A Smart System for Haptic Quality Control
Introducing an Ontological Representation of Sensory Perception Knowledge

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Abstract: Perceived quality has become an important factor in the choice of products by customers. The human perception process involves complex phenomena at a physical and psychological level that enable us to sense the world and extract information about it. Because of the qualitative way humans represent and communicate sensations, the field of sensory perceptions makes extensive use of semantics. The use of knowledge-based systems in the field of perceived quality is hence natural. This project focuses on haptics in quality control in industry. In particular, the aim is to develop a smart system which will enable to make decisions about the haptic quality of a product. This paper introduces the framework used for the development of this smart system, based on the KREM model. An ontological structure is proposed in order to represent knowledge related to the measure of sensory perceptions in general, and of haptic ones in particular. The proposed domain ontologies about haptic control, that were elicited using semantic analysis, are aligned with the SSN ontology.

1 INTRODUCTION

Humans perceive the world and particularly objects in the world through their different senses, which allow them to not only understand, but also make their own opinion and judgment about these objects. Considering this fact, perceived quality has naturally become a major factor of the choice of products by customers. In an industrial context, controlling perceived quality is often limited to controlling the visual aspect of products, which in some cases is enough, but in most cases does not fully correspond to the perception a customer can have when interacting with a product. In particular, the action of touching the product usually comes right after a first visual observation.

Touch involves complex physical and psychological phenomena which lead to very precise but also very subjective haptic perceptions. Haptic perceptions are a combination of tactile and kinesthetic perceptions (Lederman and Klatzky, 2009). Tactile sensations are obtained thanks to sensory receptors localized in the skin. Kinesthetic sensations are obtained thanks to receptors localized in muscles, tendons and joints. As a simplification, considering contacts with a product, tactile sensations can be understood as the sensations obtained locally on the surface of the product and kinesthetic sensations as the ones obtained more globally over the product.

Therefore, on the one hand the control of haptic sensations involves the comprehension of the process of creation of haptic perceptions, at physical and psychological levels. On the other hand, it involves the formalisation of this knowledge in order to extract control protocols and make this knowledge usable by an automated system. In this context, knowledge based systems are especially suitable.

The KREM framework is presented in section two for the development of a Smart System for haptic quality control. This framework highlights the use of four main components (knowledge, rules, experience, meta-knowledge) to take into account the specificities of the system to be developed. In particular, this paper details the Knowledge component. An ontological structure is introduced in section three. It presents the different domains of knowledge involved and the corresponding ontologies, as well as the upper level ontology used to structure the concepts. A domain ontology structuring haptic knowledge is then presented in section four, with the integration of the proposed formalization of the haptic sensations.

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2 A FRAMEWORK FOR THE DEVELOPMENT OF A SMART SYSTEM FOR HAPTIC QUALITY CONTROL

One framework used in order to develop a smart system is the KREM model (Zanni-Merk, 2015), that has been successfully used in several different domains (Zanni-Merk et al., 2015; Gartiser et al., 2014).

Conventionally, a smart system is composed of a fact base and a rule base, on which various types of reasoning can be made. But the observation of the drawbacks of this classic architecture (the difficulties in eliciting expert knowledge, mainly because experts operate tacit knowledge, and basically, the non-completeness of this elicitation (Milton, 2008)) led to the proposal of this model, based on the use of semantic technologies.

Semantic technologies use methods from automatic language processing, machine learning and knowledge representation to build the ontologies and the rules that will enable its implementation. Semantic technologies are also intended to create new meaningful relationships, and therefore new knowledge, based on information of different natures and forms. Enriching documents with meta-data or creating specific linguistic or terminological standards are examples of the possibilities offered by semantic technologies to facilitate decision making through effective knowledge management.

But decision-making, to be effective, must result from reasoning and analysis on this knowledge and must also take into account the experience and expertise of decision-makers. Naturally, the capitalization of experience appeared as a possibility of improvement of the architecture, in the form of specific knowledge structures and reasoning mechanisms, such as SOEKS (set of experience knowledge structure) (Sanín and Szczerbicki, 2009) and CBR (case based reasoning)(Aamodt and Plaza, 1994).

Finally, the use of meta-knowledge to lead the execution of our knowledge-based systems became a need. Meta-knowledge is knowledge about the domain knowledge, the rules or the experience. It can be in the form of context, culture or protocols that steer the use of that knowledge. Context is any information that characterizes a situation related to the interaction between human beings, applications and the surrounding environment (Dey et al., 2001) and is identified as belonging to four types: identity, location, status, time. Context is typically the location, identity and state of people, groups, and computational and physical objects. Time is information that helps to recognize a situation using historical data. The Culture aspect of meta-knowledge intends to reflect the different ways decisions are made in different cultures while Protocols include typically the ways the other pieces of knowledge are used to accomplish the task we are facing to (for example, diagnosis); or strategies for problem solving or heuristics. Meta-knowledge may be closely related to experience knowledge.

Figure 1: The KREM architecture with its four interrelated components: Knowledge, Rules, Experience and Meta-knowledge.

To take these ideas into account, the KREM model has four interacting components that can be declined by project or application domain. The re-use of components is, of course, encouraged. The KREM components are (Figure 1):

- The *Knowledge* component that contains the domain knowledge to operate, by means of different domain ontologies.
- The *Rules* component that allows different types of reasoning (monotone, spatial, temporal, fuzzy, or other) depending on the application.
- The *Experience* component that allows the capitalization and re-use of prior knowledge.
- The *Meta-knowledge* component, including knowledge about the other three bricks that depends on the problem.

The way the domain knowledge is formalized will shape the way the rules are expressed. Experience will complete the available knowledge and rules. Finally, meta-knowledge will directly interact with the rules and the experience to indicate which rules (coming from experience or from the initial rule set) need to be launched according to the context of the problem to solve.

A modular architecture, such as KREM, is one of the main architectural design pattern for large and complex systems. In this pattern, each module or component has a specific functionality providing separation of concerns that, in turn, support re-use or replacement (*i.e.* changes in a single module would not affect the others, permitting the continuous operation of the system). Moreover the communication between modules needs to be based on well defined interfaces to provide low coupling.

Formalising and structuring Knowledge are the first steps of the development of the Smart System. The following sections are hence focused on the Knowledge component, which will eventually be integrated to a larger KREM architecture and therefore coupled with the other modules previously presented.

3 TOWARDS AN ONTOLOGICAL STRUCTURE FOR HAPTIC QUALITY CONTROL

The use of formal models, such as ontologies, is essential for the development of a smart system. However, very few studies have proposed ontologies directly related to the description of human perceptions, or more specifically to the perceived quality. One rare example of a similar domain ontology has been proposed by (Myrgioti et al., 2013), but this study focuses on software development for haptic interfaces. This section presents the proposed ontological structure for the measuring of sensory perceptions and its particularization towards haptic quality control.

3.1 Upper-level Conceptual Model

The first step in the construction of a conceptual domain representation is the identification of the general ontological structure in which the domain ontology can be included. In particular, the use of a high-level ontology is essential in order to form the "skeleton" of the structure. There are multiple upper-level ontologies, but we will focus here on the Semantic Sensor Network (SSN) ontology (Compton et al., 2012), supported by the W3C [1], that has been identified as particularly relevant considering the context of the study and the opportunities of further development. Compton et al. (2012) introduced the SSN ontology in order to describe sensors and observations. Besides the perspectives of future development of the present study around the system of sensors, the SSN ontology proposes a way to conceptualize the links between properties, sensors and observation. In addition, SSN is a core ontology that is based on the well-known top-level DUL ontology (DOLCE+DnS_Ultralite, 2010).

Figure 2 is a reduced version of the SSN ontology including the stimulus-sensor-observation pattern proposed by (Compton et al., 2012), focused only on some of the entities relevant to this study. This representation involves the different concepts of interest, regarding the aim of knowledge integration about haptic perception, as well as future automation of the process. An alignment between this extract of the SSN ontology and the proposed domain ontology is presented below.

[1]World Wide Web Consortium (http://www.w3.org/)

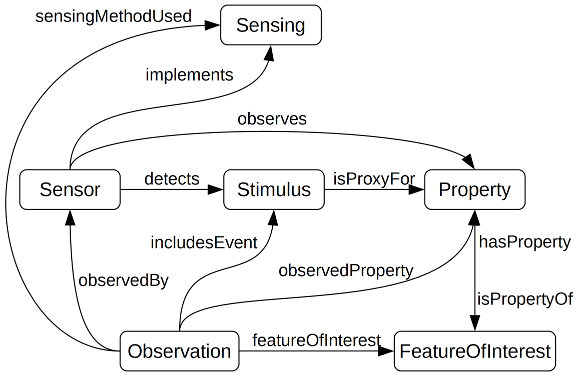

Figure 2: Extract of the SSN ontology (Compton et al., 2012).

3.2 Global Ontological Structure

Because of the diversity of domains involved in the control of the haptic quality of products, an ontological structure is proposed in Figure 3. It aims at organizing knowledge that composes each domain into different domain ontologies, which can be aligned to the upper-level ontology, i.e. the SSN ontology here. This ontological structure is presented as a classical ontology hierarchy (Roussey et al., 2011) with a top-level ontology, a core ontology, a general ontology, a task ontology and multiple domains ontologies. The domains involved here are: the sensors, the objects of study (products to be controlled), the sensory perceptions (and haptic perceptions in particular) and the context. In addition, the control process is represented as a task ontology.

The haptic quality control will then make use of the elements of each of the domain ontologies, in a flexible and adapted way following the context of application and industrial constraints (formalised throughout the *Context* ontology). The following section focuses on the *Haptic Perception* ontology which gathers knowledge about haptics and enables a direct correspondence with human perceptions. The other domain ontologies involved in this structure are part of the development process for the formalization of haptic quality control, but they will not be extensively detailed in this paper. Here is a brief description of these ontologies : the *Sensor* ontology gathers knowledge about industrial sensors which are relevant for the measuring of sensations. The *Object of Study* ontology contains information about the products or the samples on which the quality control is performed. The *Control Process* ontology aims at gathering the tasks and protocols necessary in order to perform the quality control. Moreover, the *Context* and *Control Process* ontologies are mainly part of the Meta-knowledge components.

In addition, the proposed ontological structure has been made general enough in order to foresee possible utilization with other kinds of senses, for instance vision, hearing or taste, as shown with dotted line boxes in Figure 3.

4 HAPTIC DOMAIN ONTOLOGY

This section presents our first developments of a domain ontology integrating haptic perception knowledge and its alignment with Compton's core ontology. In order to develop this ontology it was necessary to start with the gathering of knowledge about this domain, by understanding the main concepts involved as well as structuring and formalizing the vocabulary involved. The proposed haptic perception ontology is then detailed and an example is presented.

4.1 Formalization of Knowledge about the Haptic Domain

The sense of touch has been widely studied at a biological level in order to understand how it works. A summary of the perception process is presented hereafter. Considering the description of sensations, only few studies have proposed to analyse and select descriptors. Moreover, these studies usually focused on specific types of application and material. A more general and generic approach is proposed here. It intends to formalize and structure knowledge about haptics by gathering relevant vocabulary and relations from multiple sources, such as sensory analysis studies as well as vocabulary databases, and extracting sensation classes.

4.1.1 Perception Process

The process of creation of a tactile perception starts with touch, which can be defined as the stimulation of the skin by thermal, mechanical, chemical or electrical stimuli. Sensory systems, and sensory receptors in particular, activate as soon as a stimulus is detected. They transform the energy received through the stimuli into electrical energy by a change of neuronal electrical potential (transduction). Encoded information is then processed by the nervous system in order to produce sensations. Sensory systems located in the nervous system interpret these sensations by comparison to memories and known sensations. Perceptions are the results of this process. A schematic view of the tactile perception process is provided in Figure 4 (De Boissieu, 2010) and De Rossi and Scilingo (2006).

In principle - and considering similar external conditions such as temperature, humidity, level of tiredness, etc. - a sensation is identical, or near-identical, for everybody. However, a perception differs from one person to another, and depends on experience and/or culture.

4.1.2 Usual Haptic Sensation Descriptors

Humans communicate about sensations using words. The field of sensory perceptions makes hence great use of semantics. In particular regarding haptic sensations, more than 200 descriptors could be listed, as a result of the search performed across the literature. Some examples are provided below, along with the specificity of these descriptors.

Descriptors found in the literature are usually related to specific types of product and material. They also depend on the language and culture of the controllers. Sensotact (Crochemore et al., 2003) is a reference method introduced by Renault in order to describe the tactile perceptions of vehicle interiors. It employs ten descriptors distributed following the exploration mode (hardness, responsiveness, memory effect, sticky, fibrous, relief, scratchy, blocking, slippery and thermal). Considering textile products only, Issa et al. (2005) proposed six invariant descriptors common to French and English languages (flexible/rigid, falling, thin/thick, soft, creasable, responsive). In the same field of application, Picard et al. (2003) found five pairs of descriptors (soft/rough, thin/thick, mellow/hard, smooth/rough, pleasant/harsh), from a set of twenty-four and Sola (2007) listed fourteen descriptors. Considering paper sheets, Summers et al. (2007) reduced it to two descriptors (rough and stiff). In the field of packaging, Dumenil-Lefebvre (2006) suggested two groups of descriptors, respectively for the tactile description of ground-glass (sticky, rough, granular, slippery, cool, greasy) and a multi-material group, including plastic, cardboard, etc. (adherent, sticky, supple, elastic, markable, rough, granular, slippery, scratchable, cool).

The descriptors listed in the different studies are hence very different from one product to another, as well as from one type of material to another. While some descriptors are common across different materials (for instance, soft that is used similarly for wood, fabric, leather, ceramic), some others are very specific to one type of material. For example, descriptors like

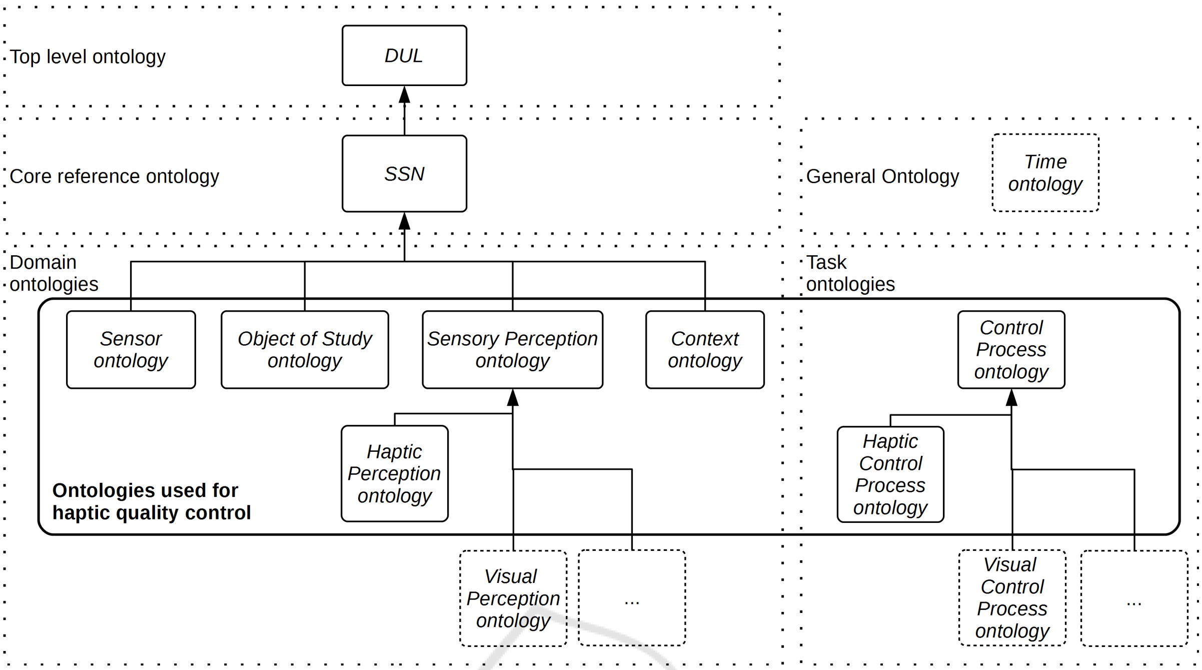

Figure 3: General ontological structure and domain ontologies of haptic quality control.

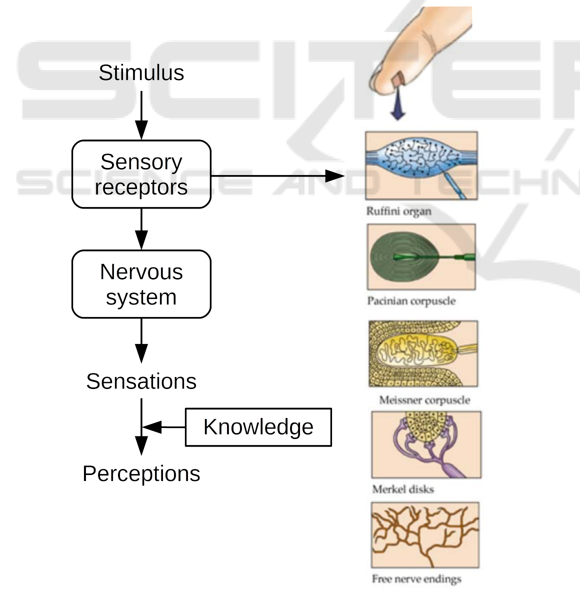

Figure 4: The human tactile perception process. Inspired from De Boissieu (2010) and De Rossi and Scilingo (2006).

furry, fuzzy, fluffy, etc. are mainly used for the description of fabric.

Translations from one language to another can also make these lists change, because the correspondence between the meanings of translated words is not always complete, or can be expressed with several different words, following the context. For example, *frais* in French could be translated into *fresh* or *cool*. Some words also do not have any translation, which is the case of *bouchardé* in French which comes from a tool: the *boucharde*, which is originally used to print marks on concrete (Sola, 2007). Differences between cultures, often represented by the difference in language, can sometimes induce a difference in the meaning of the same words, for example a sensation of cold might not be perceived the same way by people living in cold or hot areas.

4.1.3 Formalizing Haptic Sensations

Considering the diversity of the vocabulary used in order to describe haptic sensations, there is a strong need for the formalisation of the way these sensations are described. For instance, studies performed in the context of visual quality control (Baudet, 2012; Maire et al., 2013) demonstrated the feasibility of reducing the list of descriptors used and therefore formalizing visual aspect anomalies.

The proposed method makes use of the semantic characteristics of the descriptors in order to extract generic categories of haptic sensations. In particular, a classification of the usual descriptors was performed. First, semantic relations between descriptors were used in order to group them. Synonym and antonym links were drawn from semantic databases like Wordnet [2] and the Thesaurus [3]. Then, a graphical

[2]WordNet: https://wordnet.princeton.edu/
[3]Thesaurus: http://www.thesaurus.com/

tool [4] and the OpenOrd method (Martin et al., 2011) were used in order to gather elements with strong relations and spread the ones with weak relations. The result is shown in figure 5. The OpenOrd method involves the computation of the distance between nodes (descriptors), by minimizing a formula containing attractive and repulsive terms. This grouping enabled to extract categories from the meaning of the descriptors contained in these main groups.

Descriptors were also classified following three semantic axes proposed by Sola (2007), which focus on the origins and meaning of the descriptors. These semantic axes (source, effect and physical property) highlight the semantic foundations of the descriptors and the links with the characteristics of a surface. The source axis refers to a perception (sensation complemented with knowledge and experience), e.g. *oily* refers to *oil*. One needs to have the knowledge of what *oil* is to understand what an *oily* sensation is. The effect axis refers to sensations, which involve a judgement from the evaluator. These sensations are hence subjective, or even hedonic. Finally, the physical property axis refers to a non-hedonic sensation, which can be directly measured. This classification enabled to select descriptors which were relevant to each category, and useful as an objective description of specific levels of each category of sensation. Hedonic elements (which form a separate group in figure 5) were not selected, because of the strongly subjective judgement they involve.

4.1.4 Elementary Haptic Sensations

As a result of the categorization previously presented, a set of nine elementary haptic sensations is proposed. These elementary sensations correspond to the groups identified in the classification step - with one exception of a central group (including *homogeneous* and *heterogeneous*) corresponding to general characteristics of the other descriptors. These elementary sensations are hence designed to cover all haptic descriptors listed and to be used in order to describe them in a formalised manner. Moreover, considering that these classes were constructed using descriptors from all kinds of domains of application, they enable a generic description of tactile sensations. In particular, the descriptors found in the literature, and presented above, can be described by at least one elementary sensation. Table 1 shows the list of nine elementary sensations, organised following tactile sensations and kinesthetic sensations. In this Figure, an association of stimuli and exploratory movements is also proposed. It was constructed thanks by extracting relations between stimuli and descriptors in the following studies : (Lederman and Klatzky, 2009; De Boissieu, 2010; Bensmaïa and Hollins, 2005; Jones and Lederman, 2006; Crochemore et al., 2003).

Table 1: Proposed elementary sensations, and associated stimuli and exploratory movements.

Elementary Sensation	Type of stimulus	Exploratory movement
Tactile sensations (local)		
Grip	Stretching	tangential, orthogonal
Relief	Vibration	tangential
Hardness	Pressure	orthogonal
Responsiveness	Pressure, Space localisation	orthogonal
Residue	Persistence	tangential, orthogonal
Warmth	Thermal transfer	static
Pain	Damage	orthogonal, static
Kinesthetic sensations (global)		
Weight	Pressure, Lift, Space localisation	lifting
Shape	Space localisation	envelopping

[4] Gephi: Open graph visualisation platform, url: https://gephi.org/

4.2 Haptic Perception Ontology

The formalized knowledge about the haptic domain was then used to design a domain ontology of haptic perceptions. Figure 6 shows an extract of the proposed haptic perception ontology. It was obtained using OWLGrEd (Bārzdiņš et al., 2010). A UML-like notation is used, where boxes are OWL classes, thick lines are hierarchical relations and thin lines are restrictions, labeled with object properties. Only a subset of the concept and relation restrictions are displayed for the sake of clarity, and in order to show a specific example of the characterisation of the descriptor *Slippery*. The complete ontology includes all the elements of Table 1 as well as the full list of descriptors.

The main concepts of the more general sensory perception ontology are: *Exploration*, *Stimulus*, *Sensation* and *Descriptor*. *Exploration* describes the way the stimulus is generated. *Receptor* refers to human sensory receptors which detects stimuli. *Stimulus* is the physical phenomenon that induces sensations. *Sensation* is a formal description of human sensations. It gives insights on *Descriptor* which integrates the vocabulary usually used to communicate about perceptions. In addition, individual stimuli are characterized by individual elements of *PhysicalParameter*. These elements are a decomposition of the physical properties that characterise stimuli. They are intended to be as low level as possible in order to provide elements for the control process as well as to es-

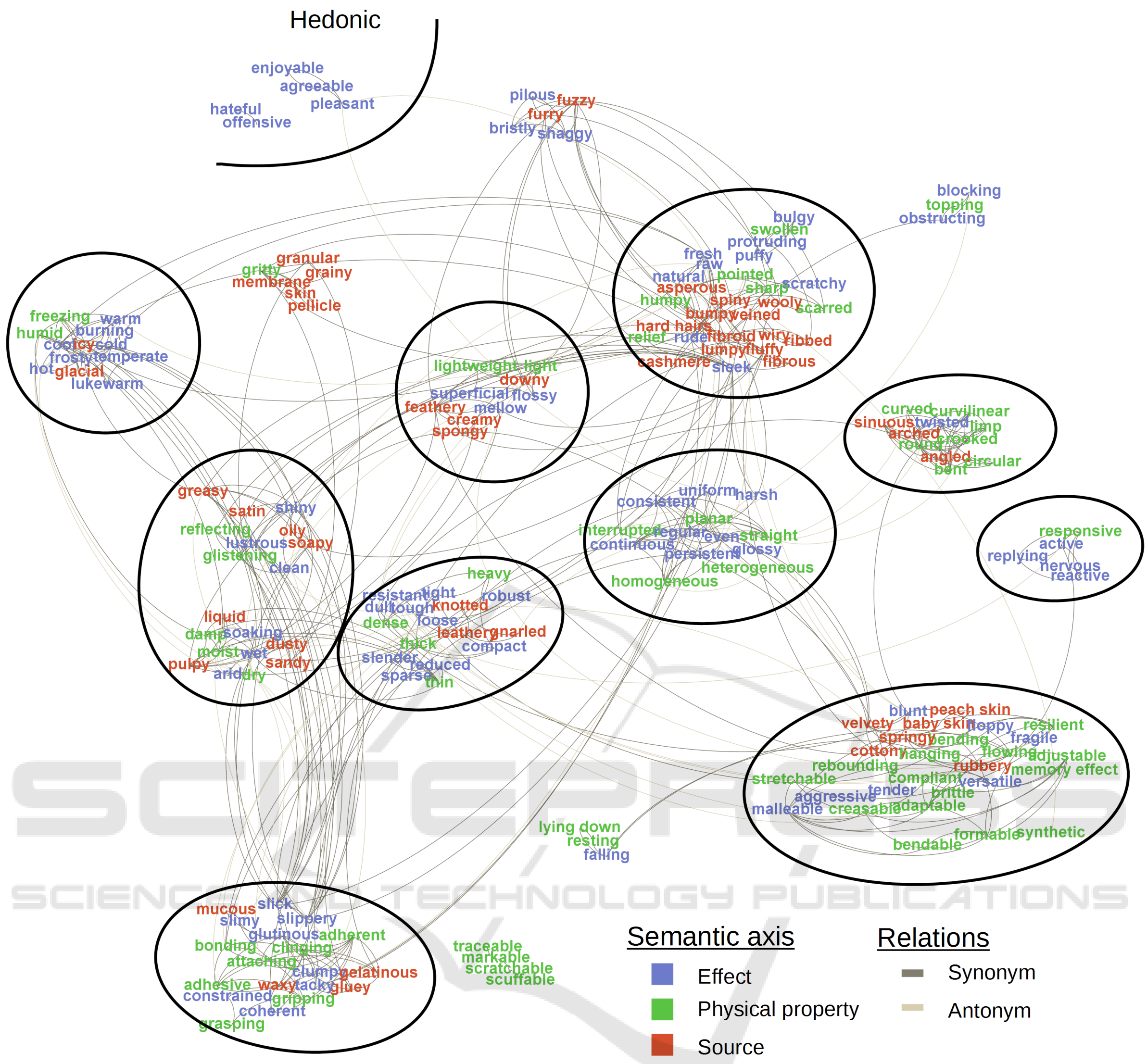

Figure 5: Extraction of categories from usual haptic descriptors using semantic classification methods.

tablish future relations with sensors.

Regarding haptic perceptions in particular, the concept of *Exploration* integrates the elements necessary for the stimuli to be generated. This includes parameters of the movements and contacts to be performed. The concept of *Stimulus* integrates the physical characteristics measured by human receptors, i.e. for instance *Pressure*, *Stretching*, *Persistence*, etc. The concept of *Sensation* integrates the proposed formalisation of haptic sensations previously presented. The elementary sensations are distributed on the two classes *TactileSensation* and *KinestheticSensation*. The usual descriptors are grouped under the concept *Descriptor* and are related to corresponding sensation categories.

Figure 6 serves also as an example of the relations involved in the description and characterization of the descriptor *Slippery*. First, the performed formalization of haptic knowledge provides information on relations between the usual descriptors and the proposed elementary sensations. Considering this specific example case, it is possible to establish that the elementary *Sensation* of *Grip* uniquely describes the *Descriptor Slippery*. *Grip* is sensed through the *Stimulus Stretching*. This specific type of *Stimulus* is characterized by the physical parameters *TangentialDeformation* and *TangentialForce*.

indent Thus, this representation provides all the elements necessary to link haptic sensations - and even more specifically usual descriptors of these sensations - to the physical properties of the stimuli that can be measured in order to provide intensity values of hap-

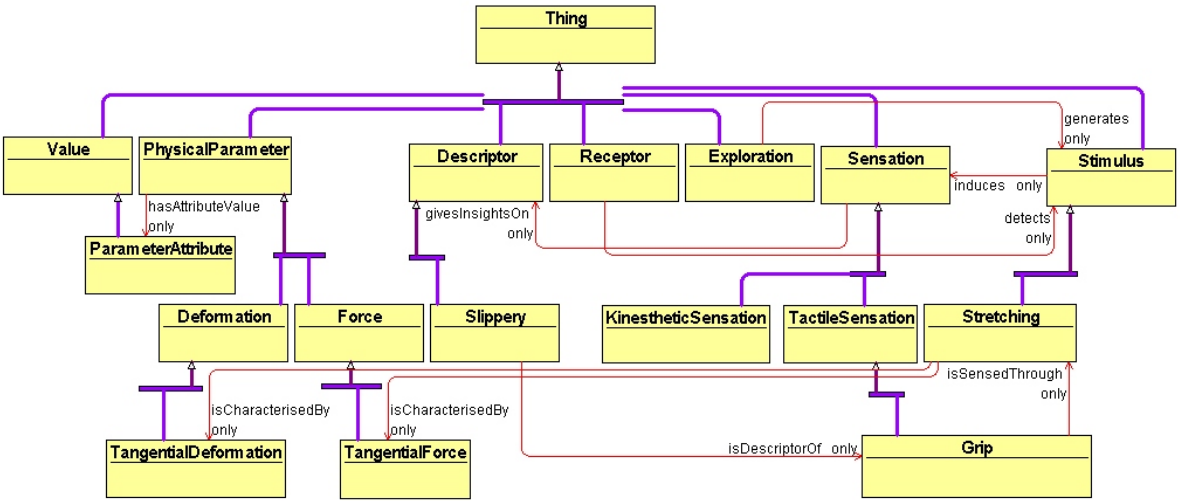

Figure 6: Extract of the proposed *Haptic Perception* ontology.

tic sensations. Moreover, this ontology also provides the related exploration parameters, as well as the sensory receptors involved in the perception process (not fully displayed in Figure 6).

4.3 Alignment to the SSN Core Ontology

Considering the aim of applying haptic perception knowledge to quality control, the higher level *SSN* ontology brings a formal structure to the proposed concepts and will enable to reason about it in a more general manner. Indeed, *SSN* is designed to provide a formal ontological framework to represent the interactions between sensors and properties, or more generally between a sensing system and features of interest.The alignment to a part of the *SSN* ontology, and more specifically to a part of the sensor-stimulus-observation pattern, is relatively natural considering the concepts proposed in the *Haptic Perception* (HP) ontology. The following alignment is proposed :

$$HP : Sensation \sqsubseteq SSN : Property$$
$$HP : PhysicalParameter \sqsubseteq SSN : Property$$
$$HP : Descriptor \sqsubseteq SSN : FeatureOfInterest$$
$$HP : Stimulus \sqsubseteq SSN : Stimulus$$
$$HP : Exploration \sqsubseteq SSN : Sensing$$
$$HP : Receptors \sqsubseteq SSN : Sensor$$

In particular, in the SSN ontology, *SSN:Property* is defined as an observable characteristic of real-world entities (*SSN:FeatureofInterest*), which are not directly observable. *HP:Descriptor* can be aligned to *SSN:FeatureofInterest*, because it corresponds to the way people usually communicate about sensations, which is not directly observable. On the contrary, *HP:Sensation* and *HP:PhysicalParameter* correspond to observable characteristics of *HP:Descriptor*. They can hence be aligned to *SSN:Property*.

5 CONCLUSIONS AND PERSPECTIVES

This work sets the basis for the development of a Smart System for haptic quality control. The main architecture of the System was presented with the use of the KREM model which provides a separation of the modules involved in the development of this system, while still enabling interaction between them. This allows for more flexibility in the development, considering future applications of the system, in particular regarding the integration of experience. The *Knowledge* component of this architecture was explored and detailed in this paper, with the proposition of a general ontological structure adapted to the constraints of the project.The high-level SSN ontology was used in order to structure knowledge corresponding to the multiple domains involved in the development of a Smart System for haptic quality control. The domain ontology integrating haptic knowledge was specifically presented. The formalization of haptic knowledge was first detailed with the proposition of generic elementary haptic sensations. Haptic knowledge was then conceptualised into the proposed *Haptic Perception* ontology and aligned with the SSN ontology.

The next steps of the development of a Smart System for haptic quality control include the development of the *Meta-knowledge* and *Rules* modules of the KREM architecture. In particular, the extraction of control rules will be realized through the application of the proposed formalization of haptic knowledge on case studies. While expert knowledge enabled a validation of the semantic analysis, the industrial testing being performed will provide more specific evaluation material. Moreover, the establishment of the influence of the application context will enable to select adapted rules. Furthermore, the proposed system being intended to automate haptic quality control, knowledge about sensors and objects of study will also be explored, as well as the relations between data from the sensors and haptic sensations which correspond to the problem of symbol anchoring.

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REFERENCES

Aamodt, A. and Plaza, E. (1994). Case-based reasoning: Foundational issues, methodological variations, and system approaches. *AI communications*, 7(1):39–59.

Bārzdiņš, J., Bārzdiņš, G., Čerāns, K., Liepiņš, R., and Sproģis, A. (2010). Uml style graphical notation and editor for owl 2. In *Perspectives in Business Informatics Research*, pages 102–114. Springer.

Baudet, N. (2012). *Maîtrise de la qualité visuelle des produits - Formalisation du processus d'expertise et proposition d'une approche robuste de contrôle visuel humain*. PhD thesis, Université de Grenoble.

Bensmaïa, S. and Hollins, M. (2005). Pacinian representations of fine surface texture. *Perception & psychophysics*, 67(5):842–854.

Compton, M., Barnaghi, P., Bermudez, L., García-Castro, R., Corcho, O., Cox, S., Graybeal, J., Hauswirth, M., Henson, C., Herzog, A., Huang, V., Janowicz, K., Kelsey, W. D., Le Phuoc, D., Lefort, L., Leggieri, M., Neuhaus, H., Nikolov, A., Page, K., Passant, A., Sheth, A., and Taylor, K. (2012). The SSN ontology of the W3C semantic sensor network incubator group. *Journal of Web Semantics*, 17:25–32.

[5] INEVA : http://www.ineva.fr/

Crochemore, S., Vergneault, C., and Nesa, D. (2003). A new reference frame for tactile perceptions: Sensotact. *5th Rose Mary Pangborn, Boston MA, USA*, pages 20–24.

De Boissieu, F. (2010). *Toucher artificiel à base d'un microcapteur d'effort : traitement du signal et des informations associées*. PhD thesis, Université de Grenoble.

De Rossi, D. and Scilingo, E. P. (2006). Skin-like sensor arrays. *Encyclopedia of sensors*, 10:1–22.

Dey, A. K., Abowd, G. D., and Salber, D. (2001). A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. *Hum.-Comput. Interact.*, 16(2):97–166.

DOLCE+DnS_Ultralite (2010). ontologydesignpatterns.org.

Dumenil-Lefebvre, A. (2006). *Integration Des Aspects Sensoriels Dans La Conception Des Emballages En Verre : Mise Au Point D'Un Instrument Methodologique À Partir Des Techniques D'Evaluation Sensorielle*. PhD thesis, Ecole nationale supérieure d'arts et métiers.

Gartiser, N., Zanni-Merk, C., Boullosa, L., and Casali, A. (2014). A semantic layered architecture for analysis and diagnosis of sme. In International, K., editor, *Knowledge-Based and Intelligent Information & Engineering Systems 18th Annual Conference, KES-2014*, volume 35, page 1165-1174. Procedia Computer Science.

Issa, M., Schacher, L., and Adolphe, D. C. (2005). Invariant attributes in the tactile characterization of fabrics. In *Proceeding, Fiber Society Spring Conference*.

Jones, L. A. and Lederman, S. J. (2006). *Human hand function*. Oxford University Press.

Lederman, S. and Klatzky, R. L. (2009). Haptic perception: A tutorial. *Attention, perception & psychophysics*, 71(3):1439–1459.

Maire, J. L., Pillet, M., and Baudet, N. (2013). Measurement of the perceived quality of a product - Characterization of aesthetic anomalies. *International Journal of Metrology and Quality Engineering*, 4(2):63–69.

Martin, S., Brown, W. M., Klavans, R., and Boyack, K. W. (2011). OpenOrd: an open-source toolbox for large graph layout. *Proc. SPIE*, 7868(JANUARY 2011):786806–786811.

Milton, N. (2008). *Knowledge Technologies*. Polimetrica, Milano, Italy.

Myrgioti, E., Bassiliades, N., and Miliou, A. (2013). Bridging the HASM: An OWL ontology for modeling the information pathways in haptic interfaces software. *Expert Systems with Applications*, 40(4):1358–1371.

Picard, D., Dacremont, C., Valentin, D., and Giboreau, A. (2003). Perceptual dimensions of tactile textures. *Acta Psychologica*, 114(2):165–184.

Roussey, C., Pinet, F., Kang, M. A., and Corcho, O. (2011). An Introduction to Ontologies and Ontology Engineering. In *Ontologies in Urban Development Projects*, chapter 2, pages 9–38. Springer London, London.

Sanín, C. and Szczerbicki, E. (2009). Experience-based knowledge representation: Soeks. *Cybernetics and Systems*, 40(2):99–122.

Sola, C. (2007). Y a pas de mots pour le dire, il faut sentir : Décrire et dénommer les happerceptions professionnelles. *Terrain*, (49).

Summers, I. R., Irwin, R. J., and Brady, A. C. (2007). Haptic discrimination of paper. In *Human Haptic Perception: Basics and Applications*, number DECEMBER 2007, pages 525–535. Birkhäuser Basel.

Zanni-Merk, C. (2015). Krem: A generic knowledge-based framework for problem solving in engineering - proposal and case studies. In INSTICC, editor, *7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management*, pages 381–388. Science and Technology Publications, Lda.

Zanni-Merk, C., Marc-Zwecker, S., Wemmert, C., and de Bertrand de Beuvron, F. (2015). A layered architecture for a fuzzy semantic approach for satellite image analysis. *International Journal of Knowledge and Systems Science*, 6(2):31–56.