma(2)}) \geq ... \geq (s_{\sigma(n)}, \alpha_{\sigma(n)})$ and $x_{\sigma(i)}$ is the attribute corresponding to $(s_{\sigma(i)}, \alpha_{\sigma(i)})$. With the convention $H_{\sigma(0)} = \emptyset$ and $H_{\sigma(i)} = \{x_{\sigma(1)}, ..., x_{\sigma(i)}\}$, for $i \geq 1$. Obviously $w_i \geq 0$ and $\sum_{i=1}^{n} w_i = 1$.

By using the Choquet integral, in [20] some aggregation operators for linguistic 2-tuples was introduced, including the 2-tuple correlated averaging operator, the 2-tuple correlated geometric operator and the generalized 2-tuple correlated averaging operator.

2.2 Linguistic Sensory Evaluation Model

In this section, we briefly review the linguistic sensory model based on linguistic 2-tuples [11] that offers linguistic terms to handle the uncertainty and imprecision involved in evaluation sensory processes, providing linguistic results.

The linguistic sensory evaluation model adapts the common decision resolution scheme proposed in [2] and consists of three phases (see Figure 1) that are reviewed in the following subsections.

Evaluation Framework. This phase defines the structure and the set of elements in the sensory evaluation process that these are:

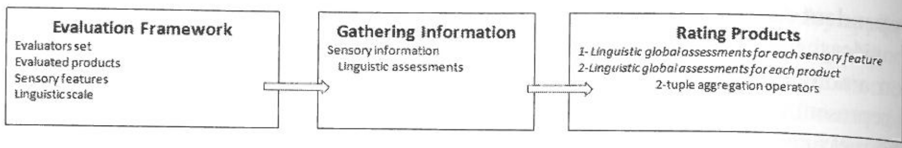

Fig. 1. Linguistic sensory evaluation model with independent sensory features

- $C = \{c_k : k = 1, ..., m\}$ is the evaluator panel.
- $X = \{x_j : j = 1, ..., n\}$ is the set of evaluated products.
- $F = \{f_i : i = 1, ..., h\}$ is the set of sensory features that identify each evaluated product.
- $S = \{s_l : l = 0, ..., g\}$ is the linguistic scale in which evaluators' assessments will be expressed.

Gathering Information. In this phase, each evaluator $c_k \in C$ expresses his/her assessment value of each evaluated product $x_j \in X$ by means of a linguistic assessment vector: $U_j^k = \{u_{1j}^k, u_{2j}^k, \ldots, u_{nj}^k\}$. This linguistic information is transformed into linguistic 2-tuples, using the *Remark* 1.

Rating Products. The aim of the sensory evaluation process is to compute a global value of the set of evaluated products, according to the sensory information gathered in the previous phase. A key issue in this process is to carry out CWW processes, aggregating the sensory information in an appropriate way by means of aggregation operators for linguistic 2-tuples. To do so, this phase consists of two steps.

1. *Computing a global value for each sensory feature*: first, it is computed a global linguistic 2-tuple, (u_{jk}, α), for each sensory feature f_k, of the evaluated product x_j, using an aggregation operator for linguistic 2-tuples $2TAO_1$.

$$(u_{jk}, \alpha) = 2TAO_1((u_{jk}^1, \alpha_1), \ldots, (u_{jk}^n, \alpha_n))$$

2. *Computing a global value for each evaluated product*: the final aim of the rating process is to obtain a global value, (u_j, α), for each evaluated product, x_j according to its global values for the set of sensory features. To do so, this step aggregates the global linguistic 2-tuple values for each feature sensory, (u_{jk}, α), using an aggregation operator for linguistic 2-tuples $2TAO_2$, assuming that the set of sensory features is independent.

$$(u_j, \alpha) = 2TAO_2((u_{j1}, \alpha_1), ..., (u_{jh}, \alpha_h))$$

Until now, sensory evaluation models have been used classical aggregation operators for linguistic 2-tuples as arithmetic average, weighted average or median average [6, 11–13] to compute the global value for each evaluated product, without assuming the interaction among sensory features.

3 Integration of Dependent Features on Sensory Evaluation Process

In this section, we present the management of dependent sensory features in sensory evaluation processes. To do so, we extend the reviewed linguistic sensory evaluation model in Section 2.2 in order to capture and model the interaction among sensory features and compute global assessments, taking into account this interaction.

In order to achieve the aim of this contribution, the fuzzy measures and the Choquet Integral are used to manage the interaction among sensory features. So, these will be used in the phase of *Evaluation Framework* as well as in the step of computing global value for each evaluated product of *Rating Products*. These phases are described bellow and illustrated in Figure 2 in the extended linguistic sensory evaluation model

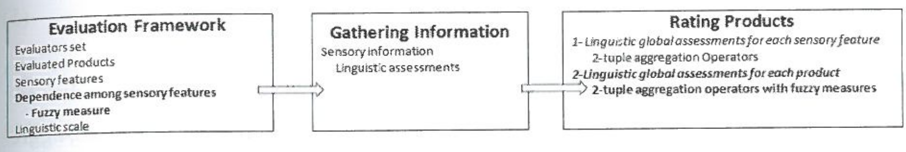

Fig. 2. Extended linguistic sensory evaluation model to manage dependent sensory features

Extending the Evaluation Framework. In the evaluation framework, it is necessary to analyze each sensory feature and its relationships or depende among them. To do so, it is necessary to define in the evaluation framework the fuzzy measure associated with the set of sensory features $F = \{f_i : i = 1, ..., h\}$:

- $\mu : 2^F \longrightarrow [0, 1]$ are the fuzzy measures that represent the dependence among the set of sensory features.

In order to clarify the use of the fuzzy measures in the sensory evaluation process, three examples are illustrated, considering a sensory evaluation process in which three sensory features are evaluated: $F = \{f_1, f_2, f_3\}$.

Example 1. *Let μ be the fuzzy measure on F given by Eq. (3), these fuzzy measures represent interaction among f_1 and f_2 due to the fact that $\mu(f_1, f_2) = 0.6 > \mu(f_1) + \mu(f_2) = 0.5$. The sensory feature f_3 is independent respect to f_1 and f_2 because $\mu(f_1, f_3) = \mu(f_1) + \mu(f_3) = 0.7$ and $\mu(f_2, f_3) = \mu(f_2) + \mu(f_3) = 0.8$.*

$$\begin{array}{c} 1 \\ 0.6\ 0.7\ 0.8 \\ 0.2\ 0.3\ 0.5 \\ 0 \end{array} \quad (3)$$

Example 2. *Let μ be the fuzzy measure on F given by Eq. (4) that is a symmetric additive fuzzy measure, these sensory features are independent and have the same* *weight in the evaluation process due to the fact that the same cardinalities of the corresponding subsets have the same value in* μ*:* $\mu(f_1) = \mu(f_2) = \mu(f_3) = 1/3$ *and* $\mu(f_1, f_2) = \mu(f_1, f_3) = \mu(f_2, f_3) = 2/3$.

$$\begin{array}{ccc} & 1 & \\ 2/3 & 2/3 & 2/3 \\ 1/3 & 1/3 & 1/3 \\ & 0 & \end{array} \tag{4}$$

Example 3. *Let* μ *be the fuzzy measure on* F *given by Eq. (5) that is an additive fuzzy measure, these features sensory are independent, there is not interaction among them. However, the sensory features not have the same weight in the set because* $\mu(f_3) = 0.5 > \mu(f_2) = 0.3 > \mu(f_3) = 0.2$.

$$\begin{array}{c} 1 \\ 0.5\ 0.7\ 0.8 \\ 0.2\ 0.3\ 0.5 \\ 0 \end{array} \tag{5}$$

Extending the Rating Products. In this phase, it is carried out CWW processes, aggregating the sensory information and considering the interaction among sensory features. To do so, the second step is extended in order to compute the linguistic global value (u_j, α), for each evaluated product, according to the interaction as well as the global values of the set of sensory features computed previously in the firs step.

- *Computing a global value for each evaluated product*: In order to manage the interaction among sensory features when the set of global values are aggregated, it is necessary to use an aggregation operator that can deal with the fuzzy measure defined in the evaluation framework. Therefore, *Choquet integral-based aggregation operators* for linguistic 2-tuples, which consider the fuzzy measure, are used to manage the interaction among sensory features and to aggregate the linguistic information.

$$(u_j, \alpha) = 2TAO_\mu((u_{j1}, \alpha_1), ..., (u_{jh}, \alpha_h))$$

It is noteworthy that the interaction of the set of sensory features is captured by fuzzy measures. Therefore, if the fuzzy measure does not capture the interaction, the Choquet integral does not consider such interaction. Thereby, depending on the properties of fuzzy measures, the Choquet Integral can include classical aggregation operators, for example *weighted means*. So, the Choquet integral with respect to an additive fuzzy measure μ is the weighted arithmetic mean with the weights $w_i = \mu(i)$. With respect to a symmetric additive fuzzy measure, the Choquet integral is the arithmetic mean and the values of μ are given by $\mu(A) = |A|/n$.

4 Dependent Sensory Features of Fruit Jam. Case Study

In this section, we present a case study to illustrate the usefulness and effectiveness of the integration of dependent sensory features in the sensory evaluation process of fruit jam samples.

4.1 Evaluation Framework

The evaluation framework includes a set of twenty evaluators, $C = \{c_1, \dots, c_{20}\}$, who assess two samples of fruit jam, $X = \{x_1, x_2\}$. Each fruit jam sample is characterized by three sensory features $f = \{f_1, f_2, f_3\}$ which are respectively: *taste*, *smell* and *texture*. In this case study, evaluators express their assessments about the set of sensory features, using the linguistic term set S that is illustrated in the Figure 3.

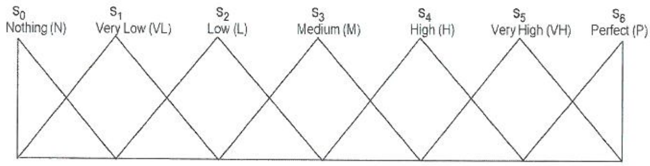

Fig. 3. Linguistic term set

Furthermore, an expert in the company provides the interaction among the set of sensory features by means of fuzzy measures that are shown in Eq. (6):

$$\begin{array}{c} 1 \\ 0.6 \; 0.5 \; 0.4 \\ 0.2 \; 0.2 \; 0.2 \\ 0 \end{array} \tag{6}$$

In this sensory evaluation process, the three independent sensory features are associated with the same weight $\mu(f_1) = 0.2$, $\mu(f_2) = 0.2$ and $\mu(f_3) = 0.2$. However, the company establishes that the sensory feature of *taste* is more important in coalition with the other two sensory features, *smell* and *texture*. Due to the fact that $\mu(f_1, f_2) = 0.6 > \mu(f_1) + \mu(f_2) = 0.4$ and $\mu(f_1, f_3) = 0.5 > \mu(f_1) + \mu(f_3) = 0.4$. Furthermore, it is more important the interaction among *taste* and *smell* than *taste* and *texture* because $\mu(f_1, f_2) = 0.6 > \mu(f_1, f_3) = 0.5$. Finally, the sensory features of *smell* and *taste* are independent, since their fuzzy measures are additive, $\mu(f_2, f_3) = 0.4 = \mu(f_2) + \mu(f_3) = 0.4$.

4.2 Gathering Information

Once the evaluation framework has been defined in the previous phase, the information must be gathered. The evaluator set provides their assessments by using linguistic assessment vectors. Therefore, each evaluator c_k provides his/her assessments about the evaluated product x_j according to each sensory feature f_i.

In this case study, the evaluator set provides all assessments, but if the provided information is incomplete, some decision-making models could be used to manage it. The linguistic information gathered by the evaluator set is shown in Table 1, this information is transformed into linguistic 2-tuples, using the *Remark* 1.

Table 1. Assessments about x_1 and x_2 provided by the evaluators

x_1	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{16}	c_{17}	c_{18}	c_{19}	c_{20}
f_1	VH	P	P	P	P	H	H	H	H	H	L	M	M	M	M	VL	VL	VL	VL	L
f_2	P	P	P	P	P	VH	VH	VH	P	P	VH	VH	VH	VH	VH	L	VH	VH	VH	VH
f_3	P	P	P	P	P	P	P	P	P	P	VH	VH	VH	VH	VH	L	VH	VH	VH	VH

x_2	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{16}	c_{17}	c_{18}	c_{19}	c_{20}
f_1	L	M	M	M	H	H	H	VH	VH	VH	N	N	VL	VL	VL	VL	VL	L	L	L
f_2	H	VH	VH	P	P	P	P	P	P	P	L	L	M	M	M	M	M	M	H	H
f_3	VH	VH	VH	P	P	P	P	P	P	P	VL	VL	L	L	M	H	H	H	VH	VH

4.3 Rating Products

In order to ensure an effective rating process, it is necessary to consider the interaction among sensory features of the evaluated product to compute a global value for each evaluated product. The description of the rating process is described as follows:

Computing a Global Value for Each Sensory Feature. In the first step of this process, the *2-tuple OWA operator* is applied, which requires an *weighting vector*. In this case study, the linguistic quantifier *"Most"* [19] is used to obtain the weight vector that is: $w = (0, 0, 0, 0, 0, .1, .1, .1, .1, .1, .1, .1, .1, .1, .1, .1, 0, 0, 0, 0)$. Global values for each sensory feature are shown in Table 2.

Table 2. Global values for each sensory feature

	x_1	x_2
f_1	$(s_3, -0.2) = (M, -0.2)$	$(s_2, -0.4) = (L, -0.4)$
f_2	$(s_5, 0.06) = (VH, 0.06)$	$(s_4, -0.03) = (H, -0.03)$
f_3	$(s_5, 0.26) = (VH, 0.26)$	$(s_4, 0.26) = (H, 0.26)$

Computing a Global Value for Each Product. Aggregating the global values for each sensory feature of each sample x_j is obtained its global value. Considering the interaction among sensory features, the Choquet Integral is used with the fuzzy measure defined in the evaluation framework. The computed linguistic global assessments are $x_1 = (s_4, 0.3) = (H, 0.3)$ and $x_2 = (s_3, 0.04) = (H, 0.04)$.

5 Conclusions

In this paper, we have presented the integration of dependent sensory features in a linguistic sensory evaluation model to capture the interaction among sensory features and to compute the global assessment of each evaluated product, considering such interaction. To do so, we have proposed the use of fuzzy measure to model the dependence among sensory features and the Choquet integral aggregation operator for linguistic 2-tuples to obtain the linguistic global assessment of each evaluated product. Finally, an illustrative example of a sensory evaluation process with interaction among some sensory features has been presented.

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