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CIE RESEARCH:

Color Reproduction and Measurement of 3D Objects

Special Excerpt

Color Reproduction and Measurement of 3D Objects

CIE Division 8 Image Technology is responsible for the study of the optical, visual and metrological aspects of the communication, processing, and reproduction of images, using all types of analogue and digital imaging devices, storage media, and imaging media. The Division is continually working on recommendations to improve color image reproduction techniques, including, for example, color-appearance models, color-difference evaluation and gamut-mapping algorithms. Current technology is able to transform color images from one digital medium to another, under various viewing conditions, while maintaining the appearance of each color in the image. This process has been applied in the graphic arts industry with great success. According to Kaida Xiao, Chair of CIE's Division 8 TC 8-17, the CIE standard observer and psychophysical data for color-appearance and color-difference modelling were developed using flat, 2D color samples. He explains that to meet the increasing requirements for color image reproduction for 3D objects, new research and recommendations are highly desired.

3D Color Imaging Reproduction

3D color printing technology, also known as additive manufacturing technology, is a revolutionary process that has been developed during the last decade to produce full color, solid objects utilizing a range of printing materials that include polymers, metals and even biological tissue. With the evolution of a number of 3D image capture techniques, accurate acquisition and transformation of the geometric data that describes a 3D object can lead to accurate digital models. In addition these models can originate in CAD software as part of the overall design process.

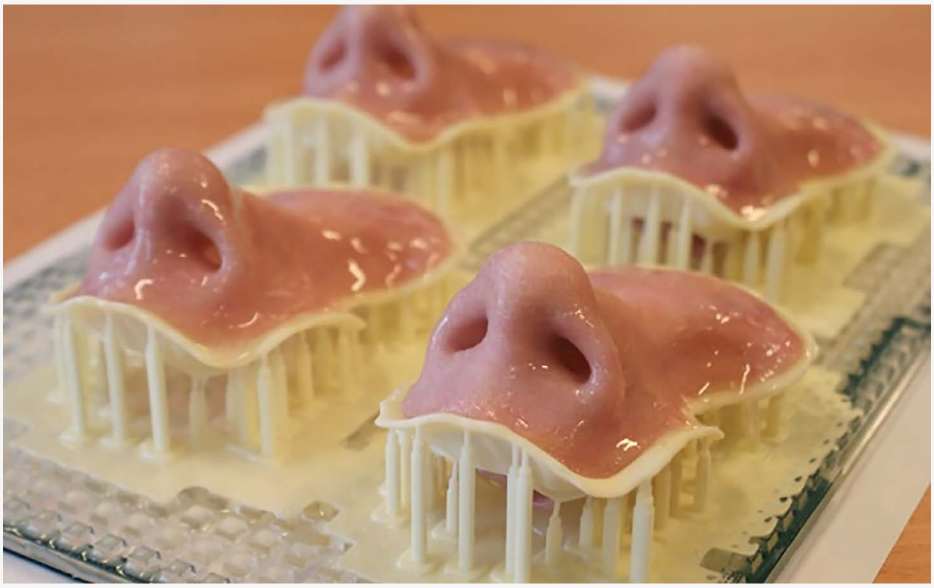
By combining 3D image generation with 3D printing techniques, it is possible to produce an accurate 3D reproduction of the original object, be it real or virtual. Moreover, the process has the ability to directly connect with other advanced manufacturing techniques, allowing customization with excellent accuracy, yielding savings in time and cost.

The process has found a number of diverse applications - for example:

- Lighting–3D objects are more sensitive to the lighting design; both the specular and non-specular aspects of reflection need to be considered as well as the shadows associated with 3D texture
- Rapid prototyping - for one-off manufacturing of devices or components for conceptual prototyping and providing unavailable repair components [1]
- Medical prosthetics - for example, to construct artificial noses for patients who require prosthetic skin replacement after tumor removal, where a custom fit is essential and accurate color reproduction is very desirable - these devices often require annual replacement and 3D printing technology provides a cost effective way to make them [2]
- 3D design - the design process often starts out with a 2D sketch followed by a concept model on a computer display leading to a 2D print - 3D printing extends this concept to produce a 3D prototype model

As compared with 2D image reproduction, appearance reproduction of 3D objects must satisfy a greater number of requirements. These include visual attributes, such as surface color, translucent color, reflectance, gloss and surface texture. Reflectance itself is a complex topic, characterized by the bidirectional reflectance distribution function (BRDF), which portrays how the reflectance of a surface depends on the 2 dimensions of incident angle and the two dimensions of viewing angle. Further, it must be considered that many surfaces are curved and they may intersect at various angles.

Characterization of the color appearance of 3D objects requires design software that captures the optical properties of the constituent materials and properly takes into account visual adaption processes of human vision, so as to avoid constraining possible observing conditions. These challenges cannot be solved sufficiently by a simple extension of 2D color image reproduction and measurement



Example of facial prostheses manufacturing (University of Sheffield/Fripp Design)

techniques [3]. Interestingly, some 3D object printers call their color process CMYK printing, even though, unlike most 2D CMYK printers, there is not possibility of using halftone printing techniques.

New scientific models and new engineering ideas will be necessary to develop and implement widespread successful accurate 3D printing of colored objects. Likely an important part of ensuring quality of large scale 3D printing will be the development of rapid 3D-object proofing methods, in analogy to analogous methods used with 2D printing, to ensure that the desired output color matching will ultimately be obtained in the final 3D printed objects.

Future Research Plans

Future research can be divided into three aspects:

- input
- processing
- output

Input: The research on input will mainly be concerned with the design and characterization the intended object. In addition to the measurement of its shape and dimensions, the appearance must be quantified with regard to color, texture, and reflection. The techniques developed can also be used to determine the reproduction quality of the printed object.

Processing: The research on processing will concern converting the input date to a smaller number of parameters, by means of models of various levels of sophistication, into simpler forms that are more amenable to subsequent use. Techniques such as parametric sub-sampling and reformatting will yield information formats that are more conducive to subsequent efficient 3D printing of manufactured objects.

Output: The research on output will concern the realization of the intended shape, with the required color, appearance and texture attributes. The various attributes will be compared with those of the original as defined in the input stage. Objective assessment is required for quality control in the complete industrial or medical manufacturing chain from the designer to the customer/patient.

Key research goals:

- To develop the metrology of non-uniform 3D objects, including the 3D shape, the local roughness, the surface texture and other properties that affect their appearance.
- To develop new ideas for measurement instruments and their application to 3D objects. Ideally this should lead to new, relatively simple instruments.
- To define a minimum set of metrological distance/similarity metrics between two objects that embed the set of differences in 3D shape, color, texture, and surface morphology.
- To consider how to make a simple but comprehensive surface model, including the physical and visual characteristics, to develop the market and industry of 3D-printed objects.
- To consider how to reproduce the desired shape, color, appearance and texture, especially when the target surface has translucent characteristics, for example, human skin. This will be a major challenge since this problem has yet to be fully resolved even for 2D materials.

In early 2017, CIE TC 8-17, Methods for Evaluating Color Difference between 3D Color Objects was established to study subjective assessment methods and recommend a dataset for color difference evaluation of pairs of 3D color objects. Eventually, the TC will report on investigations of the influence of 3D shape, gloss and optical characteristics on the perception of color difference between 3D object.

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