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QUANTIFYING SHAPE DESCRIPTORS FOR AESTHETIC CONCEPTS

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1. Introduction

Usually, consumers refer to products using adjectives or personalities commonly associated to humans. For example, by saying "this is a cute mug" or "this is an aggressive car". This way of referring to products leads to what has been called the "product personality". As described in [Govers and Mugge 2004], the "product personality" can be defined by a set of characteristics that people use to describe and discriminate products from others. The product personality can be based on the shape of the product, but also its colour, texture, smell and even the sound can be relevant to define the product personality [Janlert and Stolterman 1997]. Examples of 23 product personalities can be found in [Ortiz et al. 2011]. It has been demonstrated that the product personality perceived by consumers have direct relation with some visual product aesthetic features like simplicity, harmony, balance, unity, dynamics, novelty and timeliness/fashion [Brunel and Kumar 2007], all features well understood by industrial designers as well as artists. In this sense, usually the effective achievement of a determined personality on a product shape depends mainly on the designer personal experience and skills.

This work is oriented on developing a systematic and quantitative understanding about how a specific concept (like personality) can be imprinted in a product by modifying its appearance. Because consumers usually prefer products which personality is similar to their own [Govers and Schoormans 2005], the deep understanding on how a specific personality can be introduced in the appearance of a product under development, can be important knowledge for successfully introduce new products in the market. Our ongoing research seeks to build such knowledge and to make available to designers and engineers, a flexible and customizable new tool that allows the exploration of a range of formal solutions, by applying *geometric modifiers* which imprint concepts intuitively and smoothly (like personality) to products under shape development.

This article presents the preliminary results of a long term research that aims to develop such new tool. While in [Prieto et al. 2013] the authors describe the problem in general terms and start analyzing the correlation among shapes and perception, this paper focus on the identification of features and measurement methods to quantitatively assess product personality. At this stage, a first approach of shape descriptor allowing to properly categorizing the object shapes according to one pair of opposite concepts (Gentle-Aggressive) is presented. A survey has been conducted to obtain statistical measurements of the perception degree of the interviewees with respect to the concept pair Gentle-Aggressive, for each image subject to this study. Then, the descriptor and the measurement (statistical mean or median) for each object silhouette are utilized in a supervised learning process to obtain a model of the concept. The obtained model corresponds to an artificial neural network, which allows to predict the perception degree of the studied concepts from the descriptor of a new silhouette.

In the following, a summary of advances on supporting CAD tools on early stages of the design process and geometric shape descriptors is presented. Then the first preliminary shape descriptor is described and validated.

2. The design process

In the early stages of the design process, specifically within the concept development phase, designers must develop the general appearance of the product. The appearance involves mainly shape, color, and material properties. Because most of products are currently publicized by including pictures on billboard, the product appearance is the main (visual) communication link between the product and the potential customer. Additionally, the early stages of the design process have been reported to account for more than 75% of the final product cost [Hsu et al. 2000].

Research on the early stages of the product design have focused on 2D sketching [Dickinson et al. 2005], 3D sketching [Dekkers et al. 2011], the transition from 2D sketching to 3D modeling [Cheon et al. 2012], interactive 3D Modeling [Rahimian and Ibrahim 2011], [Fuge et al. 2012], interactive 3D models edition [Bourdot et al. 2010] and how creativity is influenced by using CAD tools [Robertson and Radcliffe 2009]. The creative process of developing the first design attempts, where the product form must be defined, is still commonly carried out by pencil and paper, without further support from CAD tools [Krish 2011]. Besides, additional interface and functionality constraints of current CAD tools modify or alter the final formal results, which even allows for the undesirable effect of recognizing what type of CAD tool was used just by looking at the final design [Crilly et al. 2009].

An attempt to support designers in the stage of form definition is reported in [Krish 2011], where a generative design method and its correspondent CAD tool for shape exploration have been presented. In this work, geometric parameters are randomly manipulated by software using pre-defined limits. The random manipulation is used to develop sets of distinctive designs. The design intents are then filtered by using constraints representing geometric viability, manufacturability, cost and other performance related constraints. Although this work represents a significant advance in the support of the shape definition task, it does not include any non-technical feature like the aesthetic concepts intended to be included in this project.

3. Linking products and personality

With the goal of developing products that better fit consumer personal needs, research has been conducted with the aim of linking some non-technical product features (like the product personality) to specific formal features, which build the product general appearance. In this direction, [Chen and Chang 2009] has successfully identified and numerically described key geometric features related to the product personality of different types of knives. The research focused on establishing precise definitions of the product shape and on studying the statistical correlation between shape features and consumers response. The reported results show the viability of the method in linking geometric features to product personalities. However, this research was focused on a specific product, without extending the research to a range of different products to find out whether a universal relationship between product personality and geometric features exists. Further research is necessary to improve our understanding on this area, to be able to transfer this knowledge onto a CAD tool. In a related approach, the influence of aesthetic features on brand recognition was investigated in [Ranscombe et al. 2012]. The study was carried out using saloon cars. By decomposing different car images into their constituent aesthetic shape features, customers were surveyed to find out whether they could recognize the car brand based just on the partial information given to them. As result, it was possible to identify the aesthetic key features that influenced customer brand recognition. Finally, in [Ortiz et al. 2011], evidence was provided regarding the feasibility of designing products with a given personality. In the study, industrial design students were asked to design products with a given product personality, considering general appearance attributes such as shape, material, colour, finish, textures, size and composition. Then, a group of 54 people was asked to assign a personality to each product. For some personalities (e.g. elegant and provocative) there was a good match between the intended product personality and the personality detected by the "consumers", leading to the conclusion that "designers can influence meaning in product appearance". However, no quantitative approaches to describe the product appearance were used, which hinders the development of an automatic CAD tool. Further research on understanding product personality association to numerically-described key geometric product features is then of fundamental importance to develop tools to assist the design process of products that predict consumer decision, because they choose products which have similar personality with them [Govers and Schoormans 2005].

4. Geometry description

In order to analyze product shapes in terms of a concept related to personality, it is necessary to find significant geometric features able to properly characterize objects with products with different perception of the concept. Among the numerical characterization techniques, we can find contour and region-based approaches [Zhang and Lu 2002]. Contour-based techniques utilize shape boundary information to characterize the shape whist region-based techniques exploit the information of all the pixels inside the boundary of the shape. In this project we will focus on contour-based characterization of shapes owing to two different reasons:

1. At first sight the human eyes start moving around the contour of the objects they look at, thus getting a general idea of the objects than they focus on other inner details for discovering other characteristics;
2. Region-based techniques necessarily require more computationally complex techniques than contour-based schemes.

The most commonly used contour-based techniques are shape signature [Ballard and Brown 1982] and Fourier descriptors [Zhang and Lu 2002]. The simplest shape signature method selects a point inside the shape contour, called centroid. Then, the contour of the shape is traveled at a constant speed by a pointer. Every t units of time, the distance from the centroid to the pointer is calculated. By plotting the recorded distance as a function of the time, a one-dimensional function that characterizes the shape is obtained. In this way, a signature describes a two-dimensional form in terms of a one-dimensional function, and it can capture its perceptual characteristics. This function is called the shape signature, and there are many variants of this technique [El-ghazal et al. 2009]. By comparing the shape signatures of different objects, similarities between them could be detected [Zauhar et al. 2003], [Narayana et al. 2011].

One disadvantage of shape signatures is that they are sensitive to scale and rotation (that is, two identical shapes of different size and rotation have different shape signatures). To avoid this, Fourier descriptors can be used. Fourier descriptors are obtained after applying the Fourier transform to the shape signature. In this way, condensed information about the harmonics composing the signature is obtained, which is insensitive to scale and rotation [Zhang and Lu 2002].

In this article, we describe the shape of products under analysis by using a descriptor based on the histogram of the shape signature points. The objective of the descriptor is to characterize the presence of different contour direction changes, in order to obtain a first set of features that could describe the frequency of contour characteristics related to gentleness-aggressiveness, present on the shape. The rationale of this descriptor is the fact that aggressive changes on contour direction (e.g. sharp edges, corners) is often related to the perception of aggressive objects, while smooth changes on change direction are often related to the gentle ones. These direction changes are accumulated in a normalized histogram of direction changes, which constitutes the chosen descriptor. The advantage of this descriptor is that is invariant to scale and rotation. Establishing a correspondence between aesthetic feature degrees and numerical features will primarily allow designers to automatically characterize the personality of a new object, and, in the future, to control the degree of different features in the object personality by modifying the numerical features associated to the product.

5. Building the shape descriptors

The procedure of building the proposed shape descriptor is briefed in **Figure 1**. The descriptor is built from the object silhouette, by normalizing the histogram of the *angular difference signature*.

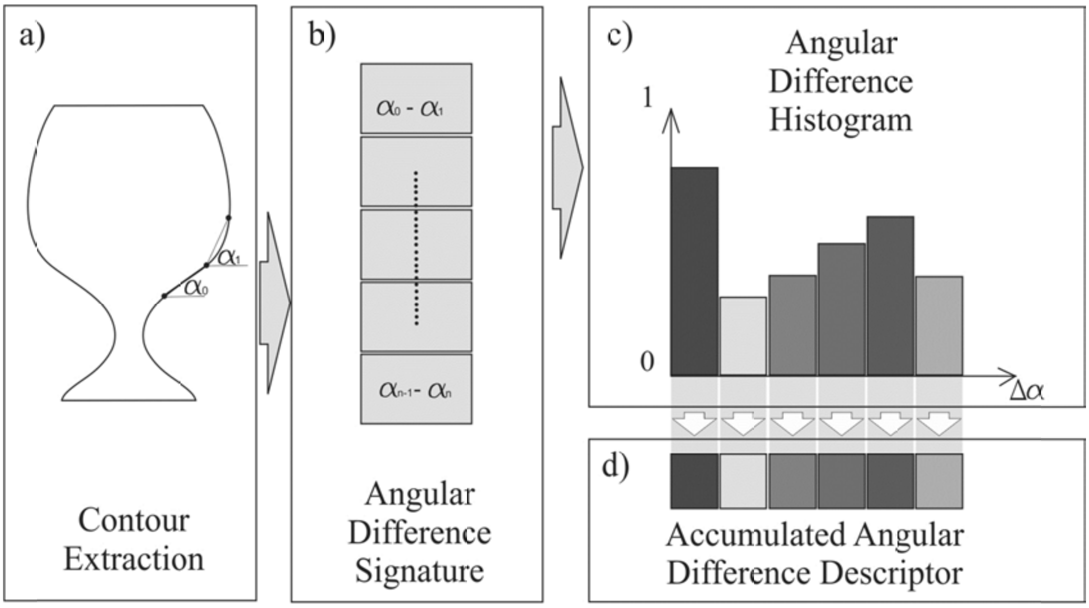

Figure 1. The image shows the process for obtaining the A2D2 descriptor

a) First, the contours of the input image are obtained. For each of these contours, the angle formed by each pair of contiguous points (or separated by a constant step) is obtained to form a *contour angle signature*.
b) Then, the difference of two contiguous angles is obtained, which results in the *angular difference signature*.
c) Next, the *angular difference histogram* is obtained by accumulating all the *angular difference* values from the signature in a set of predefined bins.
d) Finally, each bin becomes a feature of the *accumulated angular difference descriptor (A2D2)*. This descriptor is invariant to rotation and scale, and allows to properly describe the smoothness/sharpness features of the silhouette.

6. Learning the concept model

The same object silhouettes utilized to obtain the descriptor *A2D2* from previous **section 5**, have been subject of a preliminary survey to obtain statistical measurements of the perception degree of the interviewees with respect to the concept pair Gentle-Aggressive. In the work reported in this paper, silhouettes of ten glasses of wine were used. The study considered a sample of 101 Chilean engineering undergraduate students, with the following features: **gender:** 70% male, 30% female; **mean age:** 22 years; **age standard deviation:** 6.6 years.
It can be considered as an homogeneous sample in terms of background, culture and age, but no particular considerations of homogeneity were taken into account at this stage of the research. Interviewees were asked to evaluate the degree of association of each silhouette to the pair Gentle-Aggressive of opposite concepts. A mark ranging from -5 (maximum association to the concept of Gentle) to +5 (maximum association to the concept of Aggressive) had to be given to each silhouette. The images used in the survey are shown in **Figure 2**.

Figure 2. The image shows the 10 silhouettes used in the survey

The results of this survey are presented in **Figure 3.** Each figure has been associated to statistical information about the survey, including statistical mean, median, standard deviation, and reliability.

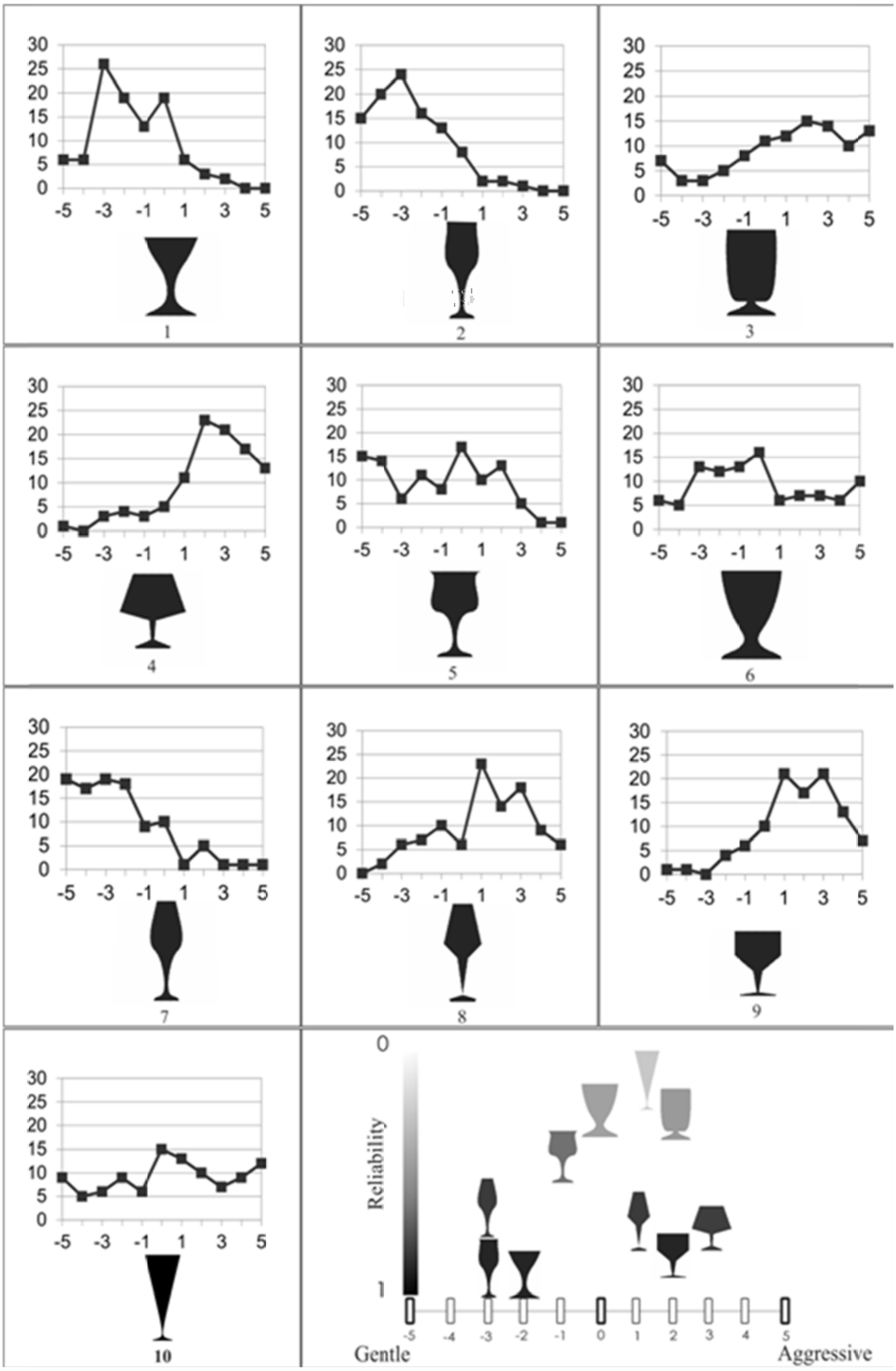

Figure 3. Briefing of the survey results. The figure shows each silhouette -from 1 to 10- with its respective histogram of the survey. In the lower right corner, the relation between the silhouettes and the median/reliability values obtained for concept from the survey, is shown

In the survey, an object silhouette with a high associated standard deviation on the concept value, can be interpreted as an object where the presence of the personality concept is unclear. The reliability corresponds to a measure of the relevance of the information and, in this case, the relevance about the concept is correlated with the standard deviation. This way, in order to quantify the relevance of the obtained concept degree information, a reliability measure **R(o)** for an object silhouette **o**, is proposed:

$$R(o) = \frac{(1-\beta)\times sd_o + \beta \times min - max}{min - max} \quad (1)$$

with sd_o, the standard deviation of the interviewees answers about the concept for the object *o*. The *min* and *max* values correspond to the minimum and maximum standard deviation among all images, respectively. β is a predefined parameter representing the minimum possible reliability value for the lowest relevance object silhouette. Then, the proposed reliability measure is a linearly decreasing function in [β; 1.0], with respect to sd_o, associated to each object silhouette, which quantifies the relevance of the silhouette in terms of the concept degree estimation. This way, the reliability can be used to weight the contribution of the object descriptor in the learning process for obtaining the personality concept model. For this research, parameter β has been empirically set to 0.25.
Then, the descriptor and the statistical mean or median of each measurement are utilized in a supervised learning process to obtain a model of the concept associated to an object silhouette. The obtained model corresponds to an artificial neural network [Igel and Husken 2000], which allows to predict the perception degree of the Gentle-Aggressive concept from the descriptor of a new silhouette. The neural network is constructed with an input layer feed by the A2D2 descriptor. After several tests, and following the rule of thumb for the hidden layer, a size of half the size of the descriptor has been considered. Finally, the output layer has one node, for obtaining the prediction for the personality concept. Also, according to the performed tests, the symmetrical sigmoid has been chosen as the activation function.
Figure 4 presents a schema of this concept model. The training phase was performed using a training set of object descriptors, considering as output of each object its corresponding mean or median concept degree from the survey, and the reliability measure for weighting the contribution of each instance to the model.

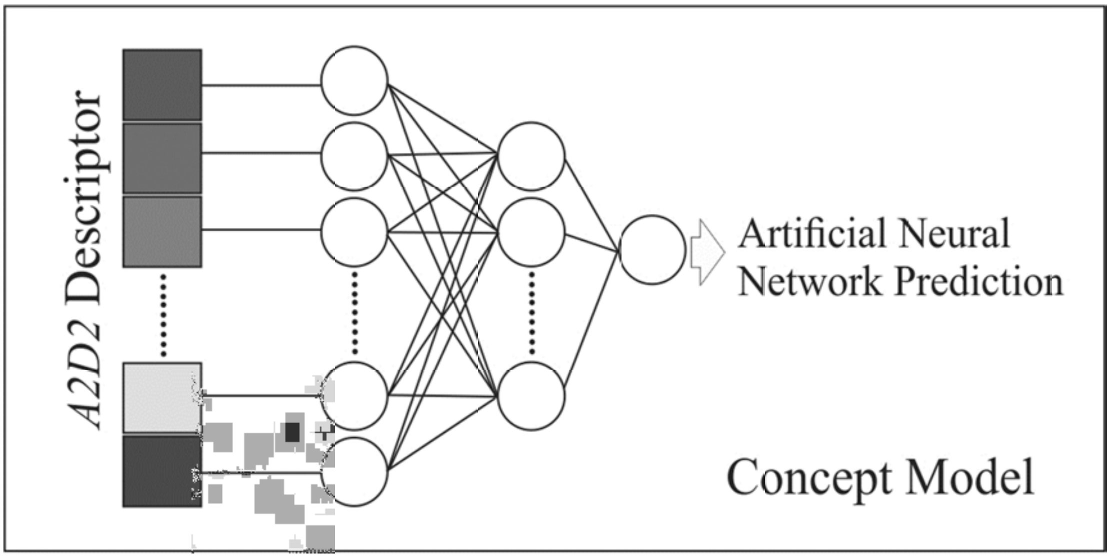

Figure 4. The concept model. A2D2 descriptor is connected to the input layer of an artificial neural network, trained with a set silhouettes, to obtain the concept prediction

7. Preliminary results

For validating the predictive capability of the neural network, leave-one-out cross-validation (LOOCV) [Kohavi 1995] has been performed using every combination of 9 silhouettes for training, and the remaining one for testing. A descriptor size of 9 bins has been considered. The results are promising, as shown in **Table 1**. The results show a mean absolute difference between predicted and survey personality context degree of **0.36**, which is less than the scale of the survey.

Table 1. Results of LOOCV validation on glass image set

Object	1	2	3	4	5	6	7	8	9	10	Mean
Mean	-1.63	-2.6	1.14	2.26	-1.18	-0.11	-2.4	1.2	1.8	0.43	
Prediction	-1.41	-2.37	0.35	2.22	-1.41	0.98	-2.57	0.08	2.00	0.49	
Abs. Difference	**0.22**	**0.23**	**0.79**	**0.41**	**0.22**	**1.09**	**0.17**	**1.12**	**0.2**	**0.06**	**0.36**

8. Discussion and future work

The capability of predicting the personality of an object is a feature of high interest in product design. The proposed approach shows promising results in this line, being able to predict, through cross-correlation, the degree of personality concept for ten different object silhouettes.

Nevertheless, this work can be extended in many ways. One of them, is the characterization of different personality concepts, which can result in the need of more complex descriptors, considering other features of different nature. Also, more research is needed to understand the effect of scale in different local shape features and the effect of applying techniques as Principal Component Analysis (PCA) to focus the learning process on relevant information.

As the first phase of a more wide project, this results open the path to develop a CAD able to modify a shape according to personality concepts in a controlled fashion.

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