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A Smart System to Standardize the Specifications of Haptic Quality Control

Bruno Albert^{a,b,c,*}, Cecilia Zanni-Merk^d, François de Bertrand de Beuvron^b, Maurice Pillet^c, Jean-Luc Maire^c, Christophe Knecht^a, Julien Charrier^a

^aINEVA, 67400 Illkirch, France

^bICube laboratory SDC team, INSA de Strasbourg, 67400 Illkirch, France

^cSYMME laboratory, Université Savoie Mont-Blanc, 74940 Annecy-Le-Vieux, France

^dLITIS laboratory, INSA de Rouen, 76800 Saint Etienne du Rouvray, France

Abstract

The specific attention paid to the quality perceived through the senses of costumers when touching a product has led to a rapid growth in the industrial interest for the field of haptics. Controlling the quality of products with such expectations has become a challenge for manufacturers, especially considering the current lack of a generic method to standardize control specifications and provide efficient control tools, whether a manual or automated control is considered. This study provides a new insight on the definition of control specifications regarding perceived quality control. Smart systems have proven useful and efficient in a number of other domains, but has never been applied in a generic manner to the control of the quality related to the sense of touch. Therefore, a system based on formalized knowledge on haptic perceptions and its relations with quality control is proposed. This paper presents the proposed approach for the standardization of haptic quality control specifications, along with an example of a manufacturing application. The structure of the proposed knowledge model is detailed, as well as the semantic approach that enabled the development of a formalized haptic sensation vocabulary. An experimental method was used to model the influence of exploration on perception, considering the application case.

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1. Introduction

Defining specifications for the control of a product that involves human perceptions remains a challenge for manufacturers. Recent studies have overcome some of these issues regarding the visual quality of products^{1,2}, but the sense of touch is still an issue in most industrial applications. In particular, domains of the industry where haptics sensations rendered by a product have an important factor on costumers satisfaction, such as wearable products (watch, bracelets,

* Corresponding author.

E-mail address: bruno.albert@ineva.fr

etc.) for instance, it is necessary to provide precise and shared control specifications, so the control protocols can be as efficient as possible.

Although the series of ISO norms related to the Geometrical Product Specifications (GPS) provides some information on surface texture specifications (e.g.³), it does not link to the human perception and to the vocabulary that can be used to describe the sensations perceived. Knowing that touch is a complex sense that involves sensory receptors spread all over the human body and that react to external or internal stimuli, the human way of expressing perceived sensations is also complex. It has evolved, along with languages to become the words we know, that can also be commonly used to describe the quality of manufactured product. Examples of such descriptions would be: "this paper page is soft", "this book is hard", etc.

However, in an industrial context of quality control, natural language tends to lead to problems because it induces the use of experience from the human controller that may not have the same perception of a similar word. For instance, one controller could perceive a page as "soft" whereas another would not, because the word "soft" might not have exactly the same meaning for these two persons, even though they both had the same sensation⁴. Thus, their perception of this sensation differed.

These issues were observed in a case study performed on a luxury watch product. In this particular case three main problems were encountered:

- The diversity of the language used to describe the expected or unexpected quality of the products, different from one person to another.
- Differences from one person to another in the perception related to a specific word.
- Disagreements on the definition of the expected quality of the product, even without using words (deciding by touching only).

Many of these problems are not specific to this case and can be observed on other applications cases and considering other industrial domains. The immediate consequences on the quality control are protocols that leave space for the human subjectivity, and hence a great variability in the acceptability decisions of the products. In order to overcome these issues and build standardized specifications for the control of the haptic quality of a product, three main contributions are proposed:

- Formalizing the vocabulary used to describe haptic sensations, in a generic way.
- Defining a precise association model between the formalized description of sensation and the descriptors (words) commonly used.
- Proposing guidelines for the definition of shared haptic quality control specifications.

In order to structure and implement the methods, a knowledge-based approach has been used. It involves the use of semantic methods for the formalization parts and an ontological representation for the structuring of the knowledge. One can note that this project focuses on the definition of specifications for the quality control process. Thus, the aim is not to study the preferences of costumers in order to design a product, although some elements of the proposed methods could possibly be used for this purpose (e.g. the formalized description of haptic sensations).

This paper is structured as follows. Section 2 presents the global structure of the proposed smart system. Section 3 details the proposed formalized description of haptic sensations and its representation in the ontological model. Finally section 4 explains the process of guiding manufacturers through the definition of the specifications using the proposed methods. These sections integrate elements of the application case performed on luxury watch bracelets.

2. Structuring haptic quality control knowledge

The use of formal models, such as ontologies, is essential for the development of smart systems. Very few studies have proposed ontologies directly related to the description of human perceptions and quality control. This is why a novel way to model knowledge related to the description and control of perceived quality was proposed and detailed in a previous publication⁵. Some elements of the global knowledge structure are reminded here, and the proposed *Sensory Perception* ontology is detailed considering the sense of touch.

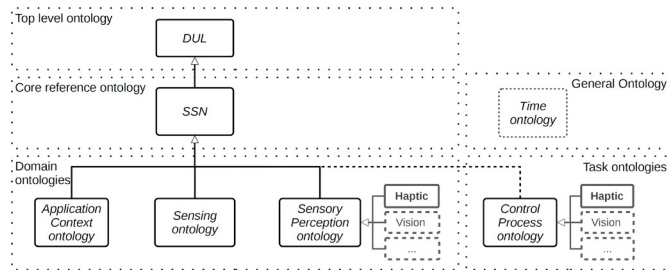


Fig. 1. General ontological structure and domain ontologies of haptic quality control.

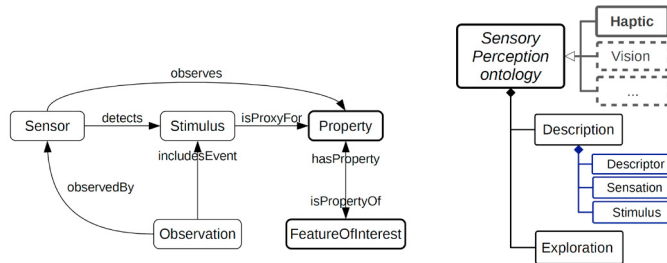


Fig. 2. (a) Extract of the SSN ontology⁶; (b) Main concepts of the proposed *Sensory Perception* ontology.

2.1. Global knowledge structure

A global ontological structure - first introduced in⁵ - is shown in Figure 1 in a refined version. It contains the different domain ontologies necessary for the development of a smart system for haptic quality control. In particular, the *Sensory Perception* ontology gathers knowledge about human senses and enables a direct correspondence with human perceptions. We specifically focus here on haptics, but the aim is to eventually gather knowledge about all senses.

The proposed model is based on a high-level ontology which provides a "skeleton" for the structure. The Semantic Sensor Network (SSN) ontology⁶ was chosen because it includes elements corresponding to properties of objects and stimuli, along with the relations between sensors and observations. Figure 2(a) is a reduced version of the SSN ontology including the stimulus-sensor-observation pattern proposed by Compton⁶. This figure focuses only on some of the entities relevant to this study. This representation involves the different concepts of interest, regarding the aim of integrating haptic perception knowledge. This extract of the SSN ontology and the proposed knowledge structure have been aligned. The details of this alignment are presented below.

The development of a domain ontology integrating haptic perception knowledge and its alignment with Compton's core ontology was detailed in⁵. The proposed ontology integrates the formalization principles previously presented, and organises them so the related knowledge can be used in the proposed Smart System for Haptic Quality Control. The developed *Haptic Perception* ontology is a part of the *Sensory Perception* ontology.

2.2. Sensory Perception Ontology

Figure 2(b) shows the main concepts of the proposed *Sensory Perception* ontology. This ontology is a generalization of the knowledge representations corresponding to each sense. Thanks to its general structure, the aim is to be as generic as possible regarding human perception.

The main concepts of the *Sensory Perception* ontology are detailed below. A direct correspondence can be made with the upper-level model shown above: *Descriptor* corresponds to *FeatureOfInterest*, *Sensation* to *Property*, and of course *Stimulus* to *Stimulus*. This structuring of the knowledge related to the sensory perception provides a way to formalize the relations between each of the concepts presented, as well as enable to propose a generic answer to the description of sensations, starting from common language.

Elementary sensation	Definition	Type of stimulus
Primarily tactile sensations (local impact)		
Grip	Sensation of stretching or holding back of the skin when touching the surface of an object.	Stretching
Relief	Sensation of vibration or sub-centimetric shapes when touching the surface of an object.	Vibration or Micro-shape
Hardness	Sensation of resistance of the surface of an object when pushing on it.	Pressure
Reactivity	Sensation of residual deformation or interaction with the surface of an object after pushing on it.	Pressure and Motion
Residue	Sensation of matter remaining on the skin after touching the surface of an object.	Persistence
Warmth	Sensation of thermal transfer between the surface of an object and the skin when touching it.	Thermal transfer
Pain	Sensation of damaging of the skin when touching the surface of an object and its edges in particular.	Damage
Primarily kinesthetic sensations (global impact)		
Weight	Sensation of mass of an object in relation to its size.	Mass, Size
Shape	Sensation of global shape of the surface of an object and its edges.	Space localisation

Fig. 3. Proposed definition of the elementary sensations, obtained from the definitions of each words and the meaning in terms of generation of each sensation (with stimuli). The links with the stimuli is also detailed.

- *Description* contains all the elements necessary for the description of the perception. *Description* is composed of three elements: *Descriptor*, *Sensation*, *Stimulus*.
 - *Descriptor* integrates the usual vocabulary for describing human sensory perceptions.
 - *Sensation* is a formalized description of human sensations.
 - *Stimulus* is the physical phenomenon that induces sensations.
- *Exploration* describes the exploration modes that enable the perception. This part is not detailed here.

In this paper, the focus is set on the description part of this knowledge model, regarding the relations between descriptors, sensations and stimuli in particular.

3. Representing usual descriptors with generic elementary haptic sensations

The proposition of a generic and structured representation of a domain starts with the comprehension of the phenomena involved in this domain. Regarding the sense of touch, and the human perception that results from this sense, stimuli are generated by the exploration, which involves a contact with the surface and sometimes a movement. The stimuli induce sensations that are expressed in a natural way by descriptors. In order to formalize knowledge related to the description of haptic sensations, a generic representation of the usual descriptors is proposed and detailed below, using the proposed elementary haptic sensations⁴.

3.1. Elementary haptic sensations

Categories of sensation were formed through a semantic analysis of several hundred descriptors of sensations related to the sense of touch⁴. The nine elementary sensations that resulted from this analysis are shown in Figure 3. The aim is to be able, using these elementary sensations, to generically describe any haptic sensation, as well as represent the usual vocabulary used for their description.

3.2. Association between usual descriptors and elementary sensations

Although usual descriptors were used for the proposition of the elementary sensations, a precise association of each word to the categories requires more investigation on the own meaning of the words and the associated sensation(s). Several ways can be followed in order to explicit these relations. One way, usually followed by sensory analysis methods^{2,7} or knowledge elicitation methods for the construction of ontologies⁸, would be to ask experts of the domain to reach a consensus for each association. However, this process would be relatively long considering the number of words involved, and would probably involve samples from a large number of application domains. This method could still be used for the validation of the proposed associations. Three approaches based on semantic analyses have been investigated in order to automate the process of building the associations. They are detailed below. In particular, they involved works from the literature (studies about sensory perceptions related to the sense of touch such as the works from Giboreau⁷, Bassereau⁹, Dumenil-Lefebvre¹⁰, Sola¹¹, etc.), as well as other sources such as Wordnet (<https://wordnet.princeton.edu/>) and the Thesaurus (<http://www.thesaurus.com/>). An example of the semantic relations found is presented in Figure 4(a).



Fig. 4. (a) Example of the raw semantic relations (synonyms here). ; (b) Example of the relations obtained between elementary sensations and usual descriptors using the first method of association: associating specific descriptors from the literature and expanding the relations using semantics ; (c) Example of the relations obtained using the second method of association: building relations with stimuli using the literature. (The software Iramuteq (<http://www.iramuteq.org/>) was used to obtain these figures)

1. Knowing that the exploration is often detailed in these papers, the stimuli involved are also sometimes mentioned. Therefore, one way to link descriptors with sensations is to look at the relations between descriptors and stimuli. Knowing the links between stimuli and sensations, it is then possible to extract precise associations for the descriptors. An example of the relations obtained is shown on Figure 4(b). However, this approach only works for some descriptors found in the literature.
2. It is also possible to use the definition of the words themselves, as well as their relations with the other words. From the semantic analysis that enable to extract categories of sensations it is possible to observe that some words are uniquely associated to one elementary sensation, and some seem to be associated to several of them. Associations of some uniquely associated words were defined using indications from the literature. This provided a basis for the complete association. Then, using semantic relations between all the words, the full association map could be automatically constructed. For example, an *icy* sensation is represented by the sensations of *grip* and *warmth*, because it synonyms of the descriptors *slippery* and *cold* which are uniquely associated to the sensations of *grip* and *warmth*.

This approach shows relatively good results. Figure 4(c) shows an example of the associations. Regarding the luxury watch example, vocabulary obtained from participants (not coarse, not smooth, not gripping, slippery) led to the selection of the sensations *Relief* and *Grip*, which were effectively relevant for the application. This confirms that the representation of these descriptors is correct. However some problems could be observed for some descriptors that do not have semantic relations with uniquely associated descriptors. In this case, a second iteration of association is performed using all the descriptors completely associated as a basis.

3. Another way to automatically generate associations is to look at the literature in a general way, i.e. as natural language. Indeed, text analysis methods automatically can provide information on the semantic associations of the words in the text. The Latent Dirichlet Allocation (LDA) method¹² was specifically investigated and applied to the multiple literature sources used in this study, while targeting only the words of interest, i.e. the usual descriptors of haptic sensations. The LDA method involves the clustering of words by themes that correspond to the semantic proximity. In particular, it uses the geographical placement of the words in the text in order to deduce their potential relations. The software R with the LDA library was used (<https://cran.r-project.org/web/packages/lda/index.html>) to apply it.

Several issues could be observed when using this type of method on the whole texts. Descriptors are often found in these papers as lists. Hence, the geographical information used to extract semantic information as done in natural language analysis, does not have much sense here. Thus, it is possible to get some idea of the associations because the words are sometimes reminded in the text, but not a precise one. Moreover, usually only specific descriptors are evoked in these papers, not all. So it is not possible to draw associations for all of them. Some sensations are also under-represented in the literature regarding the number of words. However, increasing the number of papers taken in the analysis might improve the results.

The LDA method was also directly applied on the list of descriptors and their synonyms. This approach shows much better results. As input of the LDA method, nine clusters were searched, in regards to the nine elementary sensations found. The result is a probability of association of each descriptor to each cluster. Considering that

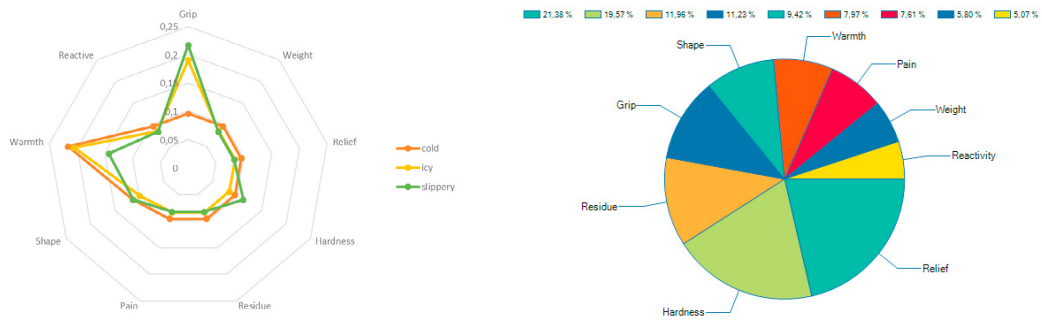


Fig. 5. (a) Example of an association result obtained using the lda method. ; (b) Percentage of descriptors associated to each elementary sensation. Results obtained using a mix of the two first approaches.

the clusters found do not have labels, it is necessary to find the corresponding elementary sensations. This task can be done using the basis mentioned above for some specific descriptors. Figure 5(a) shows an example of the association of the descriptors *slippery*, *icy* and *cold*. It illustrates the capacity of the method to provide accurate association for some of the descriptors. However, when restricting the method to nine clusters, and considering the number of words potentially associated to each sensation, some sensations are not clearly found as clusters. In the analysis performed, issues could be especially observed with the sensations of *Pain*, *Weight* and *Reactivity*, although these elementary sensations clearly showed separate groups in the semantic analysis performed to find them⁴.

To conclude, several methods were tried in order to provide a precise association between usual descriptors and elementary sensations. A mixed approach was used from approaches 1 and 2. Approach 3 using the LDA method could be used in future improvements, but the correctness of the results needs to be proven in order to use it, especially in regards to the non equal distribution of the words on each category (Figure 5(b)). Application cases are also a way to verify the associations, as well as to enrich them.

3.3. Ontological model of haptic sensory description

To access and enrich formalized knowledge in a convenient way, it needs to be organized and modeled so it is possible to reason on it. The structure proposed above was hence used to gather descriptors, sensations and stimuli, as well as the relations between them. The formal relations are the following: *Sensations represents Descriptor* ; *Stimulus induces Sensations* - with the object properties *represents* and *induces*. The proposed *Sensory Perception* ontology was filled out with the associations found, while leaving the possibility to update it for improvements and enrichment of the model. An example of the proposed ontology was presented in a previous publication⁵. A level of intensity of the sensation is also associated to each descriptor. For instance, the descriptor *slippery* is represented by the elementary sensation *Grip* with an intensity level of 1 out of 5. For some descriptor, ranges of intensity can also be considered. The notion of intensity is modelled by a data property in the ontology. Though, as this is not the main purpose of this article, the associated intensity is not detailed here.

4. Guiding manufacturers through the definition of haptic quality control specifications

Considering an industrial application case, the input of the formalization process is the vocabulary used to describe expected specification elements. Although this seems natural, it is not always easy for manufacturers to express this initial vocabulary. Guidelines are hence proposed to acquire usable inputs to provide formalized specifications.

4.1. Expressing usual vocabulary about expected sensations

In the context of sensory quality control, several ways of expressing this initial vocabulary are possible. Three of them are presented below.

Controller 1		
Job: Jeweller		
Age: 25-30		
Sample	Evaluation	Comments
1	KO	Coarse
2	OK	Not gripping
3	KO	Too smooth

Expected sensations	Unexpected sensations
1. slippery	1. coarse
	2. gripping
	3. smooth

Fig. 6. (a) Example of the evaluation of some samples and the comments given by a controller. ; (b) Example of the input vocabulary for the considered application case.

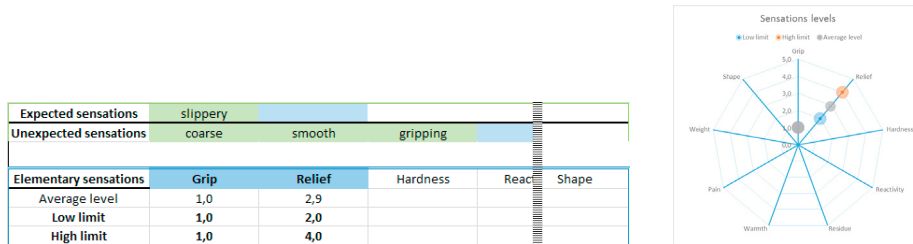


Fig. 7. Elements of the user interface used to input the descriptors and visualize the formalization results.

A specific problematic situation can often be identified when quality control issues are observed, because of defects not detected by the current quality control method, products returned from of unsatisfactory costumers, etc. The words used when expressing this problematic situation sometime integrate elements regarding the expected or unexpected haptic sensations that can be used for the formalization process.

The use of samples of the problematic products is also often a good solution to express some vocabulary about expected sensations. The samples can be real products or samples simulating the variability in the realisation of the surface. The purpose is to bring people to either judge the compliance of the surface of a sample or comparing several samples in terms of acceptability, and explaining the judgement or the ranking (as done in some studies focused on sensory analysis, e.g.¹³). This generally provides a relatively complete vocabulary of the sensations related to a specific product, as well as the differences between expected and unexpected elements. For instance, in the application case performed, this technique enabled to acquire all the words necessary for the analysis. Figure 6(a) shows an example of the comments given by a controller when judging the samples.

It is also possible to use the proposed formalized description as a guide to choose the words corresponding to expected or unexpected sensations. The method would be used in case the two others do not provide sufficient vocabulary, or in order to complete it.

The last step in the acquisition of the input vocabulary is to order the words. This can be done using several techniques. A simple one is to order them in a list, as shown on Figure 6(b). Other methods such as the analytic hierarchy process (AHP) could also be used when dealing with more descriptors.

4.2. Providing formalized and adapted quality control specifications

The acquired vocabulary can be used as an input of the smart system, which performs a query on the knowledge model described. These words enable to identify the elementary sensations of interest. The formalization process also provides a specific range of intensity level of sensation, as well as the appropriate exploration modes, but these points are not detailed in this papers as it is not its main purpose.

The specifications are given by the proposed generic definition of a haptic anomaly: A haptic anomaly is defined by a difference between the measured and the expected intensity levels of an elementary haptic sensation.

Thus, several haptic anomalies can be considered for one product. They correspond to the elementary sensations of interest identified by the formalization process. Considering the case study mentioned throughout this paper, the sensation of *Relief* and *Grip* were identified. Figure 7 shows the results of the formalization for the application case. One can note here that, on the contrary to visual anomalies¹, a haptic anomaly can also be a sensation that is too low. Meaning that the evaluation method has to take it into account.

5. Conclusions and perspectives

In regards to the observations made from an industrial application case, three contributions were developed in this paper, in order to provide a smart system for the standardization of haptic quality control specifications. First, a generic and formalized description of haptic sensations was introduced with the representation of usual descriptors using the proposed generic elementary haptic sensations. The structuring of the knowledge using ontologies enabled to propose a knowledge model of the description of sensory perceptions, focused on the sense of touch. Finally guidelines were detailed in order to help manufacturers define sensory quality control specifications, based on the proposed formalization principles. Therefore, this work provides answers to the problems of having a shared common language for the description of haptic sensations, as well as agreeing on definitions of haptic quality control specifications.

The results of the application case show an increase in the performance of the control of 16% in terms of repeatability and 33% in terms of reproducibility of the acceptability decisions compared to evaluations from experts. The specific control method developed, based on the proposed definition of haptic anomalies, were not the purpose of this paper and will be detailed in future publications.

This work introduces new perspectives in the possibilities of enrichment of the proposed model using a variety of application cases, from different industrial domains. The addition of context in the model would also enable to be more precise in the suggestion of words by the system or in the way usual descriptors are analysed by the smart system.

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