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Measurement of Naturalness: Physics and Perception

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ABSTRACT

This paper presents the outcomes of an EU project ('Measurement of Naturalness', or MONAT), which aimed to develop a measurement system to predict the perception of naturalness for a range of materials, based on an understanding of the relationship between the physical attributes of the material and the human perceptual responses. The project included the establishment of novel measurement instrumentation to characterise the perceptually-relevant properties of the materials. New data analysis and modelling techniques were also developed to isolate the key physical properties of a material that influence the perception of naturalness, and to build mathematical models to describe the perceived naturalness in terms of these properties. The predictive power of the models proved to be extremely good, with correlation values in excess of 0.8 for new samples with properties similar to those used to develop the models, and reduction of error values above 70% for samples with properties falling outside this gamut.

Categories and Subject Descriptors

I.4.1 [Digitization and Image Capture]: Reflectance; J.2 [Physical Sciences and Engineering]: Physics

General Terms

Algorithms, Measurement, Experimentation

Keywords

Naturalness, appearance, touch, measurement, perception

1. INTRODUCTION

Natural materials are generally perceived as being highly desirable and can command high prices. For example, silk, cashmere, leather, and rosewood all have a history of being associated with quality, craftsmanship and exclusivity - factors that are exploited in markets as diverse as car manufacture, packaging, and textiles. Many natural materials have an inner beauty that is hard to emulate in synthetic products, so by exploring how we decide whether materials are natural, the MONAT project aimed to understand how to create artificial materials that are more like 'the real thing', thus supporting, for example, increased product competitiveness and sustainability.

As consumer demand for natural materials grows, so does the pressure on the Earth's limited natural resources; already many hardwood forest habitats have been destroyed and trade in items such as ivory and fur has brought many animals close to extinction. Never has there been a greater need for improved materials that generate a perception of naturalness. So what are these elusive material properties and attributes, which determine whether people will perceive them as natural? And how do we make decisions based on these cues?

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The MONAT project aimed to unravel the perceptual processes underlying these questions and, by studying the complete sensory chain from the properties of the material right through to what happens in the brain, to explore to what extent it is possible to predict whether a surface will be perceived as 'natural' purely on the basis of its visual and tactile physical properties. In essence, therefore, this project acted as a feasibility study to determine whether the results of measurements made in psychophysics, neuropsychology 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. The underlying concepts, techniques and models that were investigated and developed within the project will be equally applicable to a wide range of other perceptual phenomena, such as 'cleanliness', 'ripeness' or 'quality'.

2. MATERIALS AND MEASUREMENTS

One of the first tasks within the project was to create set of test stimulus materials whose appearance and feel spanned the range from 'perceived to be completely natural' to 'perceived to be completely synthetic' (note it was the perception of the materials, not their true nature, that was important). The chosen types of material were wood, fabric and granite, selected not only on the basis that these are available in a good range of natural and synthetic variants, but also because of the high degree of familiarity that consumers have with such materials due to their use in products such as furniture, flooring, clothing and building materials. Each of the individual samples within each class of material differed from the others in terms of measurable attributes such as their colour, texture, compressibility, roughness and thermal diffusivity. The samples were mounted in grey plastic boxes, each with the same viewing aperture of 80 mm x 80 mm, to ensure consistency of presentation and avoid any clues being given by the edges of the samples.

2.1 Perceptual Measurements

Each sample was evaluated in terms of its perceived naturalness, using a variety of psychophysical scaling methods. The assessments were carried out using tactile (T) or visual (V) exploration alone, and using vision and touch together (VT). Four different psychophysical protocols were used: assignment to a finite set of numerical scores (labelled scaling), free-modulus magnitude estimation, ranked ordering and binary decision. High correlations were found between each of the methods, providing evidence that the psychophysical responses represented robust perceptual characteristics. Experiments were also carried out using a functional magnetic resonance imaging (fMRI) scanner facility, to analyse the brain activation of volunteers when using vision and touch to explore and assess the samples.

2.2 Physical Measurements

All physical properties that were considered to be relevant to the visual or tactile perception were measured using a range of specialist measurement facilities, some of which were developed as part of the project specifically to provide information matched to the sensitivity and discrimination capabilities of the human sensory systems. Leading-edge texture analysis and feature extraction algorithms were used to extract the optimum amount of perceptually-relevant information from these measurements. In the case of the visual appearance measurements, the parameters studied were colour, texture, and gloss. 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 1), which was developed at NPL specifically to capture spatial, spectral and texture information across the full sample area [1,2]. In the case of the tactile properties, the key physical parameters were friction, thermal effusivity, hardness, surface topology and roughness. In particular, a novel instrument developed at NPL was used to measure the frictional interaction between the operator's finger and the sample surface using the same movement patterns as used in the psychophysics and neuropsychology experiments within the project.

3. FROM PROPERTIES TO PREDICTION

The final element of the project was to use new and leading edge analysis and modelling techniques to determine the mathematical relationship between the measured physical properties and the perceived naturalness, with the ultimate goal of being to be able to use the physical properties of a new material to predict how natural it will seem. Eight predictive models were developed - wood, (V, T and VT), fabric, (V, T and VT) and stone (V and VT) - each using a small number of optimised physical parameters (typically 5 to 7) in order to describe and predict the perceived naturalness. The predictive power of these models proved to be extremely good for new samples with properties similar to those used to develop the models, with correlation values in excess of 0.8 in all cases (see typical examples in Figures 2 to 5).

It was also important to investigate the ability to predict perceptual responses for materials with physical properties falling outside the gamut of those used to develop the models. The original set of wood samples included only oak and oak effect specimens. Additional tests were carried out using a range of more exotic types of wood such as bamboo and walnut (an additional 20 wood samples) which increased the variation of colour and texture features. The model developed using the original samples was applied to the results of the physical measurements on these new samples, and the predicted naturalness values were compared with the actual values. The results showed that the predictive capability of the models was good, providing reduction of error values (a measure the predictive capability, defined as its accuracy relative to a prediction based on no knowledge) in excess of 70% - see Figure 6 for example. Performance was least good for the samples that were least familiar to the general public, such as bamboo. Thus the major objective of the project, to demonstrate the ability to make reliable predictions of complex perceptual attributes such as naturalness from measurements of the physical properties of a sample alone, was successfully achieved.

4. CONCLUSIONS

Given the premium our society places on natural materials, the successful outcome of the MONAT research (see [3] to [7] for further details) will potentially be of great commercial as well as scientific importance. It could help create everyday items, furniture and clothes that are more desirable than those made from current synthetics, yet cheaper and more durable than those made from natural materials. For materials like ivory, high quality synthetic substitutes could even help to protect threatened animals and plants, making luxury more affordable and saving precious natural resources.

5. ACKNOWLEDGEMENTS

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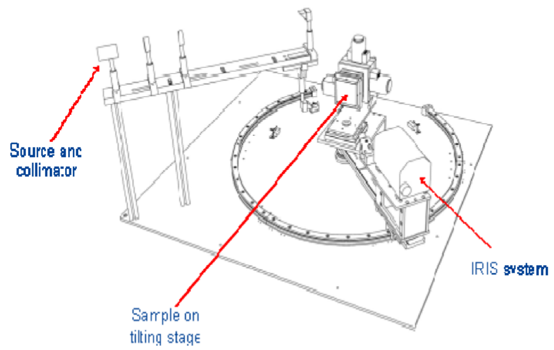

Figure 1. The NPL GASP system

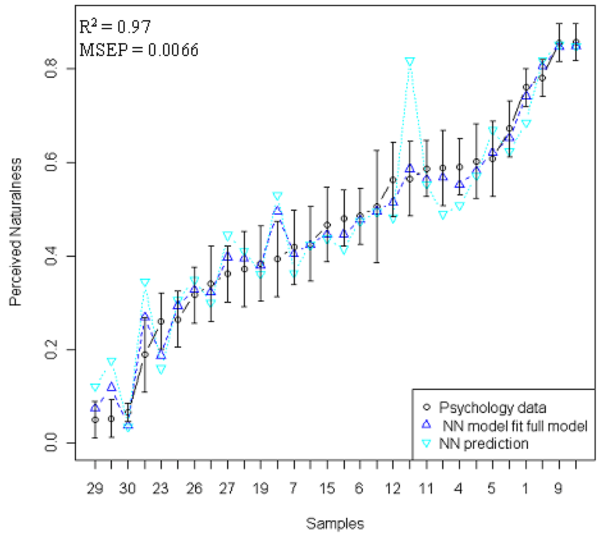

Figure 3. Results of modelling for tactile perception of naturalness of wood samples.

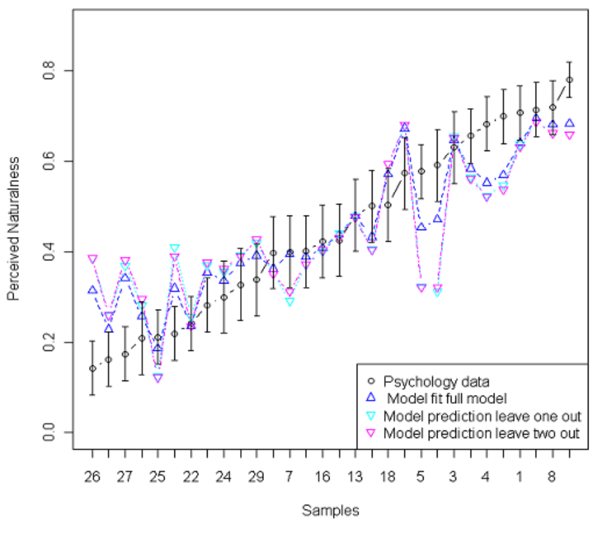

Figure 2. Results of modelling for visual perception of naturalness of wood samples. The *R*2 value is 0.83 and the MSEP values are 0.0149 (leave-one-out cross validation) and 0.0148 (leave-two-out cross validation)

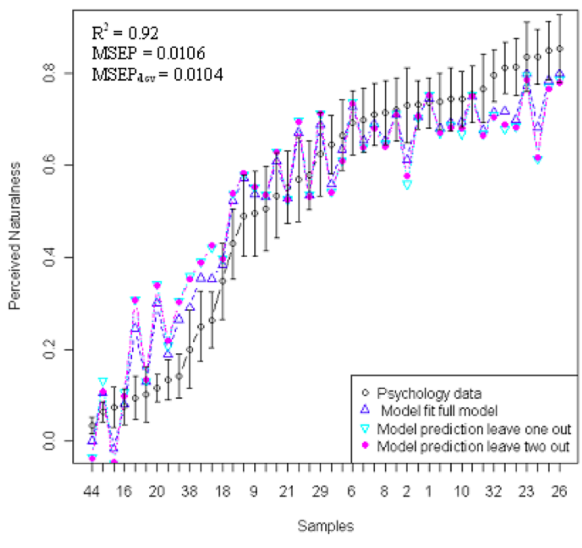

Figure 4. Results of modelling for visuo-tactile perception of naturalness of fabric samples.

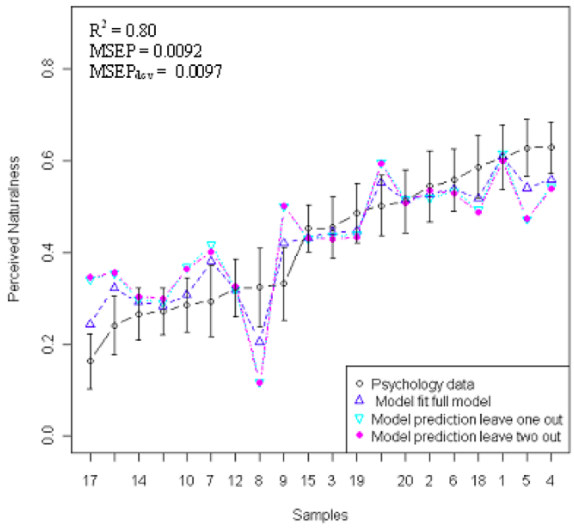

Figure 5. Results of modelling for visual perception of naturalness of stone samples.

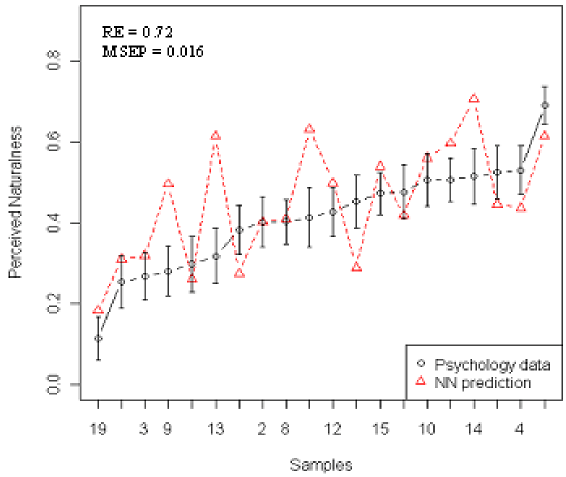

Figure 6. Results of applying visual model developed for oak-type wood samples to a validation set of 20 wood samples with physical properties falling outside the gamut of those used to develop the model. The residual error value is 0.72 and the MSEP value is 0.016 (leave- one-out cross validation).