Re-engineering of the Haptic Feedback of a Dishwasher Door

Francesco Ferrise[1], Serena Graziosi[2], Guilherme Phillips Furtado[3], Monica Bordegoni[4] and Dino Bongini[5]

[1]Politecnico di Milano, francesco.ferrise@polimi.it
[2]Politecnico di Milano, serena.graziosi@polimi.it
[3]Politecnico di Milano, guilherme.phillips@mail.polimi.it
[4]Politecnico di Milano, monica.bordegoni@polimi.it
[5]Indesit Company, dino.bongini@indesit.com

ABSTRACT

The paper describes the results of an on-going research activity whose aim is to allow companies, operating in the consumer goods market, to design the multisensory experience of their products. In case of the household appliances market, which is the research context of this study, the user experience derives from the interaction with specific product features such as the door, buttons, and drawers. Designing a good multisensory experience is complex since it means taking into account a combination of visual, hearing and haptic feedbacks a user perceives when interacting with the product. Virtual Reality offers the technologies to design and test that experience thought virtual prototypes, even if to date there is a lack of methodological approaches to practically guide and support this design activity. Relying on the results of previous authors' researches, the paper describes further methodological advances focused on making usable the proposed approach in the current design practice. The case study chosen to demonstrate the effectiveness of the method is a dishwasher door and the paper describes how to re-engineer the haptic feedback of a commercial model in order to make it more perceptually appealing at the moment of purchase.

Keywords: user experience design, virtual prototyping, haptic interaction, reverse engineering.
DOI: 10.3722/cadaps.2013.995-1006

1 INTRODUCTION

By observing people at the selling points it can be easily noticed that they enjoy interacting with the products they are interested in. The aim of this exploratory phase is to build a personal perception of the product quality that, combined with other product aspects, leads to the purchase decision. This interaction is considered so important that some recent researches [13] emphasize the importance of providing the products with some properties that invite the buyers to touch them. Touching products at the selling point has been demonstrated to be beneficial to the product success if during the design process the company has put attention to their tactile aspect [24]. In general the perceived quality of a product can be assumed as being the result of a sort of multi-criteria analysis, which involves the brand, the user expectations in terms of product functionalities/cost, and the user experience. Some authors refer to this experience as product experience [21].

The user experience is created on the basis of the multisensory interaction with the product, which involves all the senses, even those buyers are not aware of, like smell in some cases [16]. This is a well-known issue for companies operating in the automotive field that have spent a lot of effort in years trying to optimize the sound of closing doors [19], and recently also their haptic feedback [25]. Very recently, also companies in the field of household appliances are getting interested in the issue [8, 23] and they are looking for solutions to design and evaluate user experience with new products. Anyway, despite this growing interest in designing the user experience, there is still a lack of methodological approaches to face this issue.

When designing the user experience with new products, companies usually perform comparative tests involving potential customers as well as marketing experts, and taking as samples their own products or the so-called “best in class” products of competitors [2]. The outcome of these comparative tests is the expected behaviour of the new product that is a sort of combination of the most appealing features of the tested products. Once the optimum behaviour is captured, the role of the marketing experts is to translate it into project targets, and then into design specifications with the help of R&D engineers. However, a methodological approach that takes into account all these steps is missing. Indeed, the resulting design specifications are mainly qualitative indications. Besides, the initial phase of testing is limited, being based only on products already available on the market. The risk of such an approach is the homogenization of new products rather than their differentiations.

Today Virtual Reality offers the technologies to allow the design and evaluation of the user experience by using Virtual Prototypes (VP) [29]. The advantages are many. First, VPs are low cost, flexible and offer the possibility to easily create experience variants. State-of-the-art technologies allow us to develop interactive Virtual Prototype (iVP), which can be accessed through the same sensory channels used for interacting with the corresponding physical prototypes or products. Furthermore because of their digital nature changes performed on the VPs can be easily stored and used for subsequent analysis. Finally, the possibility to perform real-time measurements of users’ actions with the iVPs jointly with the possibility to store experience variants allows us to record users’ preferences, that can be processed and finally translated into product design specifications.

The aim of the research described in this paper is to fill the gap between marketing people, who identify a desired behaviour of the product by observing and interviewing potential customers, and engineers who must make it feasible by translating perceptions into numbers. In our approach, end users and marketing experts can participate to the design process, by using, evaluating and modifying the interactive Virtual Prototypes of new products. This makes the design process more effective and efficient. The approach has been tested on a case study provided by the Indesit Company (www.indesitcompany.com), an Italian manufacturer of household appliances. Specifically, the proposed approach has been focused on the study of the user experience with the door of a commercial dishwasher, and specifically on the re-engineering of the force feedback of the dishwasher door.

The paper is structured as follows. First the main achievements in the field of product experience, user experience and virtual prototyping are discussed. In the following section the methodological approach based on the use of virtual prototypes to design user experience is introduced. Subsequently the development of the case study is described by identifying potentialities and limits. Finally, conclusions are drawn.

2 RELATED WORKS

Involving final users in the product development process in order to capture their preferences is very important for the consumer goods market. In fact, even if a product might represent the best technological solution on the market addressing a specific problem, it may elicit a very poor emotional response in the users that will target the product as not appealing. Understanding this aspect too late, i.e. when the product is already on the market, is a big risk in terms of return of investments. Products considered not appealing by consumers might become unsuccessful. Studying and understanding the emotional response and appreciation of the products during the product development process might concur in designing better products in terms of marketing success [12, 17].

Many frameworks and guidelines are available in literature to help designers interpret how and in what terms a product and its characteristics influence the user experience, which includes the emotional response [3, 5, 10, 18]. 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 clearer understanding of how consumers behave and the decisional process behind their choices [11]. Besides, a significant amount of literature is also focused on defining and comparing strategies for capturing consumers' perspective [14] and understanding what could influence their emotional attachment to the product [15]. To this aim, in the last decades new forms of interactive marketing (e.g. using email, social and mobile advertising) have developed in order to increase the availability and make easier the sampling, collection and elaboration of consumers' data [1]. Besides it is also a common practice in industry to organize specific interview sessions (e.g. focus groups) during which users are asked to express their opinion about specific product features [6]. However, mainly qualitative indications can be extrapolated from these market analyses, whose translation into technical specifications is always a matter of discussion and negotiation between marketers and designers. In order to support that translation activity, another common practice in industry is to build physical prototypes. These ones (working or mainly aesthetic) are fundamental to perform on-going or final validations of the new product before launching the production [22,26]. 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 even 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 reach a real and active user engagement, which is a fundamental requirement to concretely catch users' experience [4].

One of the recent trends of the Product Development Process is the substitution of physical prototypes with their virtual replica [29]; they are flexible to changes, especially during design review sessions, and less expensive. This new approach makes available several and not costly intermediate versions of the new product concept before reaching the final solution. Recent advances in virtual reality technologies make it feasible to simulate user interaction with virtual prototypes including all the sensory modalities. Despite the technological limitations [28], a virtual environment equipped with visualization, auditory and haptic interfaces may be used to design and test the multisensory user experience with products. Visualization and auditory devices enable respectively high-quality rendering of visual and acoustic effects. On the contrary, haptic technologies still have some limitations due to the intrinsic complexities that characterize 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 [19, 27]. Instead for haptic technologies further research efforts are needed (preliminary findings toward this directions are discussed by the authors in [8, 20]). Finally, in terms of technology integrations (for recreating a complete multisensory experience), indications are provided in [9]), but further work is needed in order to make the integration more robust and enable an effective objectification of the users' interaction aspects. The paper describes a further step toward this direction.

3 THE METHODOLOGICAL APPROACH TO TRANSFORM EXPERIENCES INTO DESIGN SPECIFICATIONS

This Section describes the methodological approach that has been defined to enable a company to re-engineer the haptic feedback of a door (in this case a dishwasher door) on the basis of the optimization of the user experience. The method is schematically illustrated in Figure 1. To this aim, virtual prototypes are adopted as means that a user can adapt on the basis of her preferences until she gets her favourite experience. Specifically, in this study, according to the research objectives, only the haptic feedback is made adaptable, while hearing and visual ones are maintained fixed and used to re-create the full multisensory experience. All the sensory feedbacks can be modified in an *interactive Virtual Prototype*, as described by the authors in [7], and varied separately until an optimum of the multisensory user experience is reached. In this paper we will focus on the sense of touch.

The design of the multisensory user experience through interactive Virtual Prototypes has some open issues as for example: 1) how similar is the virtual prototype to the real product, 2) how it can be made adaptable to user preferences, and 3) how it is possible to correlate and easily translate those changes into new product specifications. To address these issues, the authors identify two fundamental stages that come respectively before and after the testing of the multisensory user experience within a virtual environment: an initial pre-processing phase, necessary to create a parametric and high-fidelity virtual replica of the product, and a final post-processing phase to transform the desired behaviour of the virtual prototype (obtained implementing the changes requested by the user) into technical and hence physical specifications.

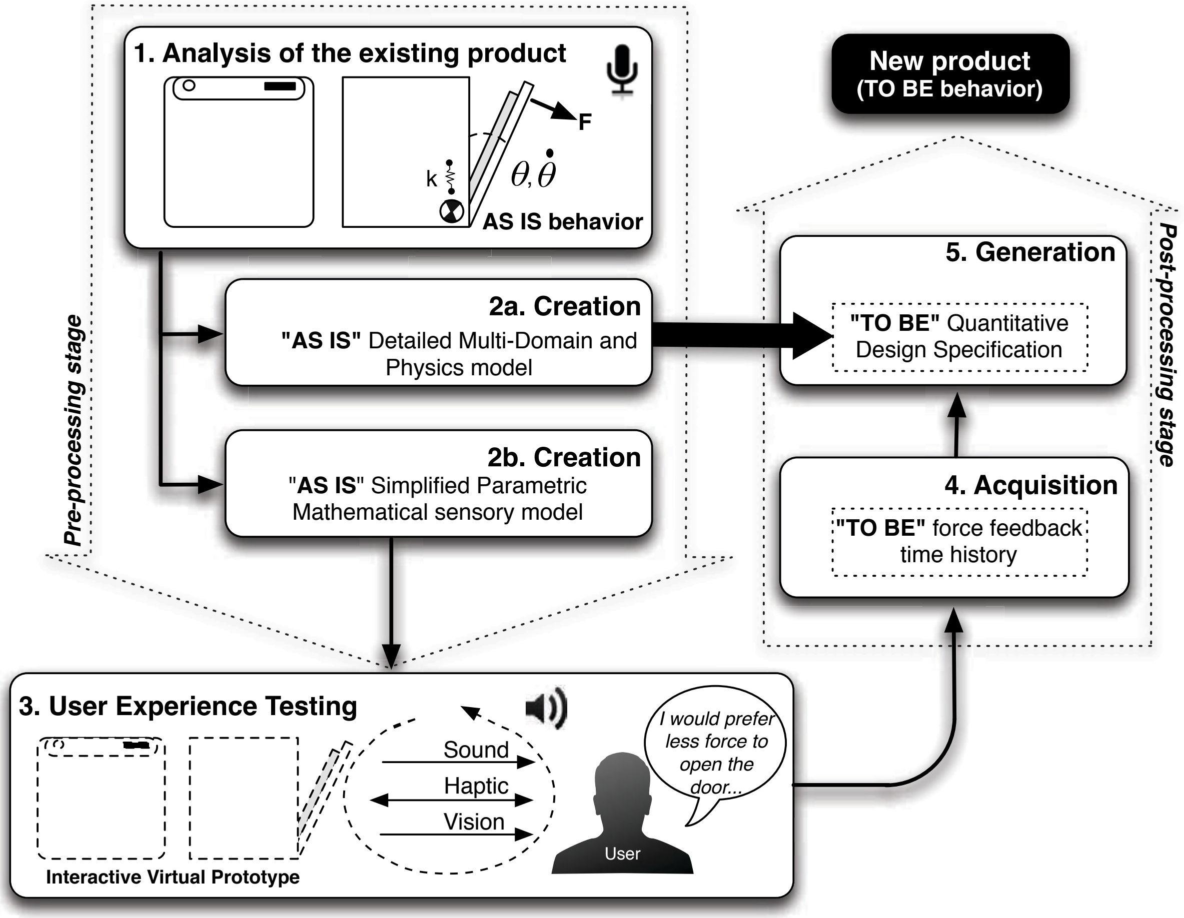

Fig. 1: The methodological approach described in the paper.

As illustrated in Figure 1, the pre-processing phase starts with the analysis of the existing product (in this study the dishwasher door) and specifically of the sub-systems or components (e.g. the door opening system) that intervene during the interaction. These are the components that will be re-engineered.

For what concerns the visualization channel, CAD models are available from the previous design activity and can be used to visually render the dishwasher door. Then, the following aspects are investigated in order to catch the "AS IS" door behaviour: opening/closing required force, the door angular position and velocity as a function of time (given an input force) and the related opening/closing sounds. Force, acceleration, velocity and displacement, are experimentally acquired to get the necessary quantitative data for describing the product dynamical behaviour. In case of the dishwasher door it is necessary to acquire its rotation during the opening/closing phase, the angular position and velocity together with the force required to open and close. Moreover, to complete the analysis of the opening/closing door sub-system, it is also necessary to study the hinge mechanism that controls the door position (e.g. links, spring and damping effects are analysed). In this case the aim is to define the list of variables that control and determine the behaviour of the product sub-system. Obviously the time necessary to perform this step can vary, depending on the amount of information already available.

The second phase of the methodology concerns the formalization of the acquired "AS IS" behaviour by means of a theoretical model, which is used for the haptic simulation. This phase is fundamental in order to come out with an easy-adaptable representation of the sub-system behaviour on which is possible to carry out simulation and/or optimization analyses. In this case two different models are generated: the detailed physical description of the system and the simplified mathematical one. While the first describes the entire mechanical behaviour of the door (in this study the physical domain taken into account has been only the mechanical one), the second represents the behaviour as set of mathematical functions that are necessary to control the position of the haptic interface used. Due to computational limit, following this "two-models" approach (i.e. detailed and simplified) is mandatory: controlling the haptic device by means of a simplified mathematical model enables us to perform real-time changes of the virtual prototype during the testing sessions with users. It is worth underlying that this approach does not limit the fidelity of the force representation since optimization algorithms are used to tune and validate these models by means of the data acquired on the physical product during the initial analysis phase.

In fact the force values and the door time-based angular position/velocity data are used to optimize the "AS IS" multi-domain and physics model using optimization algorithms. The same procedure is applied to tune the simplified parametric mathematical sensory model. That model is made parametric in order to make the virtual prototype easily adaptable according to the users' preferences. Those parameters depend on the list of variables defined during the initial phase of analysis while the functions used to model the tactile sensation describe the main aspects of the sub-system behaviour (e.g. dry friction, opening/closing force). Once the two models are tuned, the testing sessions can start with the simplified mathematical model controlling the haptic device. The user can perceive different product behaviours interacting with the virtual prototype, and ask for modifications.

Once the desired behaviour has been identified, the post-processing phase of the methodology can start. First it is necessary to acquire the new (i.e. the "TO BE") force feedback time history of the door. As done for the physical product during the analysis phase, measurements must be performed to capture the new behaviour of the door. That acquisition activity is performed on the virtual prototype by using the haptic interface as measurement system, and repeating the closing/opening actions several times in order to increase the confidence of the results. That measurement describes the position/velocity of the haptic end-effector and the force exerted by the user, as a function of time. These data are used as input for the detailed physical model already defined after the analysis of the existing product in order to obtain the design specifications. This is accomplished again by means of optimization algorithms.

4 DEVELOPMENT OF THE CASE STUDY

In this Section the development of the case study is described. The aim is to demonstrate the effectiveness of the proposed methodology and to understand its limits. In particular we first describe how the real product has been analysed and how the same haptic behaviour has been reproduced through the haptic device. The discussion is then focused on the development of the multisensory Virtual Reality environment used to capture use experience, based on visual, haptic and sound feedbacks. Finally, how this experience can be translated into design specifications is described.

4.1 Measurements Performed on the Existing Product

The first step of the development of the case study is the analysis of the real object aimed at creating the virtual replica of the product. The virtual replica, i.e. the interactive Virtual Prototype will be used for the re-engineering of the haptic behaviour of the door. The measurements on the real door have been performed using a compression donut load cell (FUTEK model LTH300, www.futek.com) with a maximum detection load of 445 N. The load cell has been mounted between the participants' hand and the door handle (as illustrated in Figure 2) in order to measure the required opening force as a function of time. In order to detect angular position and velocity in function of time an inclinometer (Columbia Research Laboratories model SI-701B) was used, with range of +/- 10° and a gyroscope (British Aerospace Systems & Equipment unipolar gyroscope) able to detect angular velocities in the range of +/- 100°/s. The signals have been acquired through the National Instruments NI cDAQ-9172 and NI 9125 analog input modules (www.ni.com) and processed through LabVIEW SignalExpress.

Three users have been asked to open the door by applying different forces with the sensors configuration showed in Figure 2. Subsequently the load cell has been glued on the external part of the door and the same users have been asked to close the door by applying different forces. The sensors have been coupled in the following ways: first the load cell plus the inclinometer were used to detect what happened in the first 15 degrees (the zero corresponding to the door closed) and then the load cell plus the gyroscope to understand the dynamical behaviour of the door. All the measurements were made in function of time, and the sensors triggered in order to easily get one parameter in function of another.

These measurements have been used to tune the parameters contained in the equations that control the haptic device in order to reproduce the same haptic behaviour.

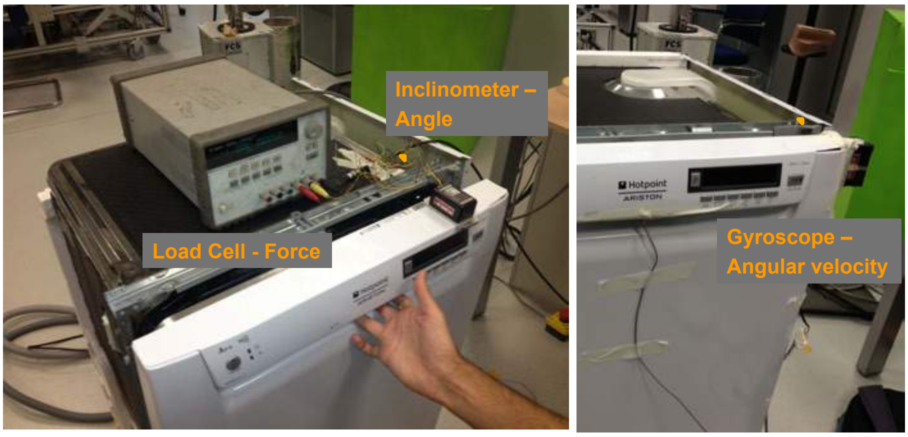

Fig. 2: Measurements performed on the commercial dishwasher used to tune the haptic mathematical models by means of optimization algorithms.

4.2 Development of the Haptic Model and use of Optimization for Fine Tuning

In the dishwasher the door is attached to the front side of the cabinet by means of a hinge placed at the bottom part of the door (Figure 3). In this case the hinge is very simple and provides an appropriate balancing force, generated by the cumulative effects of the spring and of the frictions, in order to guarantee the stability of the door during its movement from the vertical to the horizontal position. The latch mechanism used to lock the door, and specifically the component that clips into the locking mechanisms, can be represented as a leaf spring. Figure 3 illustrates the mechanical components involved in the generation of the force, and how they have been modelled.

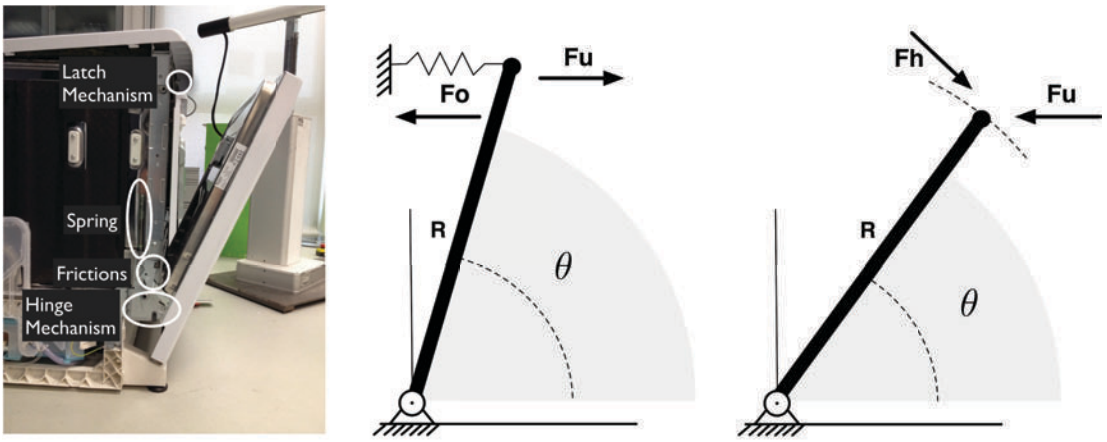

Fig. 3: Mechanical components responsible for controlling the door's motion and their schematization for the haptic rendering.

In order to let the haptic model correspond to the act of opening the door, the following points have been addressed: (1) constrain the movement of the end-effector to follow the same trajectory of the door handle, i.e. an arc; (2) relate the position of the door with the Cartesian coordinates of the haptic device; (3) evaluate what are the main effects influencing the haptic feeling, and describe them with equations.

The first problem has been addressed by constraining the end-effector to follow the intersection between two surfaces, one in which the boundaries have a circular shape with the same radius defined by the movement of the door handle (e.g. a sphere or a cylinder), and the other defined by a plane that contains the trajectory. Those surfaces attract the end-effector by applying a force proportional to the distance between the end-effector and the surface. As the proportional force tends to create undesired vibrations, damping is also applied.

The second point has been addressed by converting the position and speed of the end-effector, described with the Cartesian coordinates (e.g. x, y, z), to cylindrical coordinates (r,[illegible], z), where [illegible] when the door is fully open, and [illegible] when fully closed (as illustrated in Figure 3).

For what concerns the third problem, it should be noticed that the main effects are supposed to be tuned in real-time. Therefore it is important to describe them in an "intuitive" way: functions should represent sensations and not the dynamical parameters of the real mechanism. For example instead of using functions where the parameters correspond to a distance between two pivots or the friction on one of the sliding components, the effect perceived by the user should be represented, i.e. the parameters should correspond to the "easiness" or "smoothness" of moving the door. In this way, the operator can more easily understand how modifying a value affects his perception, e.g. in order to affect the "smoothness", the operator modifies the global friction, instead of the distance between two pivots.

The haptic model has been divided into four phases: the unlocking phase, the locking phase, the transition between locked and unlocked state, and the free movement. All phases have been modelled into different equations, which have been put together through the use of hyperbolic tangents used as activation functions, [illegible] and [illegible]:

[illegible]

[illegible]

The parameter *b* should be sufficiently big so:

[illegible] for [illegible]
[illegible] for [illegible]

$$S^*(\theta, \theta_0) \cong 1 \text{ for } \theta < \theta_0$$
$$S^*(\theta, \theta_0) \cong 0 \text{ for } \theta > \theta_0$$

For the unlocking phase, the latch mechanism is modelled as a spring (Figure 3), whose stiffness changes when the door is on the imminence of being unlocked (at θ_0). Here it becomes very rigid. The force returned by the haptic device in this section is:

$$F_o = [k\left(\theta - \frac{\pi}{2}\right) + k_\infty(\theta - \theta_0)\times S^*(\theta, \theta_0)]\times S(\theta, \theta_1)$$

Where k is the spring stiffness for $\theta_0 < \theta < \frac{\pi}{2}$ and k_∞ the spring stiffness when $\theta_1 < \theta < \theta_0$. Here θ_1 delimits where the above equation is not equal to zero.

The locking phase is analogous to the unlocking phase, the difference is that the direction of the force is the opposite, and there is only the high stiffness term:

$$F_c = k_\infty(\theta - \theta_3)\times[S(\theta, \theta_3) + S^*(\theta, \theta_2) - 1]$$

Where F_c is the force the haptic device applies for $\theta_3 < \theta < \theta_2$, where θ_2 and θ_3 delimits where the above equation is not equal to zero.

The transition phase, between the locked and unlocked phase, is a section where the door quickly switches either to the locked or unlocked state, depending whether the user is closing or opening the door. To simulate the force in this section, a negative damping is used: the system becomes unstable on that position, and is forced to move away:

$$F_t = c\dot{\theta}\times[S(\theta, \theta_3) + S^*(\theta, \theta_2) - 1]$$

Where F_t is the force applied by the device, for $\theta_2 < \theta < \theta_1$.

The predominant haptic sensation on the free movement phase is caused by the dry friction, modelled as an hyperbolic tangent acting along the trajectory (Figure 3), which changes from a higher value, when the door is fully open, to a lower value as it closes. The transition is also reproduced through the use of a hyperbolic tangent. Therefore, force $F_{\parallel}$ the device applies is:

$$F_{\parallel} = -d_1 \tanh(s\dot{\theta}) + d_2 \tanh(s\dot{\theta}) \times S(\theta, \theta_4)$$

Where d_1 and d_2 are used to adjust the magnitude of the dry friction, $d_1 > d_2 > 0$, s controls the sensitivity of the dry friction to the speed, and θ_4 is the angle used to adjust the position central when the friction starts to change; in this particular case, the coefficient b of the S function is also adjusted to control the rate of change for the dry friction.

The final force is the sum of the forces in all phases:

$$F = F_{\parallel} + F_c + F_t + F_o$$

Initially, to show the effectiveness of the proposed equations, the parameters that control the force F are adjusted so that the haptic model resembles the physical system. For the unlocking and locking phase, this is done simply based on the measurements. For the free movement phase, this is done through an optimization process where the maximum difference between the measured angular speed and the angular speed obtained from the equation, given the same input, has to be minimized.

The expression to be minimized is:

[illegible]

Where [illegible] is the measured angular speed and [illegible] the estimated angular speed from the model.

In this case study, the optimization has been done through the use of a genetic algorithm. Once the optimization is done, the parameters can be fine-tuned in real time, so the haptic model becomes as close as desired to the real physical system.

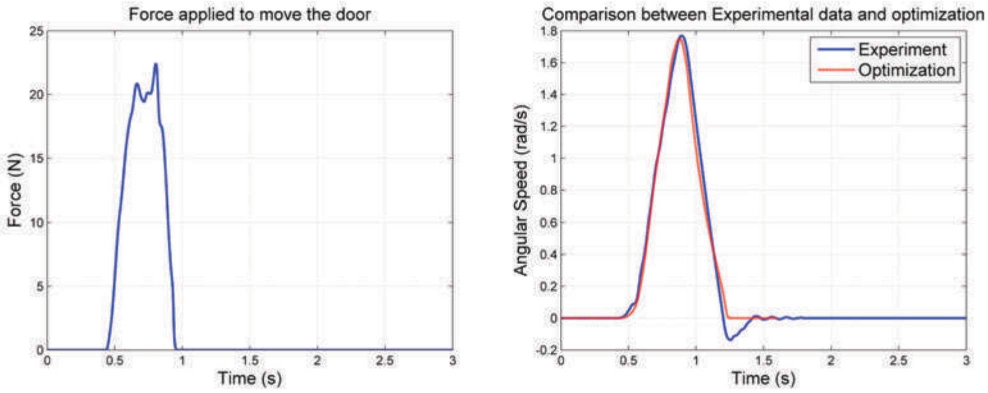

Fig. 4: Measured force applied by the user to move the door and comparison between the experimental and the simulated data after the optimization.

The optimization results represented in Figure 4 show that the equations used to represent the system are adequate. They can then be used to design the sensory behaviour of the system by allowing users to adjust the governing parameters in real-time.

4.3 Development of the Multisensory Virtual Environment for the Testing with Users

Figure 5 shows the use of the iVP to test the multisensory experience and setup her favourite haptic feedback. The choice of the hardware and software setup is the following:

- *a rear-projected wall display Cyviz Viz3D* (www.cyviz.com) for stereoscopic visualization of the product, which is based on two projectors and linear polarizers mounted on the projectors and also worn by the user as lightweight glasses;
- *a 3DOF MOOG-HapticMaster* device (www.moog.com/products/haptics-robotics/) equipped with a custom handle;
- *a single speaker* for the sound rendering positioned behind the haptic system;
- *an optical tracking system by ARTracking* (www.ar-tracking.de) used to calculate the user's point of view position and orientation in real-time.

Finally regarding the software tool the application has been developed using the H3DAPI library (www.h3dapi.org) that supports several haptic devices including the MOOG-Haptic Master. It is based on the open standards OpenGL and X3D for the visualization, and OpenAL for sound rendering. The scripting language Python is used for calculating the force applied by the user to the end-effector, which sends the value to an x3d program, that renders the feedback force and graphic scene. The program also detects keystrokes on the keypad, which are used to tune the parameters from the haptic model according to user preference.

The test consists of an end user interacting with the Virtual Prototype through the haptic device, giving feedback toward the perceived and desired sensory experience: would she desire a heavier door, the inertia of the system is increased, would she require less force to open the door, the spring stiffness is reduced on the unlocking phase.

Once the desired behaviour is defined, the data acquisition process to characterize the behaviour starts. The user is requested to repeatedly close and open the door, to capture the effort required to close the door, and to apply impulses on the end-effector at different starting positions, to capture the variation of the dry friction at different sections. The time history of the applied force, together with the position and speed of the end-effector are registered, so they can later be used on a new optimization process to identify the technical specifications of the physical system.

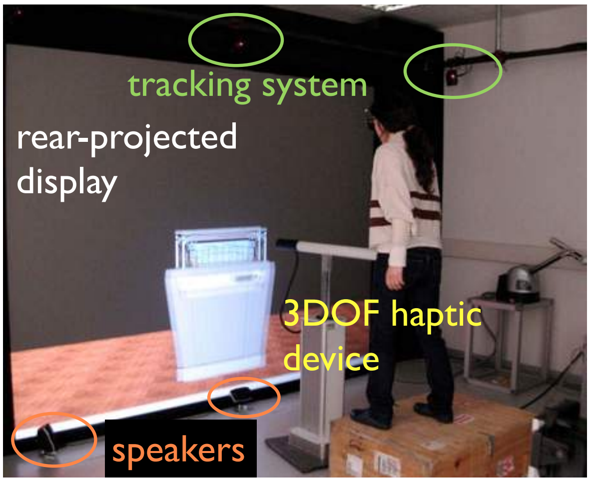

Fig. 5: The Virtual Prototype is accessed through the MOOG-HapticMaster device, while stereo visualization and sounds are returned to the user.

4.4 Use of the Optimization to Retrieve the Design Specifications of the new Product

In order to obtain the technical specifications of the new product, once the user experience has been captured, a complete dynamical model of the mechanism controlling the door is used. This model has been developed in the LMS-Amesim suite (www.lmsintl.com) preferred among the Modelica (www.modelica.org) front-ends because of the large availability of mechanical components already implemented and available to use. The dynamical model is characterized by the physical parameters that controls the motion of the door: the positions of the articulations on the mechanism, frictional surfaces, the spring compensating the weight of the door, along with its planar shape, the door inertia and the stiffness of the latch mechanism. Those parameters represent the technical specifications needed to build the new product or the specific sub-system under analysis. The process to obtain the parameters on the dynamical model is similar to the process followed to make the first estimate of the parameters used to control the haptic device; in this case, however, the time history of the position and speed of the end-effector, along with the force applied by the user, extracted during the test, are used as measurements.

5 CONCLUSIONS

The paper has described a methodological approach that enables companies to re-engineer the haptic feedback of a dishwasher door according to users' preferences. This feedback is part of a more complete multisensory user experience that is becoming important for the success on the market of new products. The methodology proposes the use of multisensory interactive Virtual Prototypes as a means to capture the user experience, and describes a way to transform perceptual qualitative feedbacks into quantitative design specification. Multisensory interactive Virtual Prototypes are based on visual, auditory and haptic interfaces. While haptic feedback can be adapted on user preferences, visual and sound cues are used to complete the experience.

A dishwasher door has been used as case study in order to validate the methodology and to identify the limits. The door mechanism has been analysed and transformed in two different models:

one simplified and parametric that is used to control the haptic device and allow an interactive design review, and the other detailed used when the users' preferences are captured to extract the design specifications. Both the models, the simplified and the detailed are tuned by means of optimization algorithms. Despite this methodology has been used to re-engineer an existing door user experience it has demonstrated to be adapt to the design of new products.

REFERENCES

[1] Barwise, P.: Farley, J. U.: The state of interactive marketing in seven countries: interactive marketing comes of age, Journal of Interactive Marketing, 19(3), 2005, 67-80. DOI: 10.1002/dir.20044

[2] Bhutta, K. S.: Huq, F.: Benchmarking – best practices: an integrated approach, Benchmarking: An International Journal, 6(3), 1999, 254 – 268. DOI: 10.1108/14635779910289261

[3] Bloch, P. H.: Seeking the ideal form: product design and consumer response, Journal of Marketing, 59(3), 1995, 16-29. DOI: 10.2307/1252116

[4] Buchenau, M.: Fulton Suri, J.: Experience Prototyping, In Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques (DIS '00), Daniel Boyarski and Wendy A. Kellogg (Eds.). ACM, New York, NY, USA, 2000, 424-433. DOI: 10.1145/347642.347802.

[5] Crilly, N.: Moultrie, J: Clarkson, P. J.: Shaping things: intended consumer response and the other determinants of product form, Design Studies, 39(3), 2008, 224-254. DOI: 10.1016/j.destud.2008.08.001

[6] Edmunds, H.: The Focus Group Research Handbook, NTC Business Books (Chicago), Illinois, 1999.

[7] Ferrise, F.: Bordegoni, M.: Cugini, U.: Interactive Virtual Prototypes for Testing the Interaction with new Products, Computer-Aided Design and Applications, 10(3), 2013, 515-525. DOI: 10.3722/cadaps.2013.515-525

[8] Ferrise, F.: Bordegoni, M.: Graziosi, S.: A method for designing users' experience with industrial products based on a multimodal environment and mixed prototypes, Computer-Aided Design and Applications, 10(3), 2013, 461-474. DOI: 10.3722/cadaps.2013.461-474

[9] Ferrise, F.: Bordegoni, M.: Lizaranzu, J.: Product design review application based on a vision-sound-haptic interface, In Haptic and Audio Interaction Design, R. Nordahl, S. Serafin, F. Fontana, and S. Brewster, eds., Vol. 6306 of Lecture Notes in Computer Science. Springer Berlin / Heidelberg, 2010, 169–178. DOI: 10.1007/978-3-642-15841-4_18

[10] Forlizzi, J.: Ford, S.: The Building Blocks of Experience: An Early Framework for Interaction Designers, DIS 2000 Conference Proceedings, ACM, 2000, 419-423. DOI: 10.1145/347642.347800

[11] Hoyer, W. D.: Maclnnis, D. J.: Consumer Behavior, South-Western Cengage Learning, 2010.

[12] Hvam, L.: Mortensen, N. H.: Riis, J.: Product Customization, Springer, 2008

[13] Klatzky, R.L.: Peck, J.: Please Touch: Object Properties that Invite Touch, Haptics, IEEE Transactions on, 5(2), 2012, 139-147, DOI: 10.1109/TOH.2011.54

[14] Malhotra, N. K.: Birks, D. F.: Marketing research: an applied approach, New York: Pearson, 2006.

[15] McCole, P: Refocusing marketing to reflect practice, Marketing Intelligence & Planning, 22(5), 2004, 531-539.

[16] Neff, J.: Product scents hide absence of true innovation, Advertising Age, Vol. 7, 2000

[17] Norman, D. A.: Draper, S. W., eds.: User Centered System Design: New Perspectives on Human computer Interaction, 1st ed. CRC Press, 1986

[18] Norman, D. A.: Emotional Design: Why we love (or hate) everyday things, New York, NY: Basic Books, 2004.

[19] Parizet, E.: Guyader, E.: Nosulenko, V.: Analysis of car door closing sound quality, Applied Acoustics, 69(1), January 2008, 12-22, DOI: 10.1016/j.apacoust.2006.09.004

[20] Phillips Furtado, G.: Ferrise, F.: Graziosi, S.: Bordegoni, M.: Optimization of the force feedback of a dishwasher door putting the human in the design loop, A. Chakrabarti and R. V. Prakash (eds.), International Conference on Research into Design, ICoRD13, Lecture Notes in Mechanical Engineering, 2013, 939-950. DOI: 10.1007/978-81-322-1050-4_74

[21] Schifferstein, H. N.: & Hekkert, P.: Product experience, Elsevier Science Limited, 2007

[22] Schrage, M.: Cultures of Prototyping, in Bringing Design to Software, T. Winograd, Editor. ACM Press: New York, 1996.

[23] Shin, S.: Lee, I.: Lee, H.: Han, G.: Hong, K.: Yim, S.: Lee, J.: Park, Y.: Kang, B.K.: Ryoo, D.H.: Kim, D.W.: Choi, S.: Chung, W.K.: Haptic simulation of refrigerator door, Haptics Symposium (HAPTICS), 2012 IEEE, 147-154. DOI: 10.1109/HAPTIC.2012.6183783

[24] Spence, C.; Gallace, A.: Multisensory design: Reaching out to touch the consumer, Psychology and Marketing, 28(3), 2001, 267-308. DOI: 10.1002/mar.20392

[25] Strolz, M.: Groten, R.: Peer, A.: Buss, M.: Development and Evaluation of a Device for the Haptic Rendering of Rotatory Car Doors, Industrial Electronics, IEEE Transactions on, 58(8), 2011, 3133-3140. DOI: 10.1109/TIE.2010.2087292

[26] Ulrich, K.T.: Eppinger, S.D.: Product Design and Development, Second Edition, New York: McGraw–Hill, 2000.

[27] Van der Auweraer, H.: Wyckaert, K.: Hendricx, W.: From Sound Quality to the Engineering of Solutions for NVH Problems: Case Studies, Acta Acustica united with Acustica, 83(5), September/October 1997, 796-804

[28] Wilson, J. R.: Cobb, S. V. G.: D'Cruz, M. D.: Eastgate, R. M.: Virtual Reality for Industrial Application: Opportunities and Limitations. (Nottingham: Nottingham University Press), 1996.

[29] Zorriassatine, F.: Wykes, C.: Parkin, R.: Gindy, N.: A survey of virtual prototyping techniques for mechanical product development, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 1 217(4), 2003, 513-530. DOI: 10.1243/095440503321628189