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THE MEASUREMENT OF NATURALNESS (MONAT)

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Abstract: This project aims to understand how basic sensory information generated by the interaction between human sensory transducers and the physical material or artefact under examination is processed within the relevant neural networks and how this contributes to the cognitive processes associated with the perception of naturalness.

Keywords: metrology, psychophysics, neuroscience

1. INTRODUCTION

Natural materials, such as silk, cashmere and rosewood, are generally associated with quality, craftsmanship and exclusivity; a fact that has been exploited in markets as diverse as the automotive sector and fashion. As a result, most consumers pride themselves on being able to distinguish “the real thing” and generally avoid products that they perceive as being made from “fake” materials. But how is this perception formed?

Our perceptual inferences and decisions about any object or material with which we interact are based on the interpretation of data characterising that object. These data are collected via the various human sensory modalities (visual, tactile, olfactory etc.), each of which has its own particular sensing regimes and biases. This multisensory information provides the input to a hugely sophisticated cognitive activity, which interprets these data in terms of our memory, emotional state etc. This generates low and high level perceptual responses, which eventually result in us making some decision.

This project aims to unravel this perceptual process and, by identifying relationships between the physical attributes of the material and the associated sensory, neural and cognitive processes, determine which properties of materials lead them to be perceived as natural or synthetic. By identifying the extent to which the material properties drive this distinction, the most appropriate physical measures for this perceptual process can be determined. In essence, therefore, this project can be considered as a feasibility study to determine whether the results of measurements made in psychology, neuroscience and physical metrology can be combined into a scientific model, such that the model will be able to predict typical observer perception in new situations.

‘Naturalness’ was chosen for study in this project because the perception of whether or not a material is natural typically shows good reproducibility from one observer to another. This means that the identification of the underlying neural processes and the development of appropriate measurement parameters will not be clouded by poor consistency and reproducibility in the neurological and psychological data. This is in contrast to some other perceptual parameters, such as ‘beauty’ and ‘pleasantness’, which show more inter-observer variability due to the greater importance of factors such as emotion, personal history and cultural differences. It is anticipated that the underlying concepts, techniques and models that will be investigated and developed within the project will be equally applicable to a wide range of other perceptual phenomena, such as ‘cleanliness’, ‘ripeness’ or ‘quality’.

Experimental investigations within the project have focused on visual appearance and touch. These are key mediators for the perception of naturalness and are generally responsible for generating an initial impression, which may then be confirmed, or otherwise, by other senses such as smell. Furthermore, sight and touch can often send conflicting ‘messages’ about a material or object (e.g. materials such as artificial silk frequently look ‘real’ but feel ‘synthetic’): understanding how these two senses interact and compete forms an important part of the project and will provide insights that can be applied more widely to other senses and percepts in the future.

On completion of the project, manufacturers may use the information to develop improved materials that appear more natural, leading to products that are more desirable than those made from current synthetics, yet cheaper and more durable than those made from natural materials. Most importantly, these improvements in replica natural products will help reduce the need to exploit the Earth’s dwindling supply of natural resources. However, as well as obvious applications in areas such as automotive design, furniture, textiles and fashion, the outcomes may also be useful in the development of improved virtual reality systems for recreation and training purposes (e.g. flight simulators and surgical training).

2. METHODOLOGICAL OVERVIEW

For the purposes of this study, naturalness has been defined as: 'the probability that a material or object is perceived as being natural i.e. perceived as being derived form nature'. The experimental methodology is based on the premise that the perception of whether or a not a material is 'natural' is primarily determined by the physical characteristics of that material and the ways in which these interact with, and are interpreted by, our sensory and cognitive systems (Figure 1).

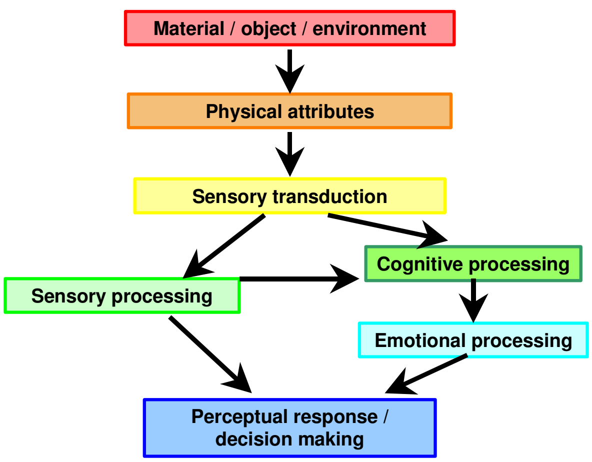

Figure 1. The perceptual process

When we look at and touch a surface, for example, interactions between the material and the sensory transducers in our skin and eyes generate sensory impulses, which then pass along nerve fibres to the brain. The strength of the signals depends not only on the physical characteristics of the material, such as its roughness, colour and texture, but also on factors such as the sensitivity of the sensory transducers and the environmental conditions. Surface structure at the nano-scale, for example, will not be sensed by our fingertips, but may affect the visual appearance. Once they reach the brain, the nerve impulses are combined and interpreted to generate the final perceptual response.

This project seeks to explore each stage in this process, in order to develop a fuller understanding of how the human perceptual system functions and provide a complete link from the physical (objective) properties of a material right through to the perceptual (subjective) impression of whether it is natural. A key feature of the project is the development and application of innovative, leading-edge techniques and knowledge from the fields of metrology, psychophysics, neuropsychology and mathematics to support the development of software models that bridge the gap between measurement of the physical attributes of an object and the human perception of whether that object is natural; models that can then be used to predict human reactions to new materials and objects. Where necessary, the project team is developing new capabilities for properties that it is currently not possible to measure (e.g. visual texture and multi-angular appearance of materials) and adapting leading-edge methods for use in novel ways (such as the use of functional neuroimaging techniques to establish dynamic neural pathways and interactions between these). The project is also using cutting-edge MEMS technology to develop a new measurement tool for touch, based on a bio-mimetic approach.

3. EXPERIMENTAL TEST SAMPLES

Several different types of material have been chosen for study, selected in each case to cover a range from 'natural' to 'synthetic'. To ensure consistency in the measurements it is paramount that quasi-identical samples are used by each of the three scientific disciplines involved in the project: psychology, neuroscience and physical metrology. Sets of nominally identical test samples have therefore been pre-selected and prepared at the National Physical Laboratory (NPL) for use by each of the partners. Durability tests were performed on each sample type, in order to quantitatively assess the degree to which a particular sample may be used before its physical characteristics are altered such that it may give erroneous or misleading results. Psychological, neurological and physical measurements have then been performed using these test stimuli, following pre-agreed protocols.

The samples chosen for the first phase of the project were wood and fabric, selected due to the availability of a range of natural and synthetic counterparts. In the case of the fabric samples, these were hand woven using various mixtures of un-dyed wool, cotton, polypropylene and acrylic fibres. The samples varied from 100% natural to 100% synthetic in controlled mixes of each of the materials. The natural samples consisted of 100% wool or cotton and 75%/25%, 50%/50% and 25%/75% wool-cotton combinations. Likewise, the completely synthetic samples contained these same mixes of acrylic and polypropylene. The intermediate materials (neither fully natural nor fully synthetic) contained all possible mixes of each natural and each synthetic fibre in 25% steps (e.g. 75%/25%, 50%/50% and 25%/75% wool-acrylic mixes). For the 50%/50% combination one fibre was used as the warp and the second as the weft. For the 75%/25% combination all threads in the warp direction were fibre 1 and threads in the weft direction were alternately of fibre 1 or fibre 2. For the 25%/75% combinations all threads in the warp direction were fibre 2 and threads in the weft direction were alternately of fibre 1 or fibre 2. Each combination was produced in both a coarse and a fine weave.

Unlike the fabric samples, it was not possible to obtain wood samples that could be varied in a controlled way from natural to synthetic. In this case, therefore, a variety of wood and wood effect materials were obtained; vinyl, veneer, laminate, photocopies and real wood. The real wood was subjected to varying degrees of processing in a controlled manner: sawn, sanded, weathered, oiled, waxed and varnished. Due to the inherent randomness of natural wood it was impossible to provide identical samples for each of the partners. The same was generally true of the laminates and vinyl. To assess the degree of sample variation, all samples were photographed under controlled lighting prior to being distributed for experimentation.

In order to ensure consistency of presentation, and avoid any clues being given by the edges of the samples, they were mounted in grey plastic boxes, each with the same viewing aperture of 80 x 80 mm. In the case of the fabrics and the vinyl and photocopy wood samples, a backing of Plexiglas (wood samples) or hardboard (fabric samples) was used to ensure that the material was firmly mounted.

4. EXPERIMENTAL PROCEDURES

4.1. Physical measurements

All visual and touch measurements were made at a resolution and dynamic sensitivity which is appropriate for comparison with human sensory systems. In the case of the visual appearance measurements, the parameters studied were colour, texture, gloss and white light reflectance. The cornerstone of these measurements was a novel multi-spectral goniometric system, known as IRIS/GASP (image replication imaging spectrometer and gonio-apparent spectrophotometer – see Figure 2), which was specially designed at NPL in order to capture spatial, spectral and texture information across the full sample area [1,2]. Robust characterisation of the illumination and detector systems and the geometric configuration was carried out to ensure the results are valid and have a rigorous metrological basis.

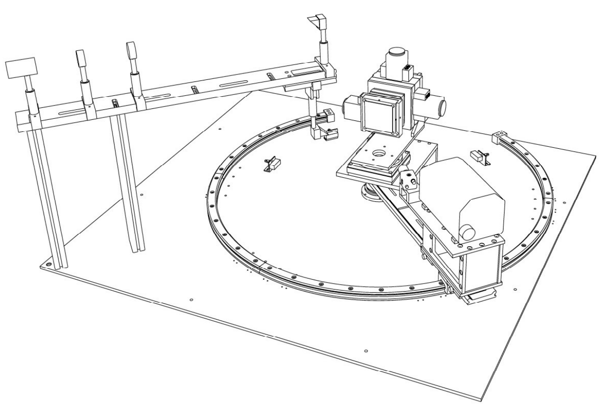

Figure 2. Schematic of the multi-spectral goniometric system developed at NPL, known as 'IRIS/GASP'

In the first phase of the investigation, which is reported here, white light reflectance images of the wood and fabric samples were taken with fixed illumination in forty-two detector positions around each sample. In later stages of the project it is planned to extend the investigations to include the capture of multispectral images, for up to 22 discrete wavebands in the visible spectral region, to give information on colour variations over the surface of the materials.

The detector was a SPOT insight firewire 4-megapixel monochrome scientific camera, linked to custom written LabVIEW® software to allow full camera and goniometric movement automation. All the images were corrected for non-uniformity in the sample illumination and dark signal. Textural analysis of the images was performed using a variety of algorithms, including histogram estimation, Haralick nearest neighbour co-occurrence matrices, and Gabor filter banks [3,4].

In the case of the touch-related physical parameters, measurements were carried out to determine the thermal conductivity, hardness, surface topography and multi-directional surface friction coefficients of the samples. The friction coefficients were determined using an instrument developed at NPL that measures the frictional interaction between the operator's finger and the sample surface using the same movement patterns as used in the psychology and neuroscience experiments.

4.1. Psychophysical and cognitive neuroscience studies

The psychology and neuroscience experiments required the observers to make visual and touch assessment of the samples under strictly controlled environmental conditions. In particular, the lighting and the temperature were kept constant across all participants and experimental conditions.

Protocols were developed to ensure the samples were manipulated in a consistent and repeatable manner. For the tactile experiments, exploration of each sample was constrained such that three clockwise circular rotations over the surface of the sample were carried out, with each rotation taking approximately one second. This rate of movement reflects an average natural speed of exploration (assessed in a pilot study). Exploration was carried out using the index finger only of the dominant hand and during the tactile-only experiments participants were asked to keep their eyes fixated at a fixation cross to avoid eye movements. No specific exploration procedures were defined for the visual assessments. The results from the durability tests carried out prior to despatch of the samples were used to ensure that the samples were replaced with new ones before any significant changes in the surface properties occurred.

For the first phase of the psychophysical experiments four different protocols were used. The first was based on a binary decision task where participants had to explore each sample (3 seconds) and categorise it as either natural or not [5], the second was a labelled scaling method (7 steps from not-natural at all to completely natural), the third used a free-modulus magnitude estimation procedure of the degree of perceived naturalness, and the fourth was ranked ordering (placing the materials in order of perceived naturalness). Different exploration modalities were used: touch only, vision only and visuo-tactile (bimodal). Each participant was seated behind a desk and the stimuli were placed in front of them on the surface of the desk so that the angle between the thorax of the participant and the stimulus was approximately 90°. In the tactile only condition, a curtain was placed between the participant and the stimulus to prevent viewing of the sample. In all cases participants heard a constant stream of white noise through headphones to prevent acoustical input derived from the exploration of the samples. The data from all four approaches were analysed separately using a number of statistical measures. Comparison of the results showed good agreement between all four methods and the results for all methods and all observers were therefore combined to yield an average naturalness index for each sample, ranging from 0 (always perceived as synthetic) to 1 (always perceived as natural). The results are summarised in Figure 3.

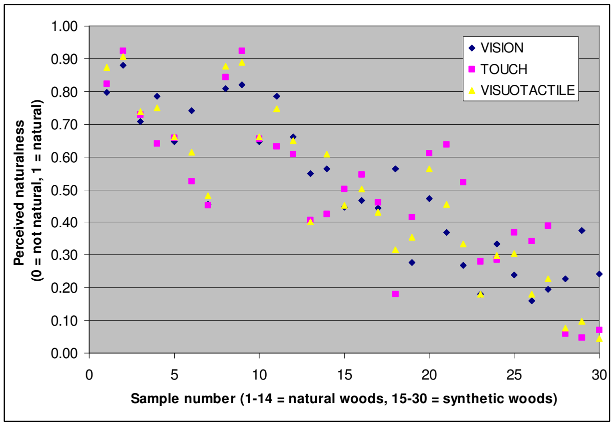

Figure 3. Average results using all methods and all participants for each modality.

A binary decision task, involving assessment of the sample as either natural or non-natural, was also used for the cognitive neuroscience investigations, which were carried out using a 3T functional magnetic resonance imaging (fMRI) scanner. In the first phase uni-modal visual and tactile, as well as visuo-tactile measurements were conducted. In the visual condition, images of the samples were projected onto a screen controlled from the fMRI control room. Each image was presented at 90° to the participant, in a full-face image. During the tactile modality, the subject was positioned comfortably on the scanner bed with his/her right arm supported by cushions to prevent any tension in the subject's arm, and samples were mounted on specially designed presentation apparatus (Figure 4). In the visuo-tactile condition, the subject viewed an image of a sample, while exploring a congruent sample through touch. In each condition, the samples were presented for 3 seconds.

Images from the fMRI scanner provide an estimate of the blood-oxygen-level-dependent (BOLD) contrast in different regions of the brain. The BOLD signal during a given condition is meaningless on its own; it must be compared with a baseline condition i.e. images must be subtracted from one another. In the first phase, therefore, only samples representing the extremes of the naturalness grading (i.e. stimuli that were identified in the behavioural studies as being consistently categorised as natural or synthetic) were used. These imaging data were used to analyse whether there were differences in activation when assessing a 'natural' or 'synthetic' material.

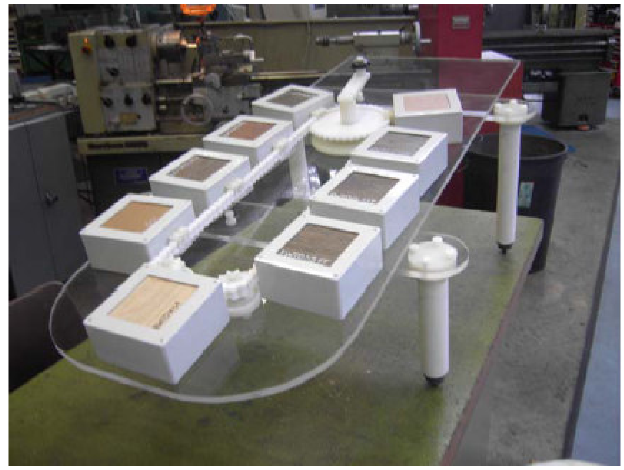

Figure 4. Photograph of the presentation apparatus used for tactile exploration experiments in the fMRI scanner.

5. DATA MODELLING

The first stage of the modelling involves classification analysis using a variety of different linear and non-linear classification techniques [6], to separate the samples into defined classes using their physical properties as the basis for the discrimination. It is important to remember that the aim was not to classify the samples in terms of the actual type of material (i.e. truly natural or truly synthetic), but in terms of subjective human observations of the degree of naturalness, based on the psychophysical studies. The following classes have therefore been chosen for the classification analysis:

- Perceived as fake - samples with naturalness index less than 0.3
- Perceived as likely to be fake - samples with naturalness values between 0.3 and 0.5
- Perceived as likely to be natural - samples with naturalness values 0.5 to 0.7
- Perceived as natural - samples with naturalness values greater than 0.7

Each mode (visual and tactile) has been analysed separately i.e. data from appearance measurements were compared with visual-mode psychophysical results, and touch-related physical measurement data were correlated with tactile-mode psychophysical results.

The initial results of this analysis for the wood samples are shown in Figure 5 (visual mode) and Figure 6 (tactile mode). In each case the classification was based on Fisher Linear Discrimination (FLD), which is a supervised learning classification approach in which the within-class variance and between-classes variance are first calculated and the data are then projected into a new space where the discrimination between classes is optimised and the variation within class is minimised.

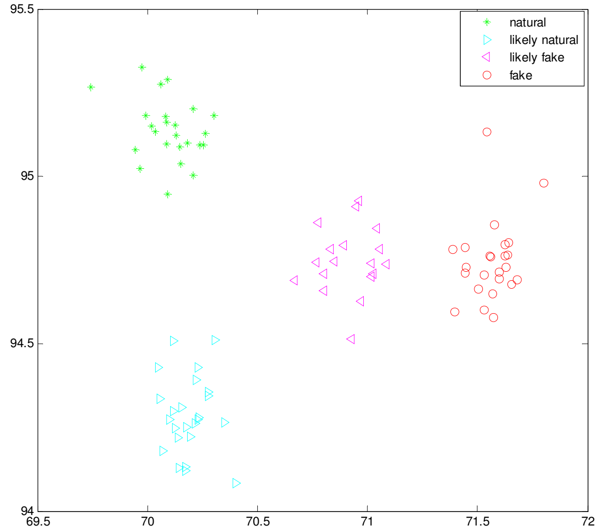

Figure 5. Classification of wood samples into four classes representing the degree of perceived naturalness as determined from the visual modality psychology test results. The x and y axes represent physical data related to the visual properties of the materials (visual texture features).

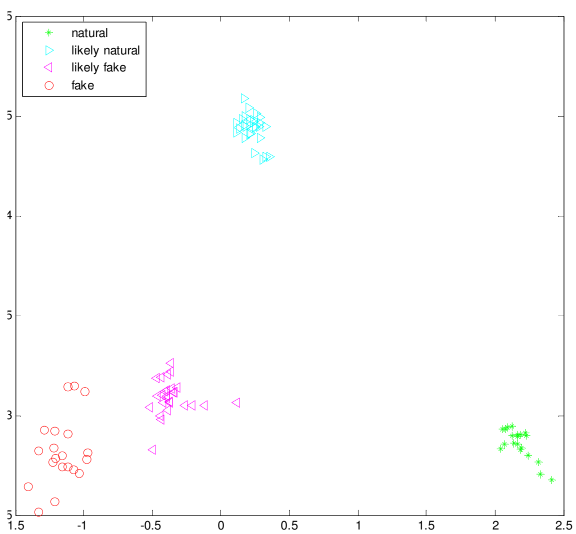

Figure 6. Classification of wood samples into four classes representing the degree of perceived naturalness as determined from the tactile modality psychology test results. The x and y axes represent physical data related to the mechanical properties of the materials (surface topography and surface friction).

6. FUTURE WORK

The results shown above demonstrate that it is possible to achieve good discrimination between the perceptual classes based on data relating to the physical properties of the materials. However, although encouraging, these initial findings must be treated with some caution: the number of variables in the physical data is similar to or even exceeds the number of samples, so it would be expected that reasonable discrimination would be possible. The next stages of the analysis, which are still underway at the time of writing this paper, will therefore be to:

- Validate and improve the models by testing their performance with ‘new’ samples i.e. samples of the same type (wood or textile) but which have not been used to develop the classification algorithms.
- Develop feature extraction procedures, in order to identify the physical parameters that are most significant in the classification.
- Refine the data analysis and modelling procedures, giving increased weight to these key physical parameters.
- Include the effects of uncertainties in the physical measurements and in the results of psychophysical studies within the models.
- Incorporate data from both modalities (visual and tactile) into the model, based on perceptual results from the bimodal (visuo-tactile) psychophysical investigations.

In the final stages of the project, the predictive capabilities of the model(s) will be refined, other types of sample (fabric and stone) will be included and the results of the neuro-imaging experiments will be integrated.

7. CONCLUSIONS

At the time of writing the first full iteration of measurement and modelling is being completed; further results will be presented at the conference. However early indications are that it seems possible to link measurements of the physical properties of materials with the degree of perceived naturalness determined by human subjects. This suggests that the ultimate goal of the project, to establish a predictive model for perceived naturalness, should be feasible.

ACKNOWLEDGEMENTS

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