Synthesis of Haptic Textures Transmitting Predetermined Feelings and Emotions

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Abstract

Textures are widely present in our daily life. In the last years many researchers have focused their efforts on the study of tactile texture perception as a result of their expanding interest in the fields of psychophysics (LaMotte, Srinivasan, 1991), neuroscience (Connor, Johnson, 1992), and computational modeling (Lederman, Klatzky, Tong, Hamilton, 2006). This increasing interest is partly because of the many applications where tactile sense could play a crucial role as, for example, product design (Henson, Barnes, Livesey, Childs, Ewart, 2006).
Despite the wide use of haptic textures there is a lack of scientific studies on the emotional qualities and expectations associated with specific textures. In order to fill that gap, a new project, financially supported by the European Commission, aims at providing methods and a theory to objectively measure, model, and predict psychological effects emerging from the touch of textures.
In this article, the main guidelines of the project aimed to the synthesis of haptic textures specified to evoke certain feelings and expectations are presented.

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Introduction

We all know that stepping careless onto a wet marble floor might cause us to slip. The same way we know that running on grass in the park is safe; even if we fall we're unlikely to get hurt. Although we may not be aware of it, texture provides us with information that triggers certain emotional qualities and expectations. Knowing how to measure and control these would result in an untapped source of information.

Despite the wide use of visual and haptic texture in industrial design, architecture and art to convey information there is virtually no systematic research on the emotional qualities and expectations associated with specific textures.

SYNTEX is the name of an ongoing project financially supported by the European Commission through the Sixth Framework Programme (FP6) and within the NEST initiative (New and emerging science and technologies). It aims at providing methods and a theory to objectively measure, model and predict psychological effects, like the above mentioned, related with the use and interaction with textures. The project started on November, 2006 and has a duration of 3 years.

It is expected that the project will have substantial impact on product design in its most general sense: buildings, consumer products, interfaces of computer programs, internet pages, games,… All of these cases will profit from the ability to use texture in a predictable way to communicate additional information and achieve intended psychological effects.

To achieve the desired result, the following deliverables are needed.

- a computational model of human texture perception and interpretation based on neurophysiological and psychological experiments. This model will be able to measure the degree to which a certain emotion is associated with a given texture in a particular subject or group of subjects.
- a new investigative method on how to assess and model human interpretation of visual and haptic textures. This method will also be applicable to other areas of human sensory and emotional processing.
- a set of algorithms that are able to synthesize artificial textures that will be associated with a defined set of emotions.
- a set of 24 artificially generated textures designed to bias the experience of 12 different emotions (e.g. happiness, safety, aversion), each to two extents (light and strong bias) and the psychological evaluation of these textures.

The project team includes a wide variety of experts from many fields. It is coordinated by the machine vision group of the Austrian Technology Center PROFACTOR, with extensive experience in machine vision, mainly for the inspection of textured surfaces, and process automation. Some of the experiments (Functional magnetic resonance imaging - fMRI) are being performed at the Neuroimaging Centre of the University of Groningen, that participates through the Laboratory of Experimental Ophthalmology (LEO) and the Neuroimaging Centre of the School for Behavioural and Cognitive Neuroscience. Another set of experiments are performed by the ISIS group of the University of Amsterdam, specialists in multimodal human-computer interaction, cognitive vision, data space visualization, theory of computer vision, multimedia data mining... The “affective engineering” scope (Nagamachi, 1995) is incorporated by the Affective Design Research Group of the University of Leeds, composed of other groups like mechanical engineering, colour chemistry, psychology and linguistics. The mathematical part of the team is represented by the Department of Knowledge-Based Mathematical Systems of the Johannes Kepler University of Linz, with long tradition in basic research in fuzzy logic. The synthesis of the samples for the tests is being performed by Fundacion PRODINTEC, which has equipment for rapid prototyping, micromilling, vacuum casting and laser sintering. These samples are then applied to standard laminates, manufactured by the Austrian company Fundermax.

Methodology

The project is scheduled around three cycles of psychological and neurophysiological experiments combined with a concurrent development of a computational model. The modeling employs a new approach that is driven by mathematics: starting from a model based on existing knowledge (on texture perception), major mathematical gaps (rather than gaps in psychological understanding) are identified, and experiments are designed to fill these gaps. Fuzzy logic is being incorporated to account for the inherent fuzziness of emotions. From the results of the modeling process, a number of textures are synthesized that will be used for testing. It is worth to note that the objectives of the project include both approaches: how to measure responses and emotions to textures, and how to manufacture textures that should provoke specific responses among the users. That's why the synthesis of textures is a major part of the project.

Modeling

Modeling starts from simple input/output relationships, where the correlation between physical properties of the textures (such as the topography of tactile textures or color distribution on visual textures), and perceived properties (such as "natural", "simple" or "elegant") is investigated.
The physical properties are defined by means of textural features which are supposed to be "biologically plausible". These features are based on knowledge about e.g. the physiology of the human fingertip or the processing of visual textures in the human brain (Jones, O'Neil, 1985). Machine learning methods are applied to extract a relevant set of features and to accomplish the prediction of the perceived properties. Gaps in the knowledge about how the human brain processes textures are bridged by generally applicable mathematical models such as neural networks or other approximation methods.

Synthesis

Synthesis of textures serves two purposes in the project. It includes on the one hand the production of samples that can be used in the experiments and on the other hand the development of synthesis algorithms that are able to create textures for certain feelings or expectations.

For sample production, rapid prototyping, micromachining (mechanical micromilling) and layer manufacturing (laser sintering and 3D printing) are used to create stamps for tactile textures.

- Mechanical micromilling processes are naturally downscaled versions of the macro-level processes. In these processes, the tools are usually in direct mechanical contact with the workpieces and, therefore, a good geometric correlation between the tool path and the machined surface can be obtained (Case, Ren, Kwon, Kok, Rachedi, Klenow, 2004) (Takács, Vero, Mészáros, 2003). An ultra-precision Computerized Numerical Control (CNC) machining centre (Kern-microtechnic GmbH) is used. This equipment is specially designed for applications requiring highest precision on the workpiece (deviation of position $\pm$ 0.5 μm), excellent surface quality (Ra $<$ 0.1 μm), and high speed and feed rates. Furthermore, the micromachining centre is suitable for milling critically machinable materials such as ceramics and hardened steel.
- Layer manufacturing comprises a set of different technologies used to directly fabricate, layer-by-layer, physical models from 3-D computer aided design (CAD) solid models (Mansour, Hague, 2003). Since there is not any interference between tools and formed parts, these techniques are capable to create parts of any geometry and complexity, which usually cannot be machined by traditional CNC technologies. Furthermore, they produce durable models with outstanding surface finish and fine details. Haptic textures needed for the project will be also synthesized by using LMT. Particularly, 3D printing (PolyjetTM-based system) and direct metal laser sintering (DMLS) techniques (Santos, Shiomi, Osakada, Laoui, 2006) are the facilities available at Prodintec for the production of the samples. 3D printing equipment (Objet-Eden330) uses a UV light to cure a photosensitive liquid into a solid plastic part. The DMLS equipment (EOS GmbH) works in a similar way to 3D printing but, however, uses a powder rather than a liquid photopolymer as its build medium enabling the production of functional parts directly from a wide range of materials such as stainless steel, Titanium, metal alloys, etc.

These stamps are used in an imprinting process to create laminate boards with a specific visual texture and a specific tactile texture (Figure 2). 576 different combinations of visual and tactile textures are thus being produced.

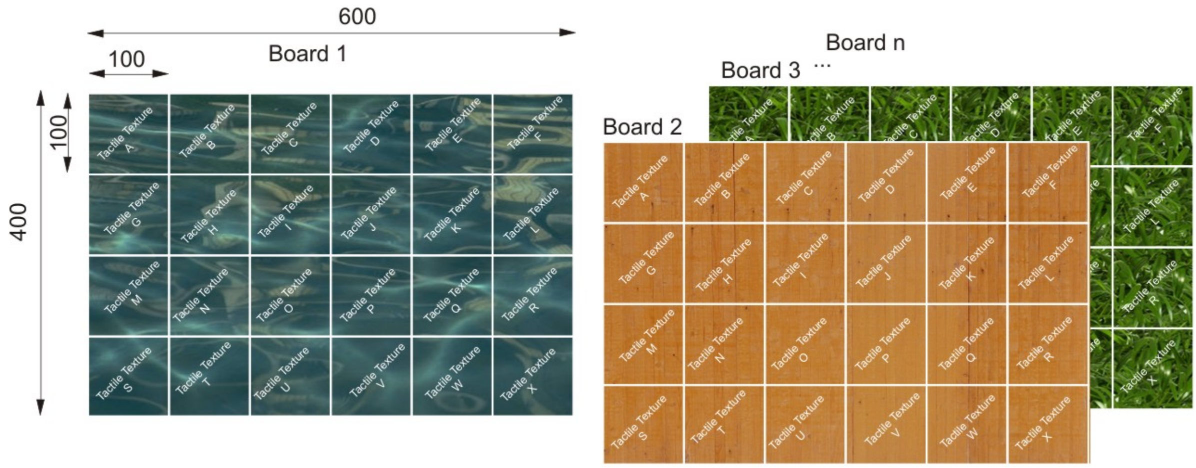

Figure 2: Samples used for experimental work.

Synthesis algorithms for textures are used to create visual and tactile textures that have specific properties. At the start of the project existing texture synthesis algorithms were used to generate textures. These methods are then being extended with the capability to mix two or more sample textures. Finally a feature-based synthesis algorithm is planned that is able to create textures for specific perceived properties.

Results and Discussion

At the moment this article is being presented, the first experimental cycle has been finished including the analysis of the data produced in these experiments. Samples for the 2^{nd} cycle have been selected and data collection in the experiments of this 2^{nd} cycle has been finished, but data analysis is yet to begin. The results of the 1^{st} experimental cycle have been used to set up the semantic space for visual and tactile textures. It was decided to further investigate the following 12 perceived properties (6 pairs of antonyms):

like - dislike (also positive-negative)	simple - complex
natural - artificial	elegant – not elegant
warm - cold	rough – smooth

These were selected to address properties that mainly use tactile input (rough-smooth), visual input (simple-complex) or both (warm-cold). The three other pairs were chosen to cover higher-level concepts, of which natural-artificial was selected to have a reference to another related project, called “Measurement of Naturalness” (MONAT), which is also taking place in the "measuring the impossible" topic of the aforementioned FP6.

Modeling

The main objective of this modeling is to generate a model of human texture interpretation with the goal of measuring the feelings/expectations/associations evoked by a certain texture. Until this moment in the project modeling has been mainly dedicated to developing features that are biologically plausible.
So far, much effort has been devoted to develop the visual model. A set of 103 features was implemented, of which most are based on existing literature about human texture perception. The focus was on those features that have some relationship to human texture perception. These features were analyzed in correlation to the texture ratings obtained in the first experimental cycle. By using a set of neural networks, the most relevant groups of features could be identified. A nonlinear correlation of 0.7 to 0.9 was achieved for some of the perceived properties.
The model for tactile texture perception is being developed meanwhile. There is much less literature on tactile texture perception than for visual perception. Thus the experiments started with a more basic analysis of the physiology of the human fingertip. By the end of the first year of the project the experimental results verified the importance of the Meissner and Pacinian corpuscles and first estimates on the relevant features sizes (about 200µm) could be made. Recently, an investigation of the ANFIS rule system, using input such as roughness (Ra), thermal properties (dT/dt) and friction to predict affective response, was ended. The resulting rule system of 27 rules achieved a good performance; however, investigations on the size of the rule system in relation to the number of samples have yet to be done.
A task for the integration of the tactile and visual model was also performed and 3 different proposals for a "high-level" model, that maps visual and tactile features to the perceived properties, were developed. In a general discussion a model was selected that provides an intermediate group of features that can be considered as step between the physical properties and the perceived properties. At this moment in the project, 4 groups of features depending on computational complexity had been developed, of which the lowest group are the physical "low-level" features as calculated previously and the highest level group are the affective responses. The future model will contain the two middle sets as an intermediate layer between low-level features and affective responses.

Synthesizing Textures

For fulfilling this objective, much effort has been spent on the development of a production process for the texture samples. Right now we are able to produce stamps with a size of 100x100mm² by silicon moulding (vacuum casting) that will then be used by the manufacturer of the laminate boards for imprinting the tactile textures. A total of 24 boards with 24 different tactile textures each were produced (Figure 3), resulting in 576 different samples.

Figure 3: Examples of manufactured boards containing visual and tactile textures

A general issue with tactile textures is the fact that there is a difference between the CAD files and the actual imprinted tactile texture. While this does cause some problems with controlling the actual physical properties of the textures, the major problem could be resolved by measuring the actual topography of the samples so that these data can be used as input to the model (instead of CAD data). Also, the characteristics of the materials of the samples used for manufacturing the boards were initially not appropriate, so much effort was needed to find suitable alternatives of materials and also to change and adapt the manufacturing process of the boards.

Regarding synthesis algorithms for textures the developments with existing synthesis algorithms has already started. These algorithms were mainly used for synthesizing larger textures from small samples. Initially, a collection of 460 textures was generated which has now grown to about 600. In month 10 developments of algorithms started to combine two existing texture samples and grow larger ones. This combining of textures will be relevant for the final feature-based texture synthesis algorithm.

Conclusions

- For the set of features implemented in the samples, good correlations were achieved for some perceived properties and feature groups. This opens the path for manufacturing parts which will transmit predetermined feelings and emotions.
- A manufacturing process for putting these specific features on products that will be on the market has been designed and tested, even though there is still much work to be done to generalize this process to many different types of products.

- Although much work is still needed, the results prove that it will be possible to design visual and haptic textures to transmit predetermined feelings, and that the manufacturing of products incorporating these textures will be possible.

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