Visualizing User Experience Through "Perceptual Maps": Concurrent Assessment of Perceived Usability and Subjective Appearance in Car Infotainment Systems

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Abstract. Users' perceptions of the appearance and the usability of an interactive system are two integral parts that contribute to the users' experience of the system. "Actual usability" represents a system value that is revealed either during usability testing and related methods by experts or during use by the target users. Perceived usability is an assumption about a systems' usability that has been made prior to, or independent of, its use. The appearance of a product can inadvertently affect its perceived usability; however, their relationship has not been systematically explored. We describe an approach that uses "perceptual maps" to visualize the relationship between perceived usability and subjective appearance. A group of professional designers rated representative car infotainment systems for their subjective appearance; a group of usability experts rated the same models for their perceived usability. We applied multidimensional scaling (MDS) to project the ratings into the same Euclidean space. The results show certain overlap between the perceptions of product appearance and usability. The implications of this approach for designing interactive systems are discussed.

Keywords: User experience, usability, perceived usability, appearance, design, interactive systems, multidimensional scaling, visualization.

1 Introduction

Users' perceptions of an interactive system and its usability are two integral parts that influence the users' purchasing decision, and they also contribute to the emerging user experience of the system. The general appearance of a product can inadvertently affect its perceived usability. For instance, a clean or neat design may lead to the assumption that the system is also easy to use; whereas a cluttered or busy design may lead to the impression of poor usability. The relationship between subjective appearance and perceived usability, however, has not been systematically explored.

Both subjective appearance and perceived usability are the results of complex cognitive processes, involving multiple assessment criteria. The assessment of appearance may involve asking whether a design looks professional or casual, exciting or boring; the perception of usability may use criteria like whether the

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interface looks self-explanatory or provides easy navigation. It is important to understand which appearance attributes are more tightly linked to the perception of usability, for two reasons. On one hand, the findings can help understand how these two integral parts interact to shape the users' experience of a product, as both are happening prior to and determining a purchase decision or pre-shape a user's attitude towards the system. On the other hand, the understanding can also guide a designer to use elements of overall appearance to generate a target perceived usability.

In this paper, we use car infotainment systems as a case study and describe an approach that uses "perceptual maps" to visualize the relationship between perceived usability and subjective appearance. We also discuss design implications.

1.1 Car Infotainment System Design

In recent years, the market for car infotainment systems has been booming, projected to increase its worth to $56 billion globally in 2011 from $27 billion in 2004 (SA, 2005). Consumers demand multifunctional systems including navigation, communication, information, and entertainment. For car radios alone, drivers desire to connect their iPods or other mp3 players, navigating and playing their favorite music while driving. The soaring need is partially driven by the trend that people want to extend their life style from their homes and offices into the mobile car environment, maintaining a consistent user experience as they know it from the usage of iPods and other devices.

In responding to this huge market demand, many companies, including car manufactures, OEMs, and aftermarket product vendors, are rushing to put out their latest designs and products. Established standards, i.e., the well-known row of 'radio buttons' at the lower margin of the car radio, are being given up by most vendors, and a wide variety of designs can be seen in the market place: touch screens, hard keys, soft keys, small or large displays, and designs with many or very few hard buttons.

Successful HMI design not only needs to incorporate the ever-growing wealth of information and functionality, but also should take into account the requirements of driving safety and human factors. The driving environment is dynamic and can become risky or even dangerous, and the HMI design of a car information system should minimize the interference effect with the primary task: driving. A design that looks attractive and is also perceived as easy-to-use might be key for a positive user acceptance of the system. Note that the actual usability of the product is critical because of the safety concern as the system is being used; perceived usability, however, will influence users whether to purchase the product or not. Ideally a truly safe and usable product will be perceived as such and be attractive at the same time and for that same reason. We believe that the reconciliation of the need to consider both: attractive appearance and perceived usability should be based on a deep understanding of the relationship between them. In the following, we review the methods that allow studying the users' perception of design.

1.2 Methods to Study Perceptions of Design

Several methods have been used to study the users' perceptions of appearance, including constructing perceptual maps (e.g., Chuang et al., 2001, Petiot & Yannou,

2004, Hsiao & Wang, 1998) and Kansei Engineering (Nagamachi, 1995). The method of perceptual mapping is the focus of our paper, and the basic idea is to build a multi-attribute perceptual space in which each product is represented by a point.

This approach typically involves several steps. First is to generate the evaluation attributes of the products (e.g Osgood et al., 1975). The attributes of subjective appearance can be solicited by asking people to vocalize their feelings or impressions towards a certain family of actual products or the images of these products. The final list of attributes is often composed of multiple pairs of antonymous adjectives. Then the next step is to collect people's subjective evaluation of the products based on the defined attributes. Lastly, multidimensional scaling (MDS) is applied to translate the evaluation data of products into a geometrical representation of a perceptual space. Principle component analysis or factor analysis are used to reduce the dimensionality of the space, typically yielding a low dimensional visualization that can be interpreted by researchers.

In the past, the approach of constructing perceptual maps has been mainly used to study the users' subjective appearance of design. Here, we used the car infotainment system as an example to apply the similar approach to study the users' perceptions of appearance and usability as well as their relationship. The method session below describes the approach in more details.

2 Method

2.1 Selecting Car Infotainment Systems

Twenty representative models of car infotainment system were initially chosen from the Consumer Electronic Show (2007), the Convergence Conference (2006), local stores (e.g., Best Buy, Circuit City), or the Internet (vendors' websites or product catalogs). The good quality, color image of each model was printed out on 1: 1 ratio according to its physical size.

A pilot study was conducted, which involved seven professional user interface (UI) designers to evaluate the degree of dissimilarity between each pair of the car infotainment systems on a scale of 1-5 (1: minimum dissimilarity; 5: maximum dissimilarity). We ran the MDS on the averaged dissimilarity matrix, and a Euclidean perceptual space was generated with each model represented as a point and the distance between any two objects depicting the level of their perceptual dissimilarity.

The goal was to find the most representative models of car infotainment system. Based on the results of MDS, 15 car infotainment systems with the least perceptual similarities were selected, and their images are shown below (Figure 1), arranged in an alphabetic order by their labels.

Subjective appearance attributes. In the pilot study, we also asked the user interface designers to vocalize their first impressions or feelings of each car infotainment system. A list of the adjectives that they used to describe the design appearance was recorded. These adjectives were then classified and clustered: the words with similar meanings were combined, and those with opposite meanings were paired. In the end, 14 pairs of antonymous words mentioned most frequently were selected as the attributes of subjective appearance (see Table 1).

Fig. 1. Fifteen most representative models of car infotainment system

Usability attributes. The usability attributes were derived from driving human factors research (e.g., Wickens, et al, 2003) as well as the established human factors design guidelines for car infotainment system (e.g., Stevens et al., 2002). The major considerations are that the driving environment is dynamic and risky, and the HMI design of the car infotainment system should minimize the interference effects with the primary driving task. Because maneuvering a car drivers heavily rely on visual monitoring, a good HMI design should support non-visual input (i.e., blind controllability) and the task operations should allow interruptions (i.e., interruptability). Some other GUI usability evaluation criteria (e.g., Nielsen's usability heuristics (1994)), if applicable to the HMI design of the car infotainment system, were also incorporated into the list.

Note that because we only consider *perceived* usability, we did not include those usability attributes that seem to depend more on interactions with the systems, e.g., feedback, error tolerance etc. Four human factors researchers were engaged in selecting and discussing the attributes of usability; and a list of seven attributes was finalized (see Table 2).

Table 1. Fourteen pairs of antonymous adjectives of subjective appearance attribute for car infotainment systems

Sample scale:	*active*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*passive*
aggressive – calm	masculine – feminine	organized – cluttered							innovative – conventional
dynamic – static	expensive – cheap	professional – casual							stylish – inelegant
exciting - boring	robust – fragile	square – organic							

Table 2. Seven perceived usability attributes for car infotainment systems

Scale:	*Very poorly supported*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Very well supported*
Blind controllability	The ability to perform certain actions that require no or minimum visual input.								
Limited interruptibility	The level of interference with the primary driving task when operating the system.								
Minimize cognitive load	Systems should minimize the cognitive load, and the design should consider human cognitive limitations (e.g., showing a limited number items per page).								
Consistency	The HMI design should be consistent in all aspects.								
Ease of navigation	Systems should be easy to navigate. Commonly used functions are easily accessed.								
Self-explanatory	The HMI is intuitive, clearly indicating current status and providing sufficient cues for performing actions.								
Ease of Use	The system is easy to use.								

2.2 Collecting Evaluation Data

The method that we used to collect the evaluation data of subjective appearance and perceived usability is similar to the semantic differential method (Osgood et al., 1957; Chuang et al., 2001).

Subjective appearance. Four experienced professional UI designers (2 females and 2 males) were asked to rate the 15 car infotainment systems for their subjective appearance (Figure 1) based on each of the attributes defined above (Table 1). The rating scale is 1-7, with 1 indicating the strongest feeling towards an adjective, and 7 towards its antonym.

Perceived usability. Four experienced usability experts (1 female and 3 males) rated the same models for their perceived usability based on each of the perceived usability attributes defined above (Table 2). The rating scale is also 1-7, with 1 meaning very poorly supported, and 7 very well supported.

2.3 Running MDS Analysis and Visualizing the Perceptual Maps

After collecting both sets of the rating data, the average matrixes of both perceptions of appearance and usability were calculated (Table 3 & 4). Multidimensional Analysis of Preference technique (MDPREF) was applied to translate the average evaluation data into a geometrical representation of a perceptual space. Principle component analysis was used to reduce the dimensionality of the space, yielding interpretable low dimensional visualizations. (More detailed information for this method can be found at http://marketing.byu.edu/htmlpages/books/pcmds/mdpref.html).

Table 3. The average matrix of perceptions of 15 car infotainment systems based on 14 subjective appearance attributes. Values range from 1 (left attribute) to 7 (right attribute).

Product Code	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Appearance															
aggressive – calm	3.0	2.5	2.3	5.8	4.8	3.0	4.8	4.0	2.8	3.5	3.5	2.3	4.0	2.0	4.0
dynamic – static	2.5	3.0	4.0	5.8	3.5	3.0	4.3	4.3	2.3	5.3	4.3	2.8	3.3	4.0	3.5
exciting - boring	3.3	2.0	5.3	6.8	2.5	1.8	3.5	4.0	2.8	4.8	4.5	2.5	3.5	3.8	3.3
expensive – cheap	4.0	3.0	5.3	6.5	2.0	2.0	2.8	1.8	2.8	2.3	3.0	1.8	2.3	2.5	2.3
innovative – conventional	4.5	2.3	5.8	6.5	2.5	1.5	3.3	2.8	3.5	3.5	3.5	2.0	3.3	1.8	3.5
masculine – feminine	4.5	1.8	4.0	4.3	4.5	3.5	3.0	3.0	3.3	2.0	3.0	1.8	3.8	2.3	3.3
organized – cluttered	5.3	2.5	5.5	3.5	3.3	3.3	2.3	2.5	2.5	2.3	3.5	6.0	3.0	4.3	2.5
professional – casual	5.5	3.0	5.0	3.5	2.8	2.0	2.3	3.3	4.0	2.0	3.5	5.5	2.5	2.3	3.0
robust – fragile	4.5	1.5	4.3	3.5	3.3	2.3	3.5	3.3	3.0	2.3	2.3	3.3	3.8	2.8	2.8
square – organic	5.8	5.0	2.5	2.5	4.3	5.3	4.3	3.0	5.5	1.3	1.8	3.5	2.3	1.8	2.8
stylish – inelegant	3.5	2.0	5.8	6.8	2.0	1.3	2.5	2.0	2.8	5.8	5.0	3.8	4.3	4.8	4.3

Table 4. The average matrix of perceptions of 15 car infotainment systems based on 7 usability attributes. Values range from 1 (very poorly supported) to 7 (very well supported).

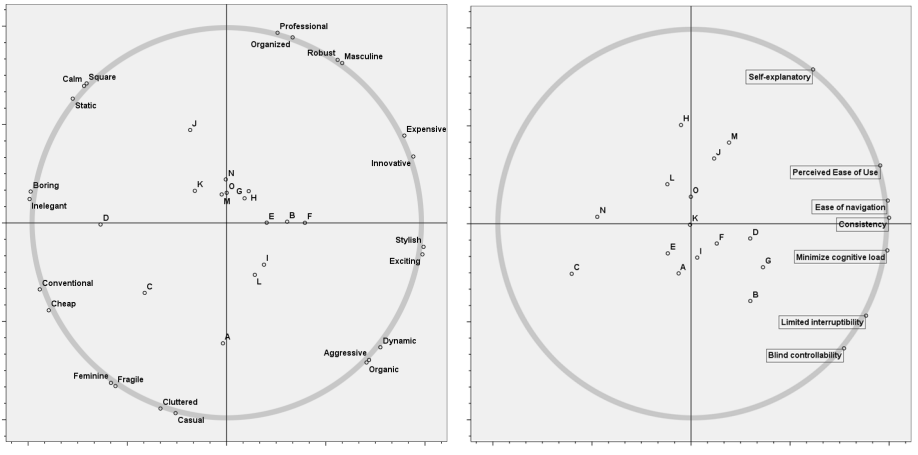
Product Code	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Usability															
Blind controllability	3.5	5.0	2.0	4.0	3.0	3.3	4.0	1.8	3.3	2.5	3.0	2.3	3.0	2.0	3.0
Limited interruptibility	3.5	4.8	2.3	4.8	3.3	3.5	4.5	2.5	3.5	3.5	4.0	3.0	3.0	2.0	3.0
Minimize cognitive load	3.5	4.3	1.8	4.0	3.3	5.0	4.5	3.8	4.0	3.0	3.0	3.0	3.8	1.5	3.5
Consistency	4.3	5.0	3.0	4.8	4.0	4.0	5.8	4.5	5.0	5.0	4.3	4.5	4.5	3.0	4.3
Ease of navigation	3.3	4.5	2.3	4.8	3.5	4.3	5.3	3.8	3.8	4.5	3.8	3.5	4.5	3.5	3.8
Self-explanatory	3.0	3.8	1.8	4.5	3.0	3.5	3.5	5.3	3.3	4.8	4.0	4.3	5.3	2.8	4.3
Perceived Ease of Use	3.5	4.0	1.8	4.5	3.5	4.3	4.8	3.5	3.5	4.8	3.8	3.3	5.3	2.5	4.0

3 Visualization Results

3.1 Perceptual Space of Subjective Appearance

Figure 2a depicts the perceptual space for a set of 15 car infotainment systems (letters A to O) and the vector model of the subjective appearance attributes, obtained from the MDPREF analysis. The Euclidian distance between any two objects represents the

level of their perceptual dissimilarity. For instance, the far separations between models J and A or D and F suggest that the level of their perceptual dissimilarity of subjective appearance are high; where as the proximity of models B and F suggests that they are perceived similar. Also taking into account of the vector model of the subjective appearance attributes, we can see that the car infotainment system J is assumed to have high values on the attributes of Calm, Square, and Static (the calculation requires some imagination; it requires to project the point J to the attribute vectors, and then to measure the distance to the origin). Whereas the car infotainment system A has high values on the opposite subjective appearance attributes: Dynamic, Organic, and Aggressive. Similarly, model F is perceived to be Innovative, Stylish, and Exciting; yet the model D is perceived to be Conventional, Inelegant, and Boring. Note that the above observations are consistent with the average ratings of subjective appearance as shown in the Table 3. The advantage of using the perceptual map is to visualize the relationship of many objects in an intuitive manner, and the visualization can also help discover result patterns.



(a) (b)

Fig. 2. Two different 2-dimensional perceptual spaces for a set of 15 car infotainment systems (as denoted by alphabetical letters A to O), the vector model of the subjective appearance attributes (a) (denoted by the points on the big grey circle with attribute names), and the vector model of the perceived usability attributes (b) (labels with rectangular)

3.2 Perceptual Space of Perceived Usability

Figure 2b shows the perceptual space for the same set of car infotainment systems but with the different vector model of the perceived usability attributes. Because we did not use a pair of antonymous adjectives to describe each perceived usability attribute, the car infotainment models with positive distance (to the origin) after the projection to some vector is perceived to be supportive. For instance, the model H and M are perceived to support Self-explanatory, whereas model C is perceived to be highly

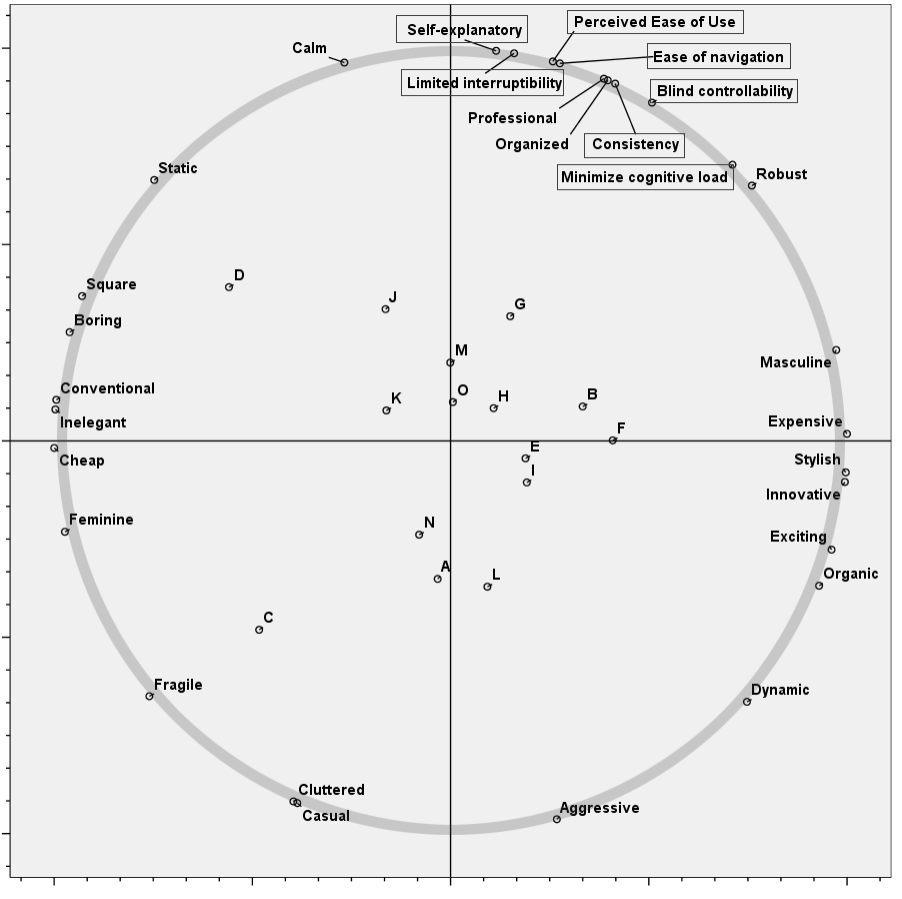


Fig. 3. The perceptual space for a set of 15 car infotainment systems (letters A to O) and the vector models of both the subjective appearance attributes (labels without rectangular) and the perceived usability attributes (labels with rectangular)

unsupportive of the attribute of Self-explanatory. In general, the model G, D, and B are perceived to support Perceived Ease of Use, Ease of Navigation, Consistent and Minimize Cognitive Load, and the model B and G also are perceived to support Blind Controllability and Limited Interruptability.

3.3 Combining the Two Spaces

To explore the relationship between the subjective appearance and the perceived usability, we projected both ratings into the same Euclidean space. Figure 3 shows the results of the perceptual space of the 15 car infotainment systems with both sets of vectors of the subjective appearance and the perceived usability attributes. The figure shows the proximity between some subjective appearance attributes and

some usability attributes suggesting certain overlap between the perceptions of product appearance and usability. For instance, the Professional and Organized subjective appearance attributes are perceived to be closely related to the perceived usability attributes of Consistent, Ease of Navigation, and Perceived Ease of Use; the Robust is positively related to the Minimize Cognitive Load. The findings suggest that a design with Professional and Organized appearance will also be likely perceived to be Ease of Use; whereas a design the Casual and Cluttered appearance will be perceived to be unsupportive to Ease of Use, i.e., difficult to use. Figure 3 also shows that several subjective appearance attributes are perceived to be orthogonal to the perceived usability attributes, e.g., Innovative and Stylish vs. Self-explanatory. The finding indicates that whether the design style of a product is Innovative or Conventional, Stylish or Inelegant, may have little influence on users' perception of Self-explanatory. The implications for designing interactive systems are discussed below.

4 Discussion and Conclusion

The subjective appearance and the perceived usability of an interactive system are two integral parts that contribute to the user experience of the system. In this paper, we use the approach of "perceptual maps" to explore the relationship between the perceived usability and subjective appearance of the car infotainment systems. The findings confirm that the appearance of a product will affect its perceived usability. In the context of car infotainment system, professional or organized HMI appearance will also be perceived as ease-of-use and ease of navigation. However, not all appearance attributes are tightly linked to the perceived usability: whether the design is stylish or not may have little influence on the perceived ease-of use.

These findings have important implications for designing interactive systems. Appearance of a product is a combination of design style, use of colors, shapes, layouts, and other design elements. Designers are often focusing on making product to look innovative, stylish, or exciting, yet they may ignore another important factor that also influences users' purchase decision---perceived usability. By also considering the appearance attributes that are closely linked to the perception of usability, the designer can achieve the goal of both attractiveness and perceived ease-of-use. Our approach is generic, and it can be applied to various product designs. The "perceptual maps" provide an intuitive way to explore the relationship between the two.

One caveat of this study is that we only examined the perceived usability; the actual usability is also critical, especially for car infotainment systems due to the safety concern. Whether the actual usability is consistent with the perceived usability and how they may interact will be a topic for future studies.

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