1 Reproduction and Measurement of 3D Objects

1.1 Description of research

3D printing technology, also known as additive manufacturing technology, is one of the most revolutionary technologies in recent years. The materials used in the process are not just limited to polymers but also metals and biological tissues, and maybe their combination in the future. This technology is used for quick prototyping, manufacturing complex 3D parts, prostheses, educational training objects and even prefabrication of housing. As compared with 2D reproduction, 3D reproduction needs to satisfy more requirements for visual attributes such as surface colour, translucent colour, bidirectional reflectance distribution function (BRDF), gloss and texture on both curved and flat surfaces. The relationship between desired 3D objects in the design process and produced 3D objects must be visually and quantitatively assessed. Characterization of the colour appearance of 3D objects requires a design software with the ability to capture both the physical properties of the materials and the visual adaption properties of the observations. This aspect will be associated with the appearance without constraints on the observing conditions.

These challenges will not be solved sufficiently by simple extension of technologies developed for 2D colour image reproduction and measurement. However, some printer makers are already describing the outputs as CMYK printing, even though there are no halftones in the printed objects. New scientific models and new engineering ideas will be necessary to give feasible analysis and practical implementation of 3D-printed coloured objects. Moreover, the final property of a 3D-printed object will have some deviations from the properties designed, thus a 3D-object proofing system will be necessary analogous to a colour-proofing system in conventional printing.

The research will be divided into three steps: input, processing and output. The input step is mainly to measure and design the characteristics for both targeted and reproduced objects. In addition to the measurement of the spatial dimensions, appearance such as colour, texture, reflection of the 3D objects must be measured and characterized. In the processing step, the input data should be analysed and reduced into a smaller number of parameters by simple or comprehensive models that convert the images into mechanical drawings for easy handling. Such parametric reformatting will contribute to the reproduction industry so as to improve efficiency in the manufacturing of the parts. The output step covers the realization of the targeted shape, with the required colour, appearance and texture attributes as designed. These attributes will be compared with the ones of the original in the input step again. Objective assessment is required for quality control in the complete industrial or medical chain from the designer to the consumer. There are many opportunities to tackle these issues.

1.2 Key research questions

- To develop the metrology of non-uniform 3D objects, including the 3D shape, the local roughness, the texture aspect and other properties impacting on the visual aspect.
- New ideas for measurement instruments and their realization for the aspect above.
- To define a set of metrological distance/similarity metrics between two objects embedding the set of differences in 3D shape, colour, texture, and surface morphology.
- How to make a simple or comprehensive surface model including the physical and visual characteristics to develop the market and industry of 3D-numerical objects.
- How to reproduce the desired shape, colour, appearance and texture, especially when the target surface has translucent characteristics. This will be a major challenge since this problem has yet to be fully solved even for 2D materials.

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1.3 Justification of the need for the proposed research topic

- Technical and metrological benefits:
  - By modelling attributes of 3D objects, clearer understanding of the surface attributes will be obtained. The model and measurement guideline will lead to more accurate reproduction and evaluation.
  - A new type of measurement instrument needs to be specified since the target is not limited to flat objects. This measurement technology could be utilized for any flexible devices such as OLED lighting and display systems.
- Research development and innovation:
  - Measurement instruments for 3D objects would be based on 2D imagers because of the necessity of measurement of small continuous areas on a curved surface.
  - Such instruments for 3D objects will be utilized for evaluation of any non-flat surface as e.g. in automobile painting.
- Social and environmental benefits:
  - By supporting the accurate reproduction of 3D printing, there is opportunity to create a new and significant market.
  - Currently vendors need to hold a large number of inventories of mass produced replacement parts, but in the future, 3D printing technology would manufacture the parts on demand. Possible environmental benefit is to reduce inventory of spare and maintenance parts by industry.

1.4 Related current activities in CIE

TC 2-85	Recommendation on the geometrical parameters for the measurement of the Bidirectional Reflectance Distribution Function (BRDF)
TC 8-14	Specification of Spatio-Chromatic Complexity
TC 8-17	Methods for Evaluating Colour Difference between 3D Colour Objects

1.5 Existing CIE publications

Report of DR 8-11 (only internally available)	Colour image reproduction for 3D printing
Report of DR 8-12 (only internally available)	3D Multi-view Image/Video Colour Data Format Conversion and Quality Control

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