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A METHOD FOR CAPTURING AND TRANSLATING QUALITATIVE USER EXPERIENCE INTO DESIGN SPECIFICATIONS: THE HAPTIC FEEDBACK OF APPLIANCE INTERFACES

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ABSTRACT

The paper describes a methodological approach specifically developed to capture and transform the qualitative User Experience (UX) of a consumer product into quantitative technical specifications. Merging the potentialities of Virtual Prototypes (VPs) and Digital Mock-Ups (DMU), a flexible design scenario is built to interpret users' desires. Visual, sound and haptic stimuli are reproduced in order to let users live a realistic multisensory experience interacting with the virtual replica of the product. Parametric models are defined to acquire users' preferences while optimization algorithms are used to transform them into technical specifications. The aim of the approach is to propose a robust technique to objectify users' desires and enable their direct and active participation within the product development process. The methodology is derived merging insights coming from four case studies as well as indications available in literature. Specifically the paper describes how to design the multisensory UX with household appliance doors and drawers with a specific focus on the haptic/force feedback objectification.

Keywords: experience design, user centred design, virtual reality, human in the loop, haptic feedback

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1 INTRODUCTION

Nowadays it is becoming strategic for companies producing consumer products, understanding and monitoring all those product characteristics that, eliciting on users a positive experience when interacting with the product, positively influence their purchase decision (Bloch, 1995). Part of this experience is related to a multisensory interaction-perception process occurring at the point of sale where all the senses are involved (Spence and Gallace, 2011).
To correctly acquire and make use of this strategic source of information (Gruner and Homburg, 2000) companies have to face with two main issues. On one hand they have to accurately identify and capture users' perceptions about the product. These are by definition mainly qualitative judgments or statistical trends. On the other, they need to appropriately translate perceptions into quantitative parameters for designing the required new product features/behaviours. Obviously, catching users' experience is highly complex since it is the result of the combined effect of several sensory (e.g. auditory, visual, haptic, olfactory) and cognitive features (Houde and Hill, 1997; Spence and Gallace, 2011).
Addressing the first issue (i.e. capturing users' perception) is commonly the job of marketing experts, while facing with the second one (i.e. the translation into technical parameters) is the role of designers. These two tasks are strictly correlated: what users perceive while interacting with a product is the result of cognitive and emotional status generated by specific design choices (Rindova and Petkova, 2007). However, as described in literature (Leenders and Wierenga, 2002), failures occur at the interface of these two company "souls", since managing interactions is not easy: different perspectives, vocabularies, targets and sources of information characterize these two companies departments (Townsend et al., 2011; Michalek et al., 2005, Griffin and Hauser, 1996).
In addition, apart from managing company internal conflicts or negotiation activities, additional shortcomings are present, making more complex such interactions. They are: a) the realistic challenge of marketing experts of properly interpreting and controlling users' feedbacks; b) the practical difficulty of designers in transforming qualitative indications into technological roadmaps or product specifications.
Hence, this paper describes a methodological framework focused on renewing the strategy companies apply to capture the multisensory User Experience (UX) when interacting with a product. Specifically, the proposed framework aims at guiding the translation of qualitative indications coming from user-product interactions into quantitative technical specifications through the use of Virtual Prototypes (VPs). VPs enable both a direct and active participation of users (or company decision makers) within the design process and the creation of flexible design scenarios where different solutions can be quickly perceived and validated. Thus, the aim of the method is to stimulate designing in an enactive way (Burns et al., 1994) and to experiment new forms/techniques to retrieve market insights and involve users in the product development process.
The methodology has been defined by focusing on a set of products of one of the European leading companies operating in the field of household appliances (the Indesit Company, www.indesitcompany.com). These products are representative of four different product families. Specifically the paper describes how to design the user multisensory experience of appliance doors, drawers and knobs. These ones represent those parts of the product that firstly come in contact with potential buyers at the point of sales, and thus could influence their willingness to purchase. As also stated in (Technical Report, 2009), compared with other consumer products, white goods design could be less influent on consumer choices with respect to price and energy efficiency features, but recently things have started to change also in this industrial sector. Moreover, taking into account these design aspects is not trivial for household appliance manufacturers due to the high investment costs and risks that a change in the product would determine. This is true especially considering the high manufacturing volumes to guarantee. For this reason, developing a robust strategy for capturing and interpreting users' perception is becoming strategic. In this paper, potentialities and limitations of the methodology, compared with the current practice, are highlighted.

2 STATE OF THE ART

Interesting frameworks and guidelines are available in literature to help designers interpret how and in what terms a product and its characteristics influence multisensory UX. Some examples can be found in (Crilly et al., 2008; Forlizzi and Ford, 2000; Norman, 2004; Bloch, 1995). These suggestions are highly useful in order to stimulate designers' sensitivities about how their solutions could affect the users' perception of the product. Models are also available in the marketing research literature providing a clear understanding of how consumers behave and the decisional process behind their choices (Hoyer and Maclnnis, 2010). Besides, a significant amount of literature is also focused on defining and comparing strategies for capturing consumers' perspective (Malhotra and Birks, 2006) such as surveys, focus group and interviews only to mention some of them. Such strategies are the ones used by marketing experts to explicitly communicate with consumers. Anyway marketing people are continuously looking for strategies and new channels in order to understand and manage market complexities and reach a level of emotional attachment that goes beyond customer satisfaction (McCole, 2004). Their aim is to retrieve feedback and insights from the market by conducting surveys and interviews with customers or channel partners. The objective is to create new market-based assets managing customer/partner relationships and increasing the net present value of company cash-flows (Srivastava et al., 1998). Indeed, in the last decades new forms of interactive marketing (e.g. using email, social and mobile advertising) have been growing in order to make easier the sampling, collection and elaboration of consumers' data (Barwise and Farley, 2005). However, mainly qualitative indications are available from these market analyses whose translation into technical specifications is highly complex.

Two main actions are currently put in place by companies in order to deal with the problem of users' feedback capturing and interpretation. The first is the organization of specific sessions (e.g. focus groups) during which, under the supervision of a group leader (Kotler et al., 2002), users are asked to indicate their reaction to specific features of commercial products used as "test samples". Usually, they are the ones considered as the best in class in terms of selling-volume/price or ranked positively by consumers' associations. The final aim of these sessions is to capture users' perspectives and opinions (Edmunds, 1999) and define a sort of "ideal product" which is "shaped" summing the top rated features currently available on the market.

Obviously, it is clear that performing this "sum" will not be "painless" because, not only a considerable effort will be necessary to integrate these desired features, but also because the final product characteristics will be inevitably far from the ideal ones. Indeed, designers have to interpret the list of consumers' needs provided by marketing experts and transform these ones into product specifications: by only looking at this wish lists designers should be able to correctly understand the users' perspective, the nature of interactions that could occur with the product (Forlizzi and Ford, 2000), and translate them into feasible technical targets. Hence, to support designers in performing these tasks, a second strategy exists: building physical prototypes. These prototypes (working or mainly aesthetic) enable an on-going evaluation of how big is the gap with the "ideal" product and of the product technical performances; indeed they are built to verify and validate market requests before launching the production (Schrage, 1996; Ulrich and Eppinger, 2000). A wide range of "decision makers" can be involved in this validation process such as product final users, the design team and representatives of company departments (e.g. marketing and manufacturing) (Erickson, 1995). Rapid prototyping techniques, as well as simulation models strongly help designers in ideating and building technological demonstrators that can help to verify important product performances. This activity is highly costly since a number of variants have to be physically prototyped before reaching the expected results. During these validation sessions ideas are explored, valued and when required rejected according to users' or company experts' decisions. Besides, except for high fidelity prototypes that are usually available only at the final stages of the development process, the previous versions are not able to recreate a proper UX (e.g. because they are made of different materials). For these reasons the sensory experience is not representative. On the contrary, to concretely catch users' experience multiple design directions need to be prototyped in order to completely depict the engagement of users with the product throughout their active participation (Buchenau and Fulton Suri, 2000). In Buchenau and Fulton Suri's work this approach is called Experience Prototyping.

For time and costs saving reasons, in the last decades VPs started gaining a strategic role within the product development process (Zorriassatine, et al., 2003). In fact, the possibilities to generate the virtual replica of new concepts enable to quickly create different variants or on-going versions to test. However open issues are still present due to three main aspects: 1) devices technological limits; 2) difficulty in correlating users' qualitative feedbacks retrieved using the Virtual Reality (VR) devices with specific product features and thus to their technical specifications, 3) difficulty in properly integrating different VR technologies (e.g. visualization, haptic and sound) which instead is at the basis for recreating a complete sensory experience. Indeed, even if for visualization devices high rendering qualities can now be reached as well as for the sound (i.e. high-quality acoustic effects), the haptic technologies have some limitations due to the high level of complexity that characterizes an interaction process involving the sense of touch. In terms of correlations between users' qualitative feedbacks with specific product characteristics (i.e. the objectification of users' perception), visualization technologies enable a reliable validation of the product aesthetic features (e.g. shapes, colours, material effects) while for sound stimuli recent studies are available toward this direction (Parizet et al., 2008; Van der Auweraer et al., 1997). Instead for haptic technologies further research efforts are needed (preliminary findings toward this directions are discussed by authors in Ferrise et al., 2013 and Phillips Furtado et al., 2013). Finally, in terms of technology integrations (for recreating a complete multisensory experience), indications are provided in (Ferrise et al., 2010), but further work is needed in order to make more robust this integration and enable an effective objectification of the users' interaction aspects.

Hence, the framework discussed in this paper aims at addressing the following research challenges: 1) strengthen the potential of VPs in recreating, investigating and measuring users' perceptions; 2) provide a strategy for directly integrating users (or their needs by means of consumers' experts) within the product development process; 3) detail a technique to objectify multisensory UX which is currently not available in literature for the haptic feedback; 4) encourage an active collaboration between R&D product engineers and marketers. Specifically, while the framework discussion will be provided in general terms, the case study discussion will be focused on detailing the haptic/force feedback objectification.

3 METHOD

Figure 1 shows the workflow of the framework. The context is the product development process, and in particular the initial exploratory phases. This approach can be applied also later on in the process to further validate more detailed concepts. In this paper we focus on the first stages of the process.

During the exploratory phases the marketing experts have already decided which is the product to change (e.g. the model of washing machine or fridge, in case of the household appliance industry). Conversely the definition of technical targets is usually the final outcome of a negotiation activity between marketing experts and designers, starting from the insights already retrieved by consumers' analysts through focus groups sessions, interviews and so on. According to the proposed framework these two phases (i.e. the consumer's insights retrieval and the technical targets negotiation) can be split into two main stages: the capture of the multisensory UX and its translation into technical specifications. Multisensory UX, in the case of domestic appliances, refers to the experience in using interactive devices, as knobs, buttons, etc.

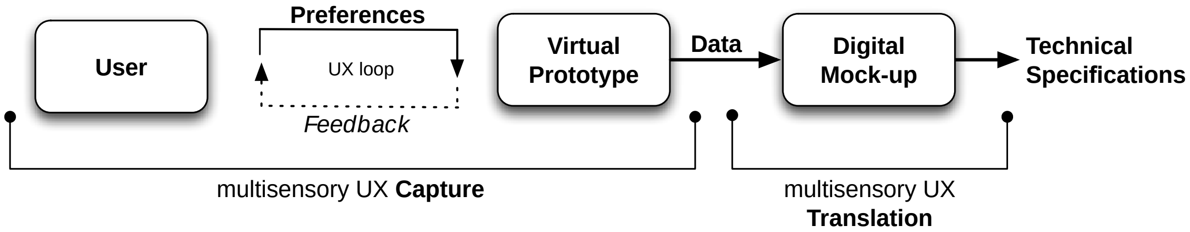

Figure 1. The proposed framework

During the first phase (i.e. the multisensory UX Capture, Figure 1), the user is asked to interact with a parametric multisensory VP and to express his/her preferences. VP realistically simulates the interactive components of products from a perceptual point of view. The VP is flexible to changes and can be updated in real time according to user's requests. The initial status/behaviour of the VP could be the same as the commercial product selected as reference for the analysis or, otherwise if new proposals for changes are available they can be tested as well. These changes/proposals generate new feedbacks on the user that will be asked again to express his/her perceptions until a desired condition will be reached. That is the multisensory UX loop (Figure 1).

As shown in Figure 2, the multisensory VP consists in: a mathematical model that controls the haptic device (i.e. the dynamics of its end effector), a range of sound clips reproduced by speakers and the stereoscopic and scale visual rendering of the prototype. Hence, by interacting with the VP, the user can modify the experience in terms of: *force effects* generated by the haptic device (e.g. "I would feel less efforts in opening”), *sound effects* coming from the speakers (e.g. “I would prefer a louder sound”) and the *visual appearance* of the product (e.g. “I would prefer a more rounded shape”). Once applied, these changes will generate new stimuli to the user. The multisensory UX loop will stop only if no further changes will be asked and a desired status/behaviour will be reached. In accordance with (Buchenau and Fulton Suri, 2000), the intent behind this phase of the framework is to evaluate ideas directing users’ attention toward important product characteristics.

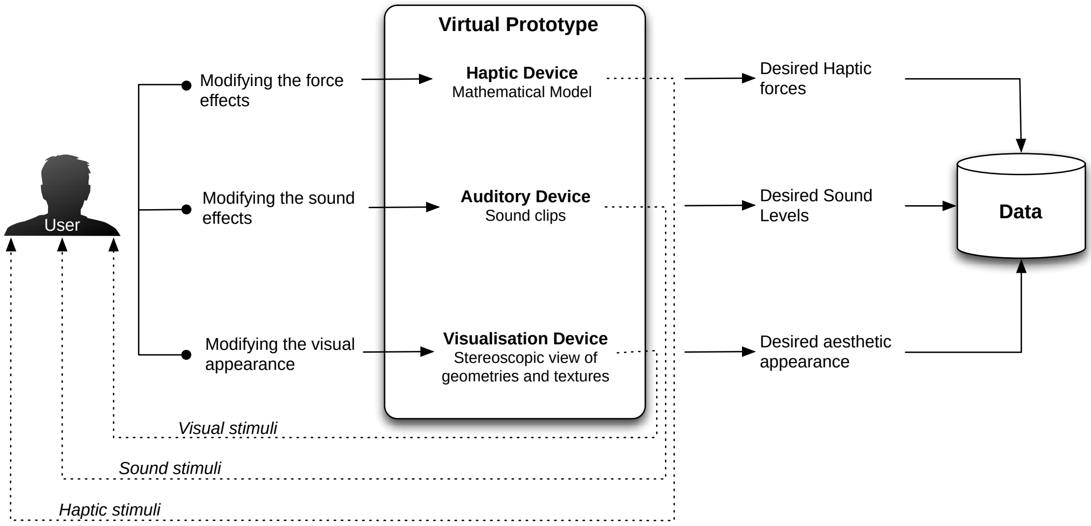

Figure 2. Multisensory UX capture

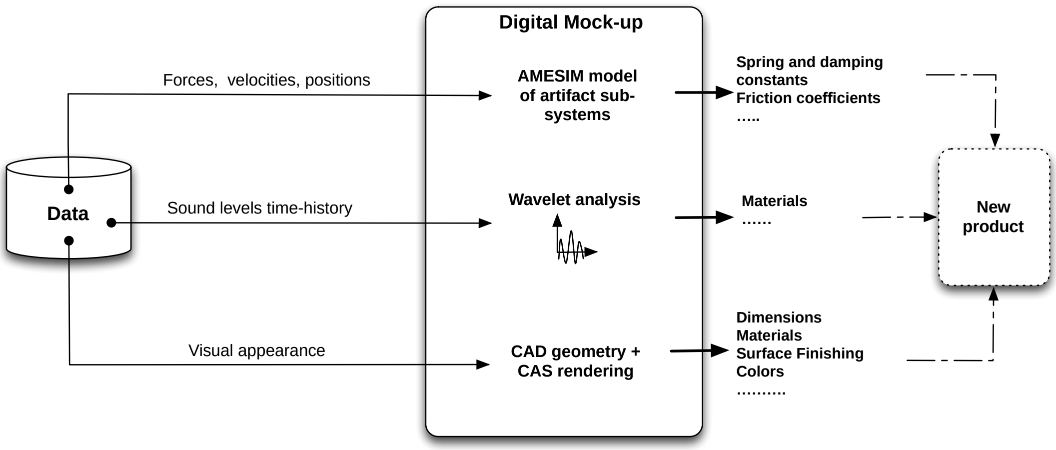

Figure 3. Multisensory UX translation into technical specifications

In Figure 3 the second step of the framework is detailed. The new product desired status/behaviour is conceived as a set of data that will be elaborated using different tools, part of the Digital Mock Up (DMU). Through the DMU the outcome of the interaction experience is translated into technical specifications. The mathematical model that controls the haptic device provides indications about the displacement, acceleration and velocity of the haptic end effector. Such information is used to calculate the force exerted by the user on interactive components as doors, drawers and knobs. Specifically, these data will be used as input for the dynamical model of the product subsystems involved in the interaction. These models, designed using a tool for digital mock-up creation as for example the LMS-Amesim suite (www.lmsintl.com), describe the behaviour of the sub-system mechanisms. They consist in set of differential equations whose variables represent the parameters of the mechanical sub-system that can be varied (e.g. the stiffness of a spring, friction coefficients and so on) while constants are the technical characteristics of the sub-system parts that cannot be changed (i.e. they define the boundary conditions of the design phase). Hence, the desired haptic interaction is transformed into a list of output values that can be used for designing specific product sub-systems.

LMS-Amesim is a Modelica compatible front end. The choice of using a Modelica-like environment allows us to simulate multi-domain problems in an easy way. For example it is easy to insert and simulate magnetic and pneumatic effects together with mechanical components.

Regarding the sound, according to (Parizet et al., 2008) a time frequency analysis can be performed in order to identify sound timbres. As done in (Altinsoy, 2012) models can be defined to evaluate and predict: the perceived quality of sounds, the emitting source (e.g. the product sub-system and specifically the parts generating the sound effects) and the exact user action or phase of the interaction determining the sound (e.g. the initial/final phases of an opening/closing activity). Finally, the desired appearance of the virtual model is used to update the CAD/CAS geometry of the product and to start a preliminary assignment of materials and finishing effects (mainly for the aesthetic features of the product). All these output data could be used to generate a new and more detailed VP. If necessary, this could be further tested since problems may occur when performing the integration of the results. Indeed, depending on the complexity and on the characteristics of the product under analysis, the same part could be contemporary responsible of the haptic interaction, of the sound effects and influencing the aesthetic appearance of the product. Furthermore, preliminary feasibility studies (technical and/or economical) could make the company discard some hypotheses. For all these reasons the necessity for a second version of the VP could come out. Obviously, once technical specifications are definitely confirmed the detail design phase can start.

4 CASE STUDY

This Section describes the case studies already developed and the ones on-going that have lead to the definition and validation of the framework discussed in this paper. Users' interaction with doors, drawers and knobs of four appliances has been studied. The selected appliances are representatives of the main four product families of a white goods' manufacturer. For the sound and visual stimuli findings available in literature have been used, while authors' efforts have concentrated on the haptic feedback. For this reason in this paper the case study discussion is focused on the haptic feedback.

As already underlined, appliance doors, drawers and knobs have a strategic role in influencing the first users' perception of a household appliance. Indeed, since at the point of sale household appliances are usually switched off, users get "familiar" with them both looking at the aesthetics, brand, price or/and at their technical characteristics, and interacting with its moving parts. Even if the various sub-systems analysed (e.g. the appliance door) are similar in terms of their main functionality (i.e. for the door it regards guaranteeing the accessibility to the internal space of the appliance) each one has also further functionalities and characteristics that influence their behaviour during the opening/closing phase. Understanding these differences is important not only (obviously) from the design point of view but also from the marketing perspective. Nowadays more and more new products are put on the market not alone but as an integral part of a new collection (as in the household appliance sector) and highlighting similarities among different types of products is essential in order to strengthen the collection identity. Hence, in designing multisensory UX the main challenges to address can be summarized as follows: enabling a realistic perception of the product, interpreting correctly the feedbacks retrieved and making a proper rationalization of this information in order to fulfill all market and cost targets.

Figure 4 summarizes the main aspects investigated during the case studies development. Specifically, the effects/behaviours selected for the analysis were the following: the door opening system (e.g. with hinge or sliding systems) and its axis of rotation, the sealing effect (and magnetic for the fridge), the sounds emitted in door closing/opening, the washing machine drawer sliding effect and its related sound in opening/closing, the knob rotation modality for the cooking/washing cycle selection.

As previously said, the behaviour of each appliance door (Figure 4) is different since additional technical aspects have to be taken into account. Indeed while washing machine and dishwasher doors have to avoid water spill, the fridge and the oven doors have to preserve the internal temperature. For this reason the sealing effect of each door is completely dissimilar due to the specific working conditions of the appliance and thus of its sub-systems. In addition each door sub-system is subjected to different frequencies of use (e.g. daily for the fridge, while typically weekly for the oven). Hence that working conditions depend on technical, cost, safety and market requirements. Besides the opening/closing action required to users is different not only because the handle position and geometry are dissimilar but also because the weight of the doors are completely different as well as their axis of rotation: product implementing features strongly influence users' actions and the way they interact with the appliance. Thus in building the virtual replica of a product all these aspects have to be properly taken into account otherwise the designed experience is not realistic.

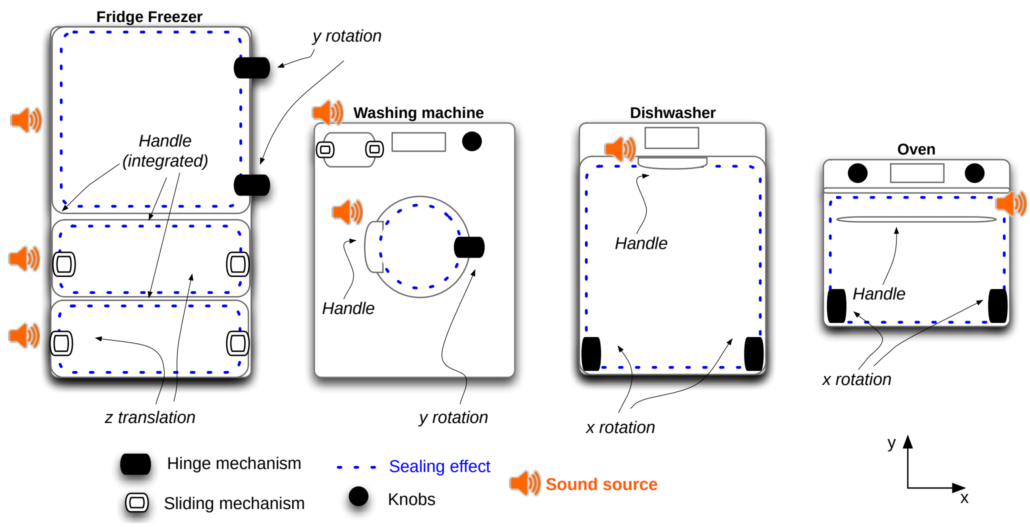

Figure 4. The aspects analysed

In Figure 5 the four case studies are summarized and an indication of the hardware set-up is provided. The image refers to the part of the framework represented in Figure 2, i.e. the multisensory UX capture phase.

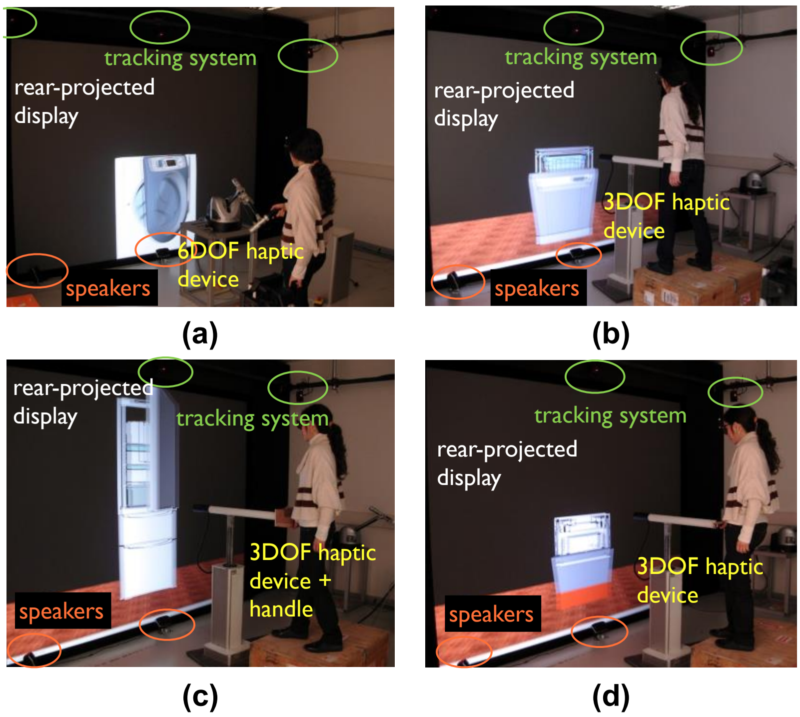

Figure 5. The four case studies: a washing machine (a), a dishwasher (b), a fridge (c), an oven (d)

The user perceives the pre-defined behaviour of the door, by looking at it and hearing sound clips. She can ask for modifications of the force until her favourite behaviour is obtained. During this phase, the following tools have been used: a rear-projected wall display Cyviz Viz3D (www.cyviz.com) for the stereoscopic and scale visualization of the prototype; the 3DOF MOOG-HapticMaster (www.moog.com/products/haptics-robotics/) for case studies "b-c-d" (Figure 5), and the 6DOF Haption Virtuose general purpose haptic device (www.haption.com) for case study "a" (Figure 5); a set of speakers for the sound rendering (event-based sounds occurring at collisions are also included in the simulation); an optical tracking system by ARTracking (www.ar-tracking.de) to capture the user's point of view position and orientation in real-time and adapt the images consequently, allowing a natural visual exploration of the prototype.
For the case studies represented in Figures 5-b, 5-c and 5-d the 3DOF MOOG-HapticMaster device has been preferred because of the higher force value returned if compared to the Haption Virtuose and

because of the need of less DOF being limited to the simulation of fewer elements (in the simulation of the oven the knob has not yet been introduced). In Figure 5-b a small rapid prototype of the shape of the handle of the fridge has been substituted to the end effector of the device, in order to improve the degree of similarity between the interaction with a real door and a simulated one (see also Ferrise et al., 2013).
Specifically in Figure 5-a the virtual environment is based on the 3DVIA Virtools modeling environment (www.3dvia.com) and in Figure 5-b, c, d is based on H3DAPI (http://www.h3dapi.org) opensource library. Both the VR tools selected manage synchronization issues among haptic, visual and sound devices.
Mathematical force models have been used to control the haptic device end effector (i.e. its displacement, velocity and acceleration) and thus the force effect generated by the virtual replica on the user's hand (Figure 2). Specifically, two different approaches have been used to build these models. For example in designing UX with the appliance door, for case studies "a" (the washing machine) and "c" (the fridge) (Figure 5) pure mathematical force models have been used. These mathematical models do not represent necessarily the physics behind the phenomena (i.e. the friction or the damping are not modelled), and allow a very high level definition of a force profile. For example in case of the door of the washing machine some local efforts have been added to represent the snap effect while opening and closing the door, and a constant effort to represent the hinge friction. In case of the fridge door a piecewise function is used. The rotational angle (displacement in case of the two drawers) is split into some small pieces, each one controlled by a parametric zero-to-third order function. When the user asks for some modifications the parameters can be changed in real-time and she can experience the new effect.
In the other two case studies, i.e. the dishwasher and the oven doors, a simplified mathematical model representing the physics has been used to control the device. It has to be taken into account that, in order to grant a real-time haptic feedback, running usually at 1*kHz* (up to 2 *kHz* in case of the MOOG-HapticMaster), this mathematical model must be simplified. For example all the friction contributions acting in the same direction are modelled in one friction, and the same for damping and springs. These functions are parametric and once the user asks for some modifications, friction, damping coefficients, as well as spring stiffness can be modified in real-time and tested again. Even if this mathematical model is simplified, the correctness of the simplifications and assumptions made were validated calibrating the "0" behaviour of the VP with the real product provided by the company (Figure 6). Specifically, some measurements (e.g. by means of load cells, inclinometers, gyroscopes) have been performed to acquire the product doors behaviours.

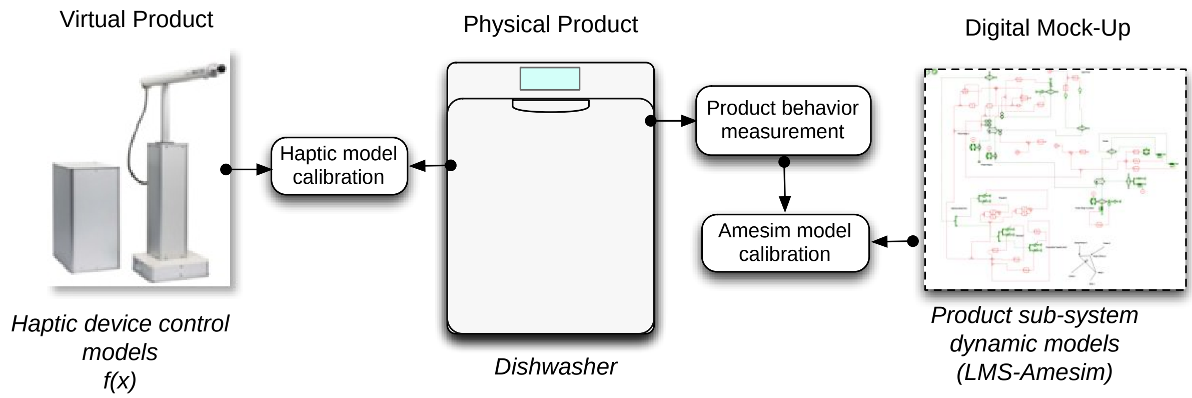

Figure 6. The initial calibration activity

The output of the haptic control models is the dynamic behaviour of the end-effector though which the force exerted by the user during the opening/closing activity can be calculated and stored.
Once the user has defined her preferred haptic behaviour the data are extracted and subsequently used as input to optimize the complex models built using LMS-Amesim. As already discussed, these complex models constitute the digital mock-up of the product (Figure 3). As done for the haptic models also these ones have been initially calibrated comparing the outputs of the simulation environment with the real behaviour of the physical product, by using optimization algorithms.

By optimizing this complex simulation in order to behave like the desired haptic feedback indicated by users, the new spring stiffness, friction coefficients, damping etc. can be calculated. These values can then be used to start the detailed design of the mechanism.

5 CONCLUSION

In this paper a framework for designing and capturing the multisensory User Experience (UX) is proposed. Through the use of Virtual Prototypes (VPs) and Digital Mock-Ups (DMU), authors define an approach for translating users' preferences into quantitative design specifications. The framework, validated trough four case studies taken from the household appliances market as well as insights available in literature, has a general intent. The aim is to provide a more robust strategy to interpret users' desires avoiding wasteful and costly trial-and-error approaches. Besides, collaboration between marketers and R&D product engineers is also fostered.

Some open issues are present that will be used as new research directions to explore. First, further efforts should be spent on defining clear guidelines for building effective interaction environments - and thus design scenarios. The point here is that those design scenarios depend on the models defined (both for the VPs and the DMU) and specifically on the variables selected to control and describe the product behaviour. Indeed, the choice of these variables not only determines the technical parameters that would be retrieved as output but also the quality of the interaction and thus the effectiveness of the interaction environment: too complex models could theoretically provide more information from the technical point of view but make the interaction difficult to control in real-time (and thus less realistic). Second how to organize the design sessions with users have to be further explored (e.g. which questions should be asked and in what terms). Since the methodology and the tools described in this paper could offer a completely new strategy for capturing consumers' feedbacks, it will be important to understand how the methodology could be integrated with the most widespread or emerging practices in consumer marketing research.

Finally, it is important to underline again that the quality of the interaction and of the users' perception objectification is inevitably affected by the technical/technological limits of the tools used. The research efforts on improving these tools are promising, and in the future these limits might be significantly reduced.

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