KEER2010, PARIS | MARCH 2-4 2010
INTERNATIONAL CONFERENCE ON KANSEI ENGINEERING AND EMOTION RESEARCH 2010

INTERACTIVE USER TESTS TO ENHANCE INNOVATION
APPLICATION TO CAR DASHBOARD DESIGN

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ABSTRACT

The development of new products that satisfy consumers' needs and preferences is a very important issue. To avoid flops, the control of the risks in product innovation and the reduction of the innovation cycles require valid and fast customer's assessments, for determining new products that effectively correspond to the customer's taste. In particular, the shape of a product is an important factor in the success or the failure of a product. Since several years, in various research fields, many works are dedicated to the design of shapes by the analysis of the user's perception. Kansei engineering for instance produced many tools and methodologies in this research area. The work proposed in this paper is in this context. It is based on the use of interactive users' assessment tests to enhance creativity, by the way of interactive genetic algorithms (IGA) for capturing users' responses. A set of parameterized designs, defined with a CAD system, are presented iteratively to the user to be evaluated by a graphical interface. This navigation in the design space may converge towards designs that maximize a subjective criterion, given in advance to the user. We describe in the paper the interest of this approach for the design of forms and the setting of design constraints. The proposed application concerns the design of "innovative" car dashboards (innovative has to be understood here as in agreement, according to the user, with a particular semantic dimension, for instance "compact", handy", …).

***Keywords**: interactive genetic algorithms, shape design, car dashboard, CAD models*

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1. INTRODUCTION

In automotive design, fitting with the expectations of the users is a crucial issue. These expectations can be functional or can concern subjective aspects (sensory or semantics). In particular, the external form of a product is an important factor in the success or the failure [1], as it conditions the ergonomics, the aesthetics but also the product semantics [2]. When industrials address a new specific semantic dimension, such as a need of "innovative dashboard", the challenge for the company is to clearly understand what does the verbatim "innovative" mean for the users, and to translate it in design attributes. On the one hand, consumers know what they want (and what they don't) but they generally are not able to formulate precisely their need in technical terms or to justify their choices according to design attributes [3]. On the other hand, companies develop competences in product design but they encounter difficulties to anticipate precisely the consumer's acceptance. Therefore, a key challenge in product design is to analyze consumer's evaluation to extract useful information for product innovation [4]. Many research works in form design are dedicated to the integration of users' response in the design process. In Japan, Kansei engineering is a powerful approach to product design involving user's perceptions [5] [6]. In engineering, the multiattribute utility theory (MAUT) has become the basic theory to express an objective function including consumers' perceptions and preferences [7]. For example, Interactive genetic algorithms (IGA) are proposed for capturing aesthetics intention of users [8].

Our work is in this context. We developed in this paper a methodology for the integration of user's assessments in the development of innovative products [9]. The different stages are illustrated by an application concerning a car's dashboard. We suppose that we wish to design a dashboard characterized by a given semantic dimension (defined in advance), and we show in the paper how user-tests can help to uncover specific design attributes. The goal of the study is not to replace the designer and to make automatic design, but to help him/her to better understand the consumer desires in term of shape. The methodology is based on a parameterized design space (i.e. the possible designs are given by different combinations of parameters), in which the products are represented by their digital mockup (CAD model). Interactive user assessments, based on the CAD model of the dashboard, are interpreted by an Interactive Genetic Algorithm (IGA), and constitute a dynamic way (the product space changes iteratively in regard to the responses of the consumer) to extract design attributes corresponding to a specific semantic dimension.

The objectives of this paper are to show how the CAD models of the dashboard are defined, to describe how they are managed by the IGA, to present the interface for the user-tests and to give key elements concerning the future results of the study (the study is still in progress).

This paper is structured as follows: Section 2 gives backgrounds on Genetic Algorithms (GA), Section 3 deals with the methodology proposed and Section 4 describes the framework of the interactive assessment tests. Finally, section 5 presents some concluding remarks.

2. BACKGROUND ON GENETIC ALGORITHMS

Genetic algorithms (GA) are evolutionary optimization methods [10]. The principle of GA is based on iterative generations of populations of individuals, converging step by step to solutions which are adapted to the problem. Individuals are described by a set of factors which are coded (their genes). Based on the principle of Darwin's natural evolution theory, the algorithm proceeds to a selection of parents, which will spread in the next generation their genetic dominant heritage, suitable for a desired objective. Classically, the fitness evaluation of the individuals is numerically calculated, ignoring the user. A particular category of GA, called Interactive Genetic Algorithms (IGA) introduces the user in the optimization loop to assess the fitness. At each iteration, the user selects individuals (products) that he/she considers as the most interesting for the desired objective. After a number of iterations (convergence loop), the method may converge to solutions that satisfy the objective desired by the user. These algorithms are used for example to explore design spaces and to encourage creativity [11] [12] [13] [14]. They have the advantage to not require an explicit formulation of the fitness function, given that the user plays this role. For some applications, this advantage is crucial [15].

3. METHODOLOGY FOR CAPTURING USER'S RESPONSE

The objective of our methodology is to uncover the main design attributes which are representative, according to the user, of a given semantic dimension (for example innovative, compact, handy ...). The key point of the methodology is that the user's assessments are iterative (the user navigate in the design space) and that the IGA may lead to the convergence of the navigation toward "representative" designs. A computational framework is proposed for the capture of the user's response to a set of "virtual" designs (Figure 1). It is based on the following stages:

- **1. Definition of the design *factors***. The factors are the design attributes of the dashboard which correspond to a variable of the design space. These factors are selected after a verbalization task with a group of subjects. This step leads to the definition of the parameterized design space, given by the factors and their corresponding levels (qualitative) or intervals of variations (quantitative).
- **2. Definition of the design variables**. The design variables are the entities that drive the CAD model. These variables are quantitative or qualitative. From the previous factors, a CAD model of a dashboard is proposed, CAD model which is compatible with the design space, i.e. which allows the representation of all the products of the experimental design considered.
- **3. CAD modeling**. The design of the dashboards is made with the CAD software CATIA. Each dashboard is contextualized in the interior of a car.
- **4. Interactive user's tests**. An interactive and iterative assessment test (using Matlab) is proposed to a set of users. From a population of dashboards, represented by their CAD models, the user has to select the ones which are the most representative of the considered semantic dimension. The IGA generates new population of dashboards which are iteratively proposed to the user for evaluation.
- **5. Analysis of the results**. The final population of dashboard is analyzed in order to uncover typical features and infer design rules. For each user, the exploration of the design space may lead to several innovative dashboards. The analysis of the results consists in finding typical characteristics for these dashboards, for all the

users (common factors, common factors for groups of users, differentiating factors).

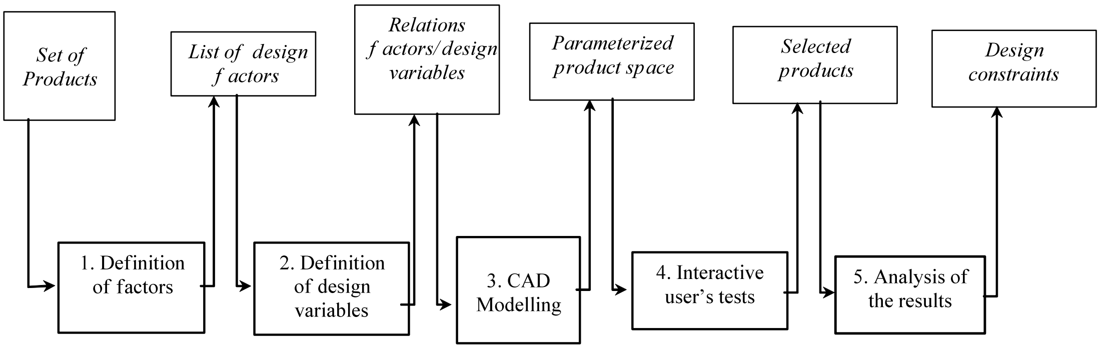


Figure 1: Synoptic of the methodology and definition of the different stages

The study being still under progress, we will next detail certain of these stages.

3.1. Definition of the design factors

Our definition of a factor is "a design attribute which is variable in the parameterized design space" (e.g. the vent type, the average height of the dashboard…). We have to define which design attributes become **factors** and which design attributes remain constant in the design space. A dashboard is a very complex product with a lot of design attributes. It is then not realistic to select all of them due to convergence problems of the IGA. Furthermore, it is necessary to only select design attributes which are influent on the "innovative dimension" under study. The number of factors is actually a compromise between two extremities: with few factors, the problem would be simple and caricatured; with a huge number of factors, the method could not converge in a reasonable assessment duration.

We firstly deployed qualitative and quantitative studies to better understand the user point of view. A group of 25 participants analyzed five key dashboards from the market. The design attributes which contribute to the "innovative aspect" (according to the users) have been extracted and organized into a hierarchy. Moreover, different scenarios were formulated (e.g., dashboard can be asymmetric).

Secondly, a lot of key dashboards of the market (of the B segment) were analyzed on an expert point of view to extract the dimensions which are usually changing between them. We have seen these models as targets which should be reached by our parameterized dashboard. Furthermore, we think that a mean to evaluate the powerfulness of our model lies in its abilities to generate these concurrent dashboards (in case they contain interesting attributes). These information were translated in quantitative data (such as the range of dimension of the Center console) and in qualitative data by creating families of dashboards (such as the "in front of driver instrument panel", the "central instrument panel" or the "dual screens"). Qualitative data were used to discern global differences of packaging (for example air vents are coded in only 4 levels: round, elliptic, rectangle, squared, rhombus). In contrast, quantitative data were used when precision was required.

Finally, an initial example of dashboard was chosen as the basis of our work. We started from a product currently sold by our company to see if it can be improved, and how. After a selection of the factors, we defined the way they can vary (the levels). We used different ergonomics rules to lock the characteristics which are standard (such as the windscreen starting-point). The amplitude of variation of each factor has been chosen by defining, by benchmarks, a percentage of maximum variation (for example, height of main body varies of 10%, width of center console varies of 15 %...). This percentage is a tradeoff between creativity and ergonomics constraints. After this work, the factors have been reduced from 50 in the second step (with the expert point of view) to 15. The list of factors cannot be published for confidential reasons. By fixing the factors and the way they can change (the levels), we defined a large number of design possibilities, making up the **design space**.

3.2. Design variables and CAD modeling of the dashboard

After the determination of the design factors, the next step is to define the parameterization of the CAD model (design variables). The problem is to set up a model which is compatible with the variation of the factors. Of course, there is an infinity of possibilities for the parameterization of the model. In order to simplify the relations factors/design variables, the model was set up in a way that, as much as possible, one factor is driven by one design variable: a one-to-one correspondence between factors and design variables was favored for the definition and the parameterization of the different sketches. The body of the dashboard was modeled by five Spline curves with 5-control points (figure 2), defined in a vertical plane for different sections (Figure 3).

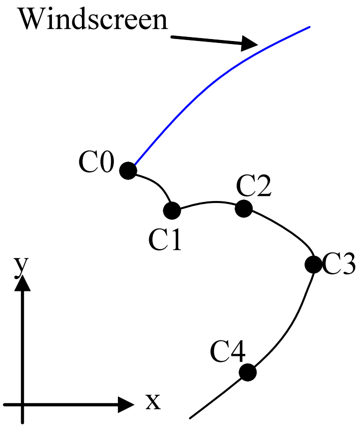


Figure 2: Definition of a spline by 5 control points in a vertical section

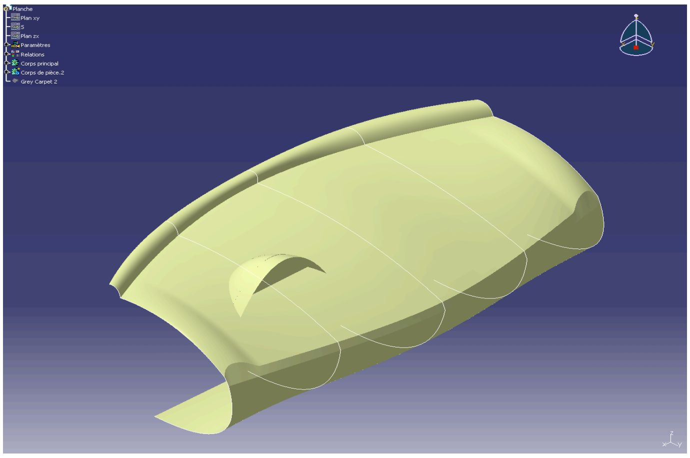
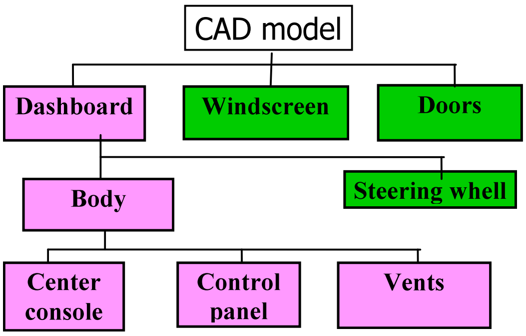


Figure 3: CAD Surface modeling of the dashboard's body (sweeping of the surface on the five different Spline curves)

The different parts of the dashboard (center console, control panel, vents) were next added to the body in a hierarchical structure (figure 3). The digital mockup is managed by two categories of design variables:

- Quantitative variables: the coordinates (x, y) of the different control points of the sketches (for example, C0, C1, C2, C3, C4 for the body)
- Qualitative variables: different type of instrument panel

The parameterization of the CAD model allows the representation of an infinity of designs, by instantiation of the design variables. In order to limit the size of the design space, for the rest of the study, we selected 15 factors and the corresponding design variables (mainly the height y and the depth x of certain control point C_i). Three levels were proposed for these 15 design variables. The size of the full factorial design is then 3^{15} = 14 348 907 possible designs. To increase the realism of the mockup, additional parts of the car interior were added (windscreen, steering wheel, doors and doors frame) (in green on figure 4). It is important to notice that these parts are not parameterized and remain the same for all the possible designs of the dashboard.



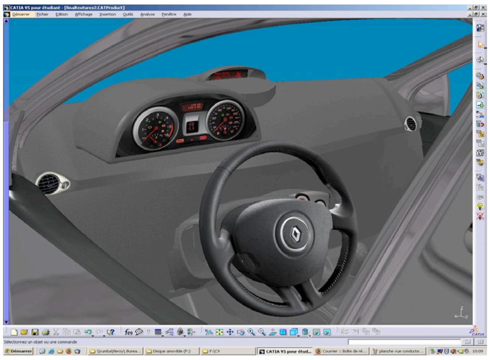


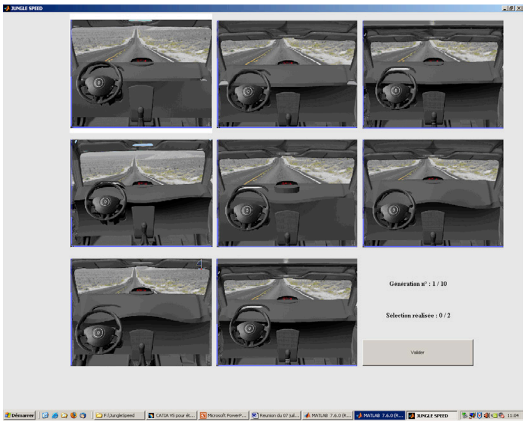
Figure 4: Hierarchical structure of the different parts of the CAD model

Figure 5: CAD model of the car interior

Finally, a CAD assembly model of the different parts is made, so as to allow the visualization on the same picture of the different factor's levels of the design (figure 5). IGA are next used to navigate in this design space.

3.3. Interactive assessment test

The evaluation of the populations of designs by the user has been made by a graphical interface (figure 6). The task is simple and intuitive for the participant. A population of eight designs is presented to the participants (figure 6). For each population, the task asked to the participant is to select k=0, 1 or 2 particular designs, which seem particularly suitable for a tested criteria (in our case, the tested criteria was "innovative").



Génération n° : 1 / 10

Sélection réalisée : 0 / 2

Figure 6: Interface for the selection of the designs by the user

Figure 7: Contextualization of the dashboard in a virtual car interior

To enhance the realism of the mockups, each design corresponding to a dashboard configuration is represented with an environment picture (a road setting, figure 7). Textures are plated on shapes to increase the objects realism. Two screens are available, each corresponding to a particular point of view: a point of view of a « driver » reproduces the view of an average man in a sitting position and a point of view "3/4 profile" (figure 5) that corresponds to a lateral view which can be seen by an average standing man located outside the car with opened doors. The framework for the interactive assessment test is given in Figure 8.

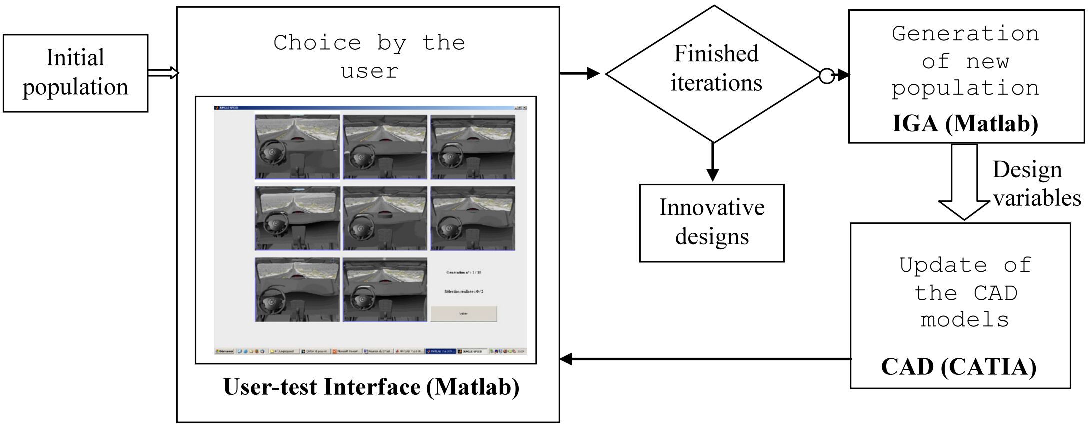


Figure 8: framework of the iterative user-test

3.4. Implementation of the IGA

The first part of the IGA, and GA in general, is to code the factors. In our study, 15 design variables evolve between three levels. Each gene is thus coded on 2 natural binary bits, that is to say thirty bits by chromosome/products. The initial population was randomly chosen and presented to the user. The size of the population, $N = 8$, has been defined by considering the maximum number of designs that could be presented together to the user on a screen. The 8 products presented represent the product space which is called a generation. In this generation, the user is asked to designate which products are representative of the semantic dimension. His/her selection (k=0, 1 or 2 products) is the basis for the definition of the next generation. This creation is done by two basic operations:

- **The cross-over**: method of recombination where two individuals, called parents, produce a new individual (child) by sharing information at a particular point randomly chosen of the chromosome (single point crossover). It is possible to study a pseudo-random effect on the change, which would aim to select the most interesting bits in this cross. The first consequence will be a more effective reorientation of the population, from one generation to another. The aim of this operator is to obtain better characteristics in the new generation while maintaining the diversity of the population.

- **Mutation**: from a parent to a child, a bit is changed on a random gene. This will then create a product with a new feature, producing possible jumps in unexplored parts of the design space.

The selection of the parents follows a principle called “Roulette Wheel”, defined by a rate x_r. In a generation of N products, the user selection will give to the k selected parents a high probability of parental selection ($x_r/k + (1-x_r)/N$). The N-k non selected individuals will have small, but also equal, wheel percentages $(1-x_r)/N$. Figure 9 shows the principle of the algorithm, with x_{mut} and x_{cro} the mutation rate and the crossover rate respectively.

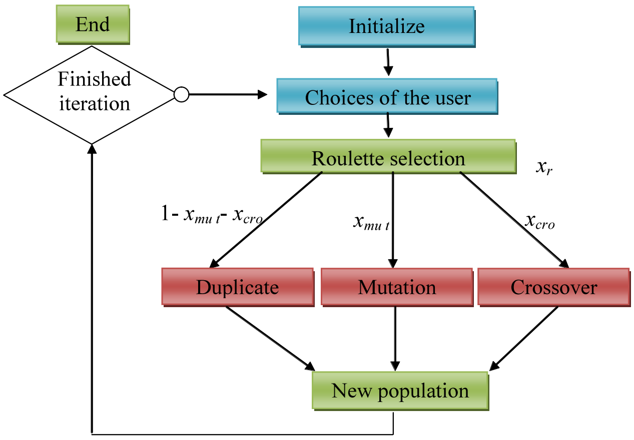


Figure 9: Flow diagram of the IGA

The stopping test includes two possibilities: either the maximum number of iterations is reached, or the difference between a population and the previous one is lower than a threshold. Several parameters must be adjusted for the convergence of the method: N_{iter} number of iterations, x_r roulette rate, x_{cro} percentage of crossover, x_{mut} percentage of mutation. To study the convergence of our algorithm and to tune the different parameters, a test was carried out with simulations of the user's choices, as in [14]. For X experiments (x=1 to X), N_{iter} generations (n=1 to N_{iter}) are successively generated. For each generation, the average distance $d_{av - nx}$ between all the products of this generation and a target, defined in advance, is calculated, as the maximal distance $d_{max -nx}$ (Figure 10).

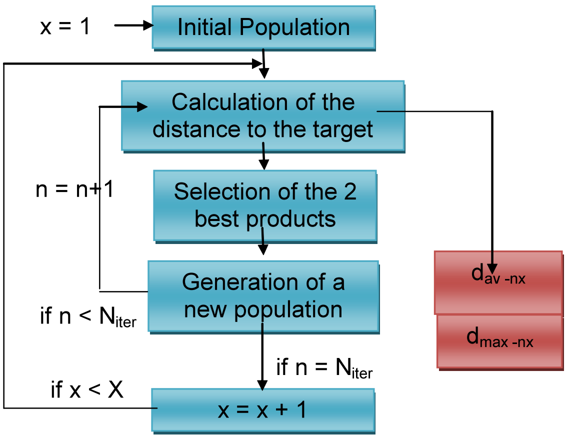


Figure 10: Synopsis of the test with simulated user's choices

The evolution of the average distances $d_{av - n}$• and $d_{max -n}$• (averaged over the experiments x) helps studying the convergence abilities of the IGA, and to tune the parameters of the algorithm. We used this process to study the convergence of the algorithm.

4. EXPECTING RESULTS

The study is still not yet finalized and tests have to be made with a larger panel of subjects. For each participant, the outputs of the selection process will be one or two **innovative designs** selected during the last iterations, and also the historic of the choices made during all the iterations. A first analysis will consist in studying the stability of the user-choices according to repetitions of the test, and analyzing the convergence of the method. For a panel of participants, a second analysis will consist in finding out the common factors of all the innovative designs. By analyses of the typical attributes of these dashboards, for all the participants (common factors to all the subjects, common factors to groups of subjects, differentiating factors), a typology of the design factors will be proposed: consensual factors, discriminating factors, non relevant factors.

5. CONCLUSION

We presented in this paper a methodology for an innovative design of car's dashboards. The methodology is based on interactive user assessments which are processed by Interactive Genetic Algorithms. We show how this process allows the determination of the design attributes of the dashboard (and their levels) which are representative of a given semantic dimension. The proposition does not replace the designer, it allows the definition of design constraints or the interpretation of preferable orientations for the customers. The user-tests are based on digital mockups of the dashboards and a parameterization of the CAD model. We described in the paper how this parameterization has been made, by the definition of "factors" (design attributes which are variable in the design space) and of "design variables" which drive the CAD model. The interest of the proposed procedure is that it structures the design space and allows a simplified but relevant definition of the CAD models. The navigation in the design space is made by IGA. We presented how the CAD models were implemented in the IGA, the general framework of the IGA, and the procedure for studying the convergence of the IGA and the tuning of the algorithm's parameters. The first results are encouraging, but we need now to test the methodology with a group of users, and to test the convergence of the IGA according to the algorithm's parameters.

The continuation of this work will consist in analyzing the results of a group of user, i.e studying the characteristics of the "innovative" dashboards selected by the users: research of the more influent factors and their levels. Several limits have to be tested: influence of the size of the design space (is it realistic to take into account more than 50 factors?); duration of the assessment tests; influence of the virtual presentation of products and existence of a just Noticeable Difference (JND) between different designs.

Acknowledgments

We acknowledge Thibault Leroy and Alistair Ispizua for their substantive inputs in the realization of this study.

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