A Fuzzy Model for Olive Oil Sensory Evaluation

Luis Martínez[1], Luis G. Pérez[1], Jun Liu[2], and Macarena Espinilla[1]

[1] Computer Sciences Department
University of Jaen
Campus Las Lagunillas s/n 23071- Jaén, Spain
{martin,lgonzaga}@ujaen.es
[2] School of Computing and Mathematics
University of Ulster at Jordanstown
Newtownabbey, Co. Antrim BT37 0QB, Northern Ireland, UK
j.liu@ulster.ac.uk

Abstract. The evaluation is a process that analyzes elements to achieve different objectives such as quality inspection, design, marketing exploitation and other fields in industrial companies. In many of these fields the items, products, designs, etc., are evaluated according to the knowledge acquired via human senses (sight, taste, touch, smell and hearing), in such cases, the process is called *Sensory Evaluation*. In this type of evaluation process, an important problem arises as it is the modelling and management of uncertain knowledge, because the information acquired by our senses throughout human perceptions involves uncertainty, vagueness and imprecision.

The sensory evaluation of Olive oil plays a relevant role for the quality and properties of the commercialized product. In this contribution, we shall present a new evaluation model for Olive oil sensory evaluation based on a decision analysis scheme that will use the Fuzzy Linguistic Approach to facilitate the modelling and managing of the uncertainty and vagueness of the information acquired through the human perceptions in the sensory evaluation process.

Keywords: Decision Analysis, Sensory Evaluation, Linguistic variables.

1 Introduction

The evaluation is a complex cognitive process that involves different mechanisms in which it is necessary to define the elements to evaluate, fix the evaluation framework, gather the information and obtain an evaluation assessment by means of an evaluation process. The aim of any evaluation process is to obtain information about the worth of an item (product, service, material, etc.), a complete description about different aspects, indicators, criteria in order to improve it or to compare with other items to know which ones are the best. The information gathered in this kind of processes is usually provided by a group of individuals, called panel of experts, where each expert expresses their opinions about the item according to their knowledge and their own perceptions.

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This contribution is focused on *Sensory Evaluation* processes [5,12,13] that is an evaluation discipline whose information, provided by the panel of experts, is perceived by the human senses of *sight, smell, taste, touch and hearing.* A suitable mathematical formulation is not easy in this type of problems because human perceptions are subjective and not objective, therefore the assessments provided by the individuals are vague and uncertain. In such a case, linguistic descriptors are direct provided by the experts to express their knowledge about the evaluated element. The Fuzzy Linguistic Approach [15] provides a systematic way to represent linguistic variables in an evaluation procedure.

In decision theory before making a decision is carried out a decision analysis approach that allows people to make decisions more consistently, i.e., it helps people to deal with difficult decisions. The decision analysis is a suitable approach for evaluation processes because it helps to analyze the alternatives, aspects, indicators of the element/s under study that it is the objective of the evaluation processes.

Nowadays, the quality of the olive oil plays a key role in its production and final price. The evaluation of the quality of the olive oil is not an easy task and is usually accomplished by olive oil Tasting Panel, which will evaluate, by means of their perceptions acquired via their senses, the features that describe the samples of olive oil. The aim of this contribution is to propose a linguistic sensory evaluation model based on a decision analysis scheme that uses the Fuzzy Linguistic Approach and the 2-tuple fuzzy representation model [6] to represent the experts' assessments.

This paper is structured as follows, in Section 2 we present and review in short the necessary concepts and processes to develop the linguistic sensory evaluation. In Section 3 we present our proposal of linguistic sensory evaluation model, and in Section 4 we expound an application of this evaluation model. Finally, this paper is concluded in Section 5.

2 Background

Our evaluation model is based on the scheme of the Decision Analysis that we present in this section. Moreover, we shall make a brief review of the Fuzzy Linguistic Approach and the Linguistic 2-tuple representation model that will be used to facilitate the computation of the linguistic information in the evaluation process.

2.1 Decision Analysis Steps

The Decision Analysis is a discipline, which belongs to Decision Making Theory, whose purpose is to help the decision makers to reach a consistent decision in a decision making problem. Here, we model the evaluation process as a Multi-Expert Decision Making (MEDM) problem. A classical decision analysis scheme is composed by the following phases (see figure 1):

- *Identify decision and objectives.*
- *Identify alternatives.*

- *Model:* For example, a decision problem is modelled as a MEDM [7] model that deals with a type of information.
- *Gathering information:* decision makers provide their information.
- *Rating alternatives:* This phase is also known as "aggregation phase" [11] due to the fact in this phase, the individual preferences are aggregated in order to obtain a collective value for each alternative.
- *Choosing best alternatives:* or "exploitation phase" [11] selects the solution from the set of alternatives applying a choice degree [1,10] to the collective values computed in the previous phase.
- *Sensitive analysis:* in this step the information obtained is analyzed in order to know if it is good enough to make a decision, or otherwise, to go back to initial phases to improve the quantity or/and the quality of the information obtained.
- *Make a decision.*

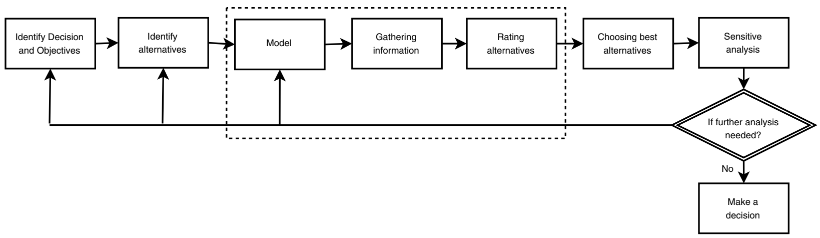

Fig. 1. Decision Analysis Scheme

The application of the decision analysis to an evaluation process does not imply the eight phases. The essential phases regarding an evaluation problem are dashed in a rectangle of the Fig. 1.

2.2 Fuzzy Linguistic Approach

Although we usually work in quantitative settings where the information is expressed by numerical values, sometimes we shall need to describe activities of the real world that cannot be assessed in a quantitative form, but rather in a qualitative one, i.e., with vague or imprecise knowledge. In that case, a better approach may be to use linguistic assessments instead of numerical values. The variables which participate in these problems are assessed by means of linguistic terms [15]. The fuzzy linguistic approach represents qualitative aspects as linguistic values by means of linguistic variables [15]. We have to choose the appropriate linguistic descriptors for the term set and their semantics. In order to accomplish this objective, an important aspect to analyze is the *"granularity of uncertainty"*, i.e., the level of discrimination among different counts of uncertainty. The universe of the discourse over which the term set is defined can be arbitrary, in this paper we shall use linguistic term sets in the interval $[0, 1]$. In [2] the use of term sets with an odd cardinal was studied, representing the mid term by an assessment of "approximately 0.5", with the rest of the terms being placed symmetrically around it and with typical values of cardinality, such as 7 or 9.

One possibility of generating the linguistic term set consists of directly supplying the term set by considering all terms distributed on a scale on which total order is defined [14]. For example, a set of seven terms S, could be given as:

$$S=\{s_0 : none, s_1 : verylow, s_2 : low, s_3 : medium, s_4 : high, s_5 : veryhigh, s_6 : perfect\}$$

In these cases, it is required that in the linguistic term set there exist:

1. A negation operator $\text{Neg}(s_i) = s_j$ such that $j = g$-i (g+1 is the cardinality).
2. A max operator: $\max(s_i, s_j) = s_i \; if \; s_i \geq s_j$.
3. A min operator: $\min(s_i, s_j) = s_i \; if \; s_i \leq s_j$

The semantics of the terms is given by fuzzy numbers. A computationally efficient way to characterize a fuzzy number is to use a representation based on parameters of its membership function [2]. The linguistic assessments given by the users are just approximate ones, some authors consider that linear trapezoidal membership functions are good enough to capture the vagueness of those linguistic assessments. The parametric representation is achieved by the 4-tuple (a, b, d, c), where b and d indicate the interval in which the membership value is 1, with a and c indicating the left and right limits of the definition domain of the trapezoidal membership function [2]. A particular case of this type of representation are the linguistic assessments whose membership functions are triangular, i.e., $b = d$, then we represent this type of membership functions by a 3-tuple (a, b, c). An example may be the following:

$$P = (.83, 1, 1) \quad VH = (.67, .83, 1) \; H = (.5, .67, .83) \; M = (.33, .5, .67)$$
$$L = (.17, .33, .5) \; VL = (0, .17, .33) \;\; N = (0, 0, .17),$$

The use of linguistic variables implies processes of computing with words such as their fusion, aggregation, comparison, etc. To perform these computations there are different models in the literature, such as, the semantic one [3], the symbolic one [4] or the 2-tuple representation model [6]. In the following subsection we shall review the 2-tuple model due to the fact, that it will be the computational model used in our evaluation proposal.

2.3 The 2-Tuple Fuzzy Linguistic Representation Model

This model has been presented in [6] and has showed itself as useful to deal with evaluation problems similar to the one we are facing in this paper [9].

This linguistic model takes as basis the symbolic aggregation model [4] and in addition defines the concept of Symbolic Translation and uses it to represent the linguistic information by means of a pair of values called linguistic 2-tuple, (s, α), where s is a linguistic term and α is a numeric value representing the symbolic translation.

Definition 1. *Let β be the result of an aggregation of the indexes of a set of labels assessed in a linguistic term set $S = \{s_0, ..., s_g\}$, i.e., the result of a symbolic aggregation operation. $\beta \in [0, g]$, being $g + 1$ the cardinality of S. Let $i = round(\beta)$ and $\alpha = \beta - i$ be two values, such that, $i \in [0, g]$ and $\alpha \in [-.5, .5)$ then α is called a Symbolic Translation.*

Definition 2 [6]. *Let $S = \{s_0, ..., s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:*

$$\Delta : [0, g] \longrightarrow S \times [-0.5, 0.5)$$

$$\Delta(\beta) = \begin{cases} s_i & i = round(\beta) \\ \alpha = \beta - i & \alpha \in [-.5, .5) \end{cases} \quad (1)$$

where round is the usual round *operation, s_i has the closest index label to "β" and "α" is the value of the symbolic translation.*

Proposition 1 [6]. *Let $S = \{s_0, ..., s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. There is a Δ^{-1} function, such that, from a 2-tuple it returns its equivalent numerical value $\beta \in [0, g] \subset \mathcal{R}$.*

Proof. It is trivial, we consider the following function:

$$\Delta^{-1} : S \times [-.5, .5) \longrightarrow [0, g] \quad (2)$$

$$\Delta^{-1}(s_i, \alpha) = i + \alpha = \beta$$

Remark 1: *From definitions 2 and 3 and from proposition 1, it is obvious that the conversion of a linguistic term into a linguistic 2-tuple consist of adding a value* 0 *as symbolic translation*: $s_i \in S \Longrightarrow (s_i, 0)$

This representation model has associated a computational model that was presented in [6].

3 Linguistic Sensory Evaluation Model Based on Decision Analysis

We must keep in mind that the information provided by the experts in sensory evaluation has been perceived by the senses of sight, touch, smell, taste and hearing, and therefore, those requirements are subjective and involves uncertainty, vagueness and imprecision.

Our aim is to propose a Sensory Evaluation model based on the linguistic decision analysis whose mathematical formalism will be the linguistic 2-tuple model in order to obtain accurate and reliable evaluation results. This proposal consists of the following evaluation phases that are graphically showed in Fig.2.

– *Identify Evaluated Objects.* This phase is problem-dependent and each problem identifies its objects of interest.
– *Model:* this phase defines the evaluation framework that establishes the evaluation context in which the information is assessed and the problem solved.
– *Gathering information:* the experts express their sensory knowledge about the objects by means of linguistic assessments.
– *Rating objects:* we propose to use of the 2-tuple computational model to obtain a rate for every object.

– *Evaluation results:* it consists of analyzing the results obtained in the previous phase with the purpose of achieving the evaluation process. These results can be used in different ways, such as:
  - To learn which element is better considered by the experts.
  - To know which features are better in the evaluated element.
  - To identify which aspects of an element should be improve in order to enhance its quality.
  - Etc.

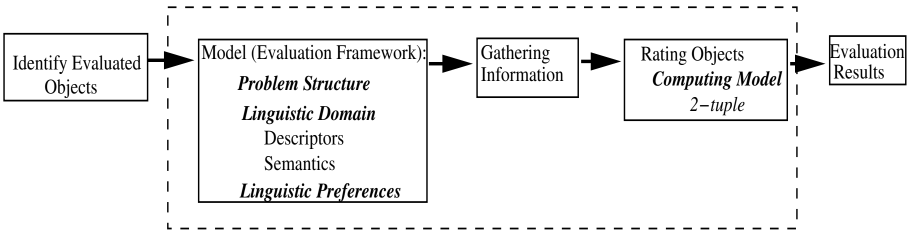

Fig. 2. A Linguistic Sensory Evaluation Scheme based on decision analysis

In the following subsections we shall present in further detail the main phases of our sensory evaluation model.

3.1 Model

This phase models the evaluation problem defining its evaluation framework, such that, the problem structure is defined and the linguistic descriptors and semantics that will be used by the experts to provide the information about the sensory features of the evaluated objects are chosen.

First of all, we must analyze which sensory features will be evaluated that depend on the evaluated object and which linguistic term set will be used to assess those features. The linguistic term set will be chosen according to:

1. *The accuracy of the evaluations:* since our senses could recognize and assess some features better than others, the granularity of the linguistic term set must be chosen according to the accuracy of our perceptions.
2. *The experience of the experts:* Some of the senses need to be trained. Therefore, the granularity of the linguistic term set used by an expert should be also chosen according to the expert's experience.

In this contribution we deal with an evaluation framework such that the different experts provide their sensory perceptions about item features by means of a linguistic label assessed in a fixed term set according to the above conditions.

3.2 Gathering Information

Due to the fact that the linguistic decision analysis we propose is based on the MEDM problems. The experts provide their knowledge by means of utility vectors that contain a linguistic assessment for each evaluated feature.

$\{e_1, ..., e_n\}$, group of experts
$O = \{o_1, ..., o_m\}$, set of evaluated objects
$F = \{f_1, ..., f_h\}$, set of evaluated features for each object
$S = \{s_0, ..., s_g\}$, Linguistic term set
e_i provides his/her preferences in S by means of a utility vector:

$$U_i = \{u_{11}^i, ..., u_{1h}^i, u_{21}^i, ..., u_{2h}^i, ..., u_{m1}^i, ..., u_{mh}^i\}$$

where $u_{jk}^i \in S$ is the assessment provided to the feature f_k of the object o_j by the expert e_i. Consequently in the gathering process every expert e_i will provide his/her utility vector U_i expressed by linguistic labels in the linguistic term set S fixed in the evaluation framework.

3.3 Rating Objects

In this phase the linguistic utility vectors provided by the experts will be used in processes of Computing with Words in order to rate each evaluated object. To do so, the information gathered will be aggregated.

This proposal will use the linguistic 2-tuple computational model, to operate with the uncertain information provided by the experts it must be remarked that several aggregation operators have been introduced for this computational model [6]. The rating process of this proposal consists of two steps:

1. *Computing collective evaluations for each feature*: in the gathering process each expert, e_i provides his/her preferences for every feature f_k of the object o_j by means of a utility assessment , u_{jk}^i. Then, the rating process in first place will compute a collective value for each feature, u_{jk}, using an aggregation operator, AG, on the assessments provided by the experts:

$$u_{jk} = AG_1(u_{jk}^1, ..., u_{jk}^n) \qquad (3)$$

2. *Computing a collective evaluation for each object*: the final aim of the rating process is to obtain a global evaluation, u_j, of each evaluated object according to all the experts and features that take part in the evaluation process. To do so, this process will aggregate the collective features values u_{jk} for each object, o_j:

$$u_j = AG_2(u_{j1}, ..., u_{jh}) \qquad (4)$$

   The aggregation operators, AG_1 and AG_2, will depend on each evaluation problem taking into account if all experts or features are equally important or there are experts or features more important than the others.
   The collective evaluation obtained will be the score obtained by the evaluated object in the sensory evaluation problem.

Table 1. Olive Oil Tasting Panel's utility vectors for the feature *sweetness*

	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8
o_1	s_4	s_2	s_5	s_3	s_4	s_5	s_2	s_7
o_2	s_4	s_3	s_4	s_2	s_2	s_4	s_5	s_3
o_3	s_3	s_3	s_5	s_4	s_3	s_2	s_4	s_2
o_4	s_5	s_4	s_4	s_5	s_6	s_3	s_7	s_3

4 Evaluating Sweetness of Olive Oil

The quality of the olive oil plays a key role in its production and final price. This quality depends on several aspects such as the condition of olives when enter the factory, the extraction processes and their sedimentation, or their storage.

The evaluation of the quality of the olive oil is usually accomplished by a testing panel that evaluate the features that describe the samples of olive oil, by means of their perceptions acquired via their senses.

The combination of smell and taste is known as flavor and defines the organoleptic properties of the olive oil. These properties, with acidity grade of the olive oil, are essential to obtain their quality. While it is easy to obtain the acidity grade of a sample of olive oil by means of chemical processes, the organoleptic properties need to be evaluated by a Tasting Panel that uses their perceptions to catch different aspects of its flavor such as fruity, bitter, pungent, etc.

Here, we shall show a simple example of how to evaluate four samples of olive oil, in order to find out the values of the organoleptic property of sweetness. These values can be used in order to decide which batches should be mixed to obtain a given flavor.

4.1 Evaluation Framework

An Olive oil Tasting Panel of eight connoisseurs $E = \{e_1, ..., e_8\}$ will evaluate the sensory feature $F = \{sweetness\}$ of four samples of Olive Oil $O = \{o_1, ..., o_4\}$. To do so, a linguistic term set S of nine terms is chosen according to conditions presented in subsection 3.1 to assess the sweetness. Its syntax and semantics are the following ones:

$s_8 : Very\ sweet : (.88, 1, 1)$ $s_7 : Rather\ sweet : (.75, .88, 1)$ $s_6 : Sweet : (.62, .75, .88)$
$s_5 : A\ bit\ sweet : (.5, .62, .75)$ $s_4 : Average : (.38, .5, .62)$ $s_3 : A\ bit\ bitter : (.25, .38, .5)$
$s_2 : Bitter : (.12, .25, .38)$ $s_1 : Rather\ bitter : (0, .12, .25)$ $s_0 : Very\ bitter : (0, 0, .12)$

4.2 Gathering Process

The preferences of our Tasting Panel for sweetness are showed in Table 1.

Now, we shall transform their preferences into 2-tuple representation model (Table 2) to manage easily this information.

Table 2. Olive Oil Tasting Panel's utility vectors for the feature *sweetness* over the 2-tuple representation model

	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8
o_1	$(s_3, 0)$	$(s_3, 0)$	$(s_6, 0)$	$(s_4, 0)$	$(s_6, 0)$	$(s_6, 0)$	$(s_4, 0)$	$(s_7, 0)$
o_2	$(s_4, 0)$	$(s_3, 0)$	$(s_4, 0)$	$(s_2, 0)$	$(s_2, 0)$	$(s_4, 0)$	$(s_5, 0)$	$(s_3, 0)$
o_3	$(s_3, 0)$	$(s_3, 0)$	$(s_5, 0)$	$(s_4, 0)$	$(s_3, 0)$	$(s_3, 0)$	$(s_4, 0)$	$(s_2, 0)$
o_4	$(s_4, 0)$	$(s_3, 0)$	$(s_4, 0)$	$(s_4, 0)$	$(s_5, 0)$	$(s_3, 0)$	$(s_7, 0)$	$(s_3, 0)$

4.3 Rating Objects

In this phase we shall carry out the following steps:

1. *Computing collective values for each feature:* In order to simplify the example we have considered that all the experts are equally important. Therefore, we have used the arithmetic mean for 2-tuples [6] for aggregating the information provided by the experts (Table 3) obtaining a collective value for sweetness for each sample according to all the connoisseurs:

Table 3. Olive Oil Tasting Panel's collective utility vector for the *sweetness*

o_1	o_2	o_3	o_4
$(s_5 = A\ b\ sw, -.125)$	$(s_3 = A\ b\ bit, .375)$	$(s_3 = A\ b\ bit, .375)$	$(s_4 = Av, .25)$

2. *Computing a collective evaluation for each object:* In this example the objective is to obtain the evaluation of the organoleptic feature. So it is not necessary to obtain a global evaluation of each olive batch according to the property analyzed. However, it is important to point out that if it would be necessary to obtain this global evaluation value we should use an aggregation method able to manage linguistic information assessed in different linguistic term sets as the methods showed in [7,8].

4.4 Evaluation Results

The purpose of this evaluation process was to find out the values of different samples of olive oil regarding their sweetness property . If we analyze the aforesaid results (Table 3), the sample o_1 obtains the highest score for it.

5 Concluding Remarks

When we face a sensory evaluation problem we must realize that we are going to work with knowledge that has been acquired via the human senses sight, taste, touch, smell and hearing. This knowledge is better expressed using words instead of numbers.

In this contribution, we have presented a sensory evaluation model based on the linguistic decision analysis and the 2-tuple computational model.

Finally we have applied this model to a specific sensory evaluation problem, the evaluation of olive oil.

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