Quantifying touch-feel perception on automotive interiors by a multi-function tribological probe microscope

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Abstract. In this paper we will report the preliminary study of people’s subjective feelings on stroking surfaces of different materials and the measured properties of these surfaces, in order to understand exactly what properties matter and to what extent the different factors weight the human perception. Ten specimens with materials ranging from natural wood, leather to engineered plastics and metal were selected for this study. These specimens were first tested by a group of untrained people for describing their subjective feel sensation in terms of smooth-rough, soft-hard, slippery-grippy, warm-cold and overall judgement of like and dislike for the sample being touched. Then the same specimens were measured for their surface properties by various techniques. In particular, the multi-function measurement has been carried out on each of specimens by a novel tribological probe microscope (TPM). The TPM is capable of measuring four functions in a single scan to provide area mappings of topography, friction, Young’s modulus and hardness. As the TPM mapping is based on a point-by-point scanning so values of the four measured functions are linked in space and in time, therefore cross correlation between functions can be established. Although the TPM measured area is small compared to fingertip, the results show that the perception is influenced by nano- and micro-scale structure of surfaces.

1. Introduction

Touch, being one of the human senses is probably taken for granted by many people. The sense of touch is used every day to pick up or feel many different surfaces made from different materials, which have many different feels to them. Humans, consciously or not, make a judgement about each of these feelings with regard to the characteristics of how the surface is felt and whether they liked this feel or not. This subjective judgement has been recognised as one key factor to win or lose customers in the future for industries such as automotives, textiles, and telecommunications, where personal taste on touch-feel perception will be a main purchase criterion. Nowadays functionality, usability, reliability and safety are taken for granted and expectation is increasingly focused on user preference.
and emotional interaction. Particularly in cars, customers will spend the majority of their contact time inside the vehicles; the choice of materials used within the interior can have a big impact on customer preference. This has led to so-called affective engineering, the study of human-product interaction at a 'soft' subjective level, which was pioneered as Kasei engineering in Japan [1].

Studies of touch and 'feel' have been limited over the years, most probably due to the ambiguous nature of the sensation. One of the first studies was conducted by a German scientist, David Katz [2], who recognised that there were modes of feel that could help to describe touch just as names are used to describe colours. These could be split up into four descriptions: moist-dry, smooth-rough, warm-cool, and soft-hard. In year 2000, a Japanese motor company, Toyota, applied these modes in their first attempt to quantify this sense of touch for painted panels via questionnaire research and multivariate analysis to identify physical quantities for soft-feel [3]. They applied traditional instruments/test devices to measure surface roughness (smooth-rough), frictional resistance (moist-dry), hardness (soft-hard), and heat radiation (warm-cool). They have found out that the soft-feel is dominated by hardness, followed by frictional resistance. The smooth-rough and warm-cool have less significance in the soft-feel. However, in other cases, researchers found out that surface finish does play an important role in the subjective feelings on stroking glass surfaces for domestic packaging [4]. The challenge here is how to quantify the touch-feel perception in terms of measurable properties of a surface. At the moment there is no commercial instrument available which can mimic a fingertip to sense the above-mentioned properties. In this paper we have applied a multi-function Tribological Probe Microscope (TPM) to measure some of the properties in a single scan, in an attempt to seek the link between the perceived touch-feel and the measured surface properties.

2. Interior Samples
The visible interior materials used in passenger cars are selected, not only for their fitness to perform their intended functions, but also for their aesthetic appearance and feel. Such materials as Polypropylene, Polycarbonate blends and Acrylonitrile/Butadiene/Styrene (ABS) are commonly used for passenger vehicle interior components such as Instrument Panels, Centre Consoles, A, B and C-Pillar Covers, etc. These can either be self-coloured by incorporation of pigmentation into the resin or be painted or otherwise coated to achieve the appearance required the vehicle manufacturers’ Styling Departments. The visible surfaces of these components are usually embossed with a grain pattern to improve the appearance and hide surface defects such as minor sink marks and flow lines that can occur as a result of the moulding process and part design. The paint finishes are usually matt or low-gloss for aesthetic reasons and also to reduce specular reflections which may impair visibility through the Windshield, Backlight or Side Glass. Paint finishes can also be “soft-feel” by the incorporation of elastomeric particles giving the painted surface a less harsh and more pleasing feel. Thermoplastic elastomeric materials are also often used to cover control knobs and switches to improve their feel and to meet head and knee impact regulations if the parts protrude. They are also used to cover stowage areas to prevent items sliding and rattling during driving. In addition, polished black marble was included to complete the spectrum of materials with a range of tactile qualities.

3. Customer Appraisal Clinic
A customer appraisal clinic was carried out during March 2003 at the Ford Product Development Centre, Merkenich, Cologne to obtain qualitative and quantitative data for the tactile perception of the ten materials listed above. The survey was based on 72 Ford employees volunteered to take part. The demographics of the volunteers spanned a range of ages and included both males and females from several countries (but mainly Germany), different ethnic backgrounds and included engineers, designers, clerical and technical staff. Most had little or no previous experience of carrying out tactile appraisals. Participants were given an assessment form for each of the 10 materials with 4 linear scales representing each of the range of tactile perceptions of smooth/rough, soft/hard, low friction/high friction and warm/cold. Participants were asked to place a mark on each scale at a position where they felt their perceptions fell in relation to the subjective extremes. The actual positions of each of the
responses was then measured and expressed as a numerical value from 0 to 100 to enable statistical analysis to be carried out. The results of averaged perception ratings are listed in Table 1.

Table 1 Mean results of the customer clinic on materials used in the investigation.

| Sample No | Material                                           | Smooth/Rough | Soft/Hard | Slippery/Gripply | Warm/Cool |
|-----------|----------------------------------------------------|--------------|-----------|-------------------|-----------|
| 1         | Polished natural cherry wood                       | 41.9         | 79.7      | 50.9              | 33.9      |
| 2         | Hard matt paint system on ABS substrate            | 24.7         | 68.7      | 50                | 40.5      |
| 3         | Soft-feel matt-coat paint system on ABS substrate  | 25.2         | 53        | 62.2              | 37.6      |
| 4         | ABS/polycarbonate blend                            | 9.6          | 76.8      | 34.1              | 40.8      |
| 5         | Styrene/ethylene/butadiene/styrene (SEBS) 75 Durometer A TPE | 31.3         | 39.8      | 82.6              | 39.9      |
| 6         | EPDM-modified polypropylene with 20% talc filler    | 15.6         | 77.1      | 42.6              | 47.7      |
| 7         | Polished black marble                              | 7            | 91.9      | 24.9              | 76.5      |
| 8         | Soft-feel top-coat paint system on an ABS substrate| 36.2         | 67.1      | 55.8              | 42.4      |
| 9         | Ungrained natural leather                          | 53.3         | 24.8      | 51.5              | 28.2      |
| 10        | “Brushed” aluminium                                | 9            | 91.6      | 26.7              | 86.9      |

4. Multi-function Measurement

TPM is a novel instrument that is capable of measuring four surface properties at micro and nanometre scales in a single scan with a controllable force range up to 30mN [5]. The four surface functions of topography, friction, hardness and Young’s modulus can be scanned over an area of 100 ×100 μm² with a Berkovich diamond tip of 0.1μm in radius. Details of the instrumentation and calibration can be found in reference [6]. The multi-function measurement is achieved by operating the TPM in two scanning modes, the normal scanning mode and the force ramping mode. At each scanning point, the TPM measures the surface height first in the normal scanning mode and then switches to the ramping mode to increase the contact force to a preset value and decrease it again, while the deformation/penetration is measured. Then the TPM moves to next scanning point and at the same time measures the frictional force. The process then repeats itself. At the end of scanning, four sets of data representing surface topography, friction, Young’s modulus and nano-hardness are available for 2-D and 3-D displays.

Table 2 Averaged parameters measured by TPM on the selected samples.

| Sample No | Roughness (um) | Friction Coefficient | Hardness (GPa) | Young’s modulus (GPa) | Force (mN) |
|-----------|----------------|----------------------|---------------|----------------------|------------|
| 1         | 1.679          | 2.088                | 11.23         | 0.42                 | 3.70       | 18.42     | 2          |
| 2         | 0.629          | 0.785                | 5.52          | 0.45                 | 0.68       | 4.79      | 0.5        |
| 3         | 0.335          | 0.4188               | 4.74          | 0.23                 | 0.36       | 0.80      | 0.5        |
| 4         | 0.070          | 0.089               | 0.79          | 0.43                 | 1.98       | 9.38      | 2          |
| 5         | 0.356          | 0.500                | 6.94          | 0.50                 | 0.21       | 0.47      | 0.5        |
| 6         | 0.404          | 0.522                | 5.69          | 0.36                 | 1.14       | 16.31     | 0.5        |
| 7         | 0.083          | 0.106                | 1.21          | 0.3                  | 33.8       | 148.3     | 2          |
| 8         | 0.722          | 0.903                | 15.18         | 0.46                 | 0.29       | 0.57      | 0.5        |
| 9         | 0.874          | 1.070                | 9.99          | 0.29                 | 0.34       | 0.75      | 0.5        |
| 10        | 0.301          | 0.382                | 2.86          | 0.27                 | 14.9       | 131.4     | 2          |

As it is based upon point-by-point scanning, and the four functions thus obtained are correlated in space and in time. The TPM has been used to map four functions over a wide range of materials from...
general engineering surfaces, to specially plasma treated materials, to soft paint and polymeric films [7, 8].

Ten selected samples were measured for four functions by TPM over an area of 100×100μm² in a temperature and humidity controlled laboratory. The averaged function parameters are listed in Table 2. For roughness measurement, Rₐ (central line average), Rₚ (root-mean-squares) and Rₜ peak to valley are given. The ramping force used in the mapping for each sample varies depending on the mechanical property of the sample. This force was determined by running a sequential loading on a sample [6]. From soft to hard, it ranges from rubber (sample 5), painted ABS (sample 2) to polished marble (sample 7). From slippery to grippy, sample 3 (painted ABS with soft-feel clear coat) takes the lead and the rubber gives highest friction. Due to limited space, here only one set of mappings is shown in Fig. 1.

![Mappings of four function on sample 8 (natural leather) (a) topography, (b) friction, (c) hardness and (d) Young’s modulus.](image)

5. Discussions
It is clear from the results of the Customer Clinic that some materials could be consistently assessed by the participants for certain of the properties with narrow distributions of their ratings. However, other materials and properties were not so easily rated by the assessors leading to wide distributions of responses, which could not be relied upon to give definitive values to enable a correlation with the corresponding objective values measured by the TPM. The aluminium and marble were clearly perceived as smooth, cold and hard to the touch by most of the participants whereas the polymeric materials appeared to be not distinctive enough to enable the participants to generally agree on the perceived properties. Surface Friction seemed to be the most difficult property to quantify subjectively. The thermoplastic elastomer (Sample 5) however was consistently rated as non-slip because of the “grippy” nature of the surface which was distinctive. It was also consistently discerned as being soft. Thus unless a surface has very distinctive surface properties, unskilled assessors find it difficult to quantify the ratings leading to the observed wide spreads of some of the ratings. This
difficulty in assessment may also be due to the design of the "clinic" as there is very little guidance in the literature on how to set up such a clinic for tactile perception. There is no shortage of information on such "clinics" in the food and beverage industries but these may not be strictly applicable. Thus it is felt at this stage that a valid statistical correlation between properties measured on the TPM and the customer perception results would be difficult to achieve with confidence. Further improvements to the tactile evaluation methods are necessary to reduce as much as possible the spread of results found with some of the materials.

The TPM, itself, has demonstrated its capability to measure a wide range of different surfaces and its repeatability has been demonstrated in previous studies. Its value to industries interested in being able to specify, quantify and control surface properties in order to define the surface feel of items is in its ability to carry out, in a comparatively short time, three of the properties that have been identified as collectively defining "feel". The only property it cannot measure at the moment is thermal conductivity. A separate measurement on thermal conductivity was conducted on these samples by using the modulated differential scanning calorimetry method [9]. The results are not discussed here. The limited measuring area ($100\times100\mu m^2$) of TPM means it cannot fully include larger surface features such as embossed grains that contribute to the tactile properties.

6. Conclusion
We have demonstrated a new approach to quantifying touch-feel perception on automotive interior components by using a novel tribological probe microscope. The results show very promising correlations between perceived feel and the measured surface parameters. TPM has great potential for use as an "electronic fingertip", especially if it can be further developed to measure over larger surface areas of up to the size of an actual fingertip.

More work has to be carried out in refining the human tactile evaluation methods before reliable statistical data can be generated that can be used in any correlation study between the subjective and objective measurement of tactile properties.

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