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A fuzzy integral based methodology to elicit semantic spaces in usability tests

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ABSTRACT

Usability tests of new products require the use of methodologies based on how to validate a prototype on the basis of the user's subjective and even unconscious feelings. This is referred to as "Affective Engineering" or "Kansei Engineering". One of the main steps when applying this approach concerns the semantic description of the product domain. Semantic description of a product is represented by a set of semantic attributes (SA), a set of words describing the domain or the product to be evaluated. A major concern is to establish the importance level of each Semantic Attribute to fit the user preferences as well as possible. The present paper proposes a new methodology making it possible to select design semantic attributes (SA) and exploit data from usability tests to integrate the user's perception and identify the importance and interaction of the semantic attributes. Applied algorithm is based on the fuzzy measures, in particular the Choquet integral. The proposed approach was applied and validated in the design process of innovative insoles.

Relevance to industry: The paper proposes a new methodology making it possible to select design semantic attributes (SA) and exploit data from usability tests to integrate the user's perception and identify the importance and interaction of the semantic attributes. Applied algorithm allows designers to validate and adjust product concepts through data resulting from usability tests.

1. Introduction

In user-centred design, the product's acceptability to the user requires the use of methodologies on how to convert subjective and even unconscious feelings, about a product, into concrete product attributes (Luo et al., 2011; Yang, 2011). This is sometimes referred to as 'Affective Engineering' (or affective, emotional design) (Fung et al., 2012; Huang et al., 2010; Jiao et al., 2006). One of the elements of affective engineering is 'behavioural design', which is about the pleasure and effectiveness related to the use of a product (Norman, 2003). One method in this context is Kansei Engineering, which has been developed in Japan in order to design feelings into products (Nagamachi, 1995). Researchers are interested in exploring the relationships between the product form features and the corresponding consumer response (Chen and Chang, 2009). Some work has focused on the selection of the critical affective features (Yang and Chang, 2012), on the clustering of sub-factors in major factors (Huang et al., 2012) or on the extraction of design rules that could link design attributes (such as product form features) and customers' affective evaluation (Fung et al., 2012; Shi et al., 2012; Zhai et al., 2009).

A methodology to deploy Kansei engineering was proposed by Schütte and Eklund (2005); this methodology states that a product can be described from two different perspectives: The *semantic description* and the *description of product properties*. Subsequently, these spaces are analyzed in relation to each other in the synthesis phase, indicating which of the product attributes evokes a particular semantic impact.

The present paper is focused on the space of the *semantic description*. Semantic description of a product is represented by a set of semantic attributes (SA), a set of words describing the domain or the product to be evaluated. This application of kansei is called Hybrid Kansei Engineering (Matsubara and Nagamachi, 1997) which defines it as "*a computer database system enabling to predict the Kansei words that product properties elicit, e.g. a using prototype or mock-up*". In this case, once the main semantic attributes (SA) are established, a big concern is to determine the relevance of each SA as regards the user. At first, an initial reduction of the semantic

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space needs to be undertake through qualitative techniques such as the affinity diagrams, or quantitative techniques such as PCA Principal component or factor analysis. Another possibility, as suggested by Almagro (2011) is to use a combination of the last two techniques. These techniques are useful to reduce the semantic space and identify statistical contribution of the SA (degree of importance) or correlation among them, but still not able to quantify the role of the interaction or "synergistic effects" of groups of (SA).

Subsequently, trade-offs in iterative manner have to be carried out in order to adjust the future product as well as possible. In terms of decision-making, these trade-offs correspond to a multiple criteria decision problem.

On the other hand, as stated by Vergara et al. (2011), there is an important influence of the sensory interaction on the users' perception and assessment of the product. This phenomenon has been named in neurological sciences as multisensory integration (Ernst and Banks, 2002). Furthermore, several studies show that cooperation among senses reinforces the perception of a particular event and improve the individual's capacity to respond to a stimulus, explaining the potential success of a new product (Bosch, n.d; Làdavas, 2008; Van Ee et al., 2009). This capacity of response has been modelled by the user's preferences, provided by the multi-criteria theory. In the case of Kansei engineering, the criteria correspond to a set of semantic attributes (SA) describing the user perception of the product defined from a semantic space as proposed by Schütte and Eklund (2005). In order to prioritize the set of SA, several techniques have been widely use, such as Multi-Utility-Attribute Theory – MAUT (Malak et al., 2009; Riedel and Pitz, 1986), Analytic Hierarchy Process – AHP (Ali Khatami Firouzabadi et al., 2008; Kanda, 2005) Ordered Weighted Average – OWA (Renaud et al., 2008; Ryoke et al., 2008), Conjoint Analysis – CA (Petiot and Yannou, 2004; Jiao et al., 2006; Isiklar and Büyüközkan, 2007) or sequential fitting decomposition (Camargo et al., 2013).

An important limit of the previously cited approaches, in order to elicit the importance level of each criterion, is that most of them consider the set of criteria as being mutually independent, neglecting or underestimating the sensory interaction among semantic attributes. This fact has a non-negligible impact on the final product design and its further acceptability to users. So there is a current need to search for methodologies which make it possible to overcome the difficulty of inferring the most relevant semantic attributes, identifying the unconscious feelings and quantifying criteria interactions from the usability tests. Some approaches have dealt with sensorial data but treat each Semantic Attribute separately (Augustine et al., 2010; Zeng et al., 2010; Zhu et al., 2010). The present paper proposes a new methodology to support the semantic description dimension in Kansei deployment. So the evaluation of the Semantic Attributes (SA) allows us to exploit usability test data, making it possible to integrate the user's perception but also to identify the importance and interaction indexes that measure influences of the SA among them.

The basis of the proposed methodology is formed by the Fuzzy integrals and, in particular, the Choquet integral (Choquet, 1954). The main advantage of this integral is its ability to take into account the criteria relevance (decision maker's preferences) and interactions among them. Fuzzy integrals, and the Choquet integral in particular, have been successfully used as fusion operators in various applications (Cho and Kim, 1995; Grabisch and Labreuche, 2008), including industrial pattern recognition, in particular to identify textile fabric defects (Schmitt et al., 2008) and monitor the improvement of an overall industrial performance (Berrah et al., 2008). Furthermore, the application of a learning algorithm developed by Grabisch (1995a, b) allows to compute the fuzzy measures and the relative weight of the set of criteria. Another significant point is that the algorithm could provide relevant results, even if the sample is composed by scarce data. Such a property is very important, as in the new product development process the usability data are often scarce and incomplete or measured on few users. The proposed methodology has been applied to a process of design for innovative massing insoles, in order to identify and qualify, in terms of importance and interaction among them, the set of semantic attributes that best describes the feelings of a group of users. The experiment consists of a set of usability tests on an insole prototype with a particular geometrical shape which makes it possible to stimulate specific areas of the foot and generate a massing effect. The questionnaire is composed of a set of semantic attributes (SA) and an acceptability index of the proposed prototype in order to identify the attributes which have an impact on acceptability and interaction among them. However, since the aim is rather to present a new methodology, some aspects of the experimental study could appear as incomplete or neglected, and may be improved in future studies.

This paper is structured as follows: Section 2 presents an overview of the fuzzy measures and their properties. Afterwards, in Section 3, a description of the proposed methodology and its implementation steps is made. The proposed methodology is applied and validated to the design process of innovative insoles in Section 4. To finish, concluding remarks and perspectives are given in Section 5.

2. Overview of fuzzy measures

Following the introduction of the concept of fuzzy sets by Zadeh (1965) to introduce the notion of vagueness to the sets theory, later (Sugeno, 1974) proposed fuzzy measures and fuzzy integrals to model the subjective feeling of uncertainty (Grabisch et al., 2002). (Orlovski, 1994) has demonstrated that both approaches converge. The difference between these approaches is the fact that for the fuzzy sets theory the vagueness is represented by a membership function to a set, while fuzzy integrals construct this function from several attributes through a multidimensional model. For this reason the fuzzy integral is aimed to be used to model multidimensional subjective evaluation. The fuzzy integral concept has been also widely investigated for information fusion (Auephanwiriyakul et al., 2002; Tahani and Keller, 1990). In fuzzy integrals, aggregation operators are usually defined with respect to a non-additive fuzzy measure (μ), which describes to what degree coalitions of criteria are important for the decision. In the following paragraphs we will formalise it and see the implications for the proposed methodology.

Let us denote $X = \{C_1,\ldots,C_n\}$ as the set of n criteria, and P as the power set of X, i.e. the set of all subsets of X.

Definition 1. *A fuzzy measure or capacity, μ, defined on X is a set function μ:*

$$P(X) \to [0,1]$$

verifying the following axioms:

$$1.\ \mu(\varnothing) = 0, \mu(X) = 1, \tag{1}$$

$$2.\ A \subseteq B \Rightarrow \mu(A) \le \mu(B) \tag{2}$$

Fuzzy measures generalise additive measures, by replacing the additivity axiom ($\mu(A \cup B) = \mu(A) + \mu(B), A \cap B = \varnothing$) with a weaker one (monotonicity).

In our context, $\mu(A)$ represents the importance, or the degree of trust in the decision provided by the subset A of X. The next step in building a final decision, is to combine the partial confidence degree