Controlling the appearance of bio-inspired photonic materials

Romain Pacanowski
romain.pacanowski@inria.fr

Pascal Barla
pascal.barla@inria.fr

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Scientific priorities:

1 Scientific Research Context

Figure 1: Thin-film material examples: (a) Thin layers obtained industrially (Saint-Gobain Recherche). Their realization requires a very fine control of the manufacturing process. (b) and (c) Dorsal view of a female Japanese jewel beetle C. fulgidissima (from [1]). (b) Beetle exoskeleton (c) electron microscopy scan of the purple part of the beetle exoskeleton revealing a complex and imperfect thin film structure (scale bar: 1 µm). (d) Colors obtained by nanostructuring cellulose [2].

The color of materials most often comes from pigments that absorb light, such as in paints. However, there are other ways to produce colors, the so-called structural colors, which are produced by structures of matter at scales comparable to visible wavelengths. Figure 1 presents some natural and artificial examples that are more specifically based on a thin layer structure. When these layers are repeated periodically, we speak of 1D photonic crystals; more complex 2D and 3D photonic crystals occur when periodicity is present in additional dimensions [3].

Materials produced by such structures have a number of interesting properties: they exhibit vivid colors which may be iridescent (their hue varying depending on the direction of observation); they retain their optical properties for longer periods of time; and they have the potential to be produced with little energy and easily recyclable materials using bio-inspired techniques. In the latter case, the photonic crystals may exhibit a number of irregularities which will affect the final material appearance.

2 Work Description

The main objective of this Ph.D. thesis is to develop tools to explore and design the appearance of photonic crystals presenting irregularities, such as those found in natural materials or artificial materials realized by self-assembly.
We will first focus on the study of the appearance of 1D photonic crystals [4], perturbed in a variety of ways: irregularities in the thicknesses of the thin films composing the microscopic structure; perturbations of interface geometry, yielding roughness at the micro-scale; loss of periodicity at large depths in the structure, or aggregation of different periodicities in depth; etc.

We will then build on this analysis to investigate the feasibility of an inverse design method, whereby one or more photonic structures achieving a desired visual appearance are automatically retrieved, in a manner similar to our recent work on more classic layered materials [5].

If time permits, we will also explore more complex photonic crystals, either considering additional dimensions of periodicity (2D and 3D photonic crystals), or the effects of polarization in helicoidal structures [2]. Another direction of research would be to manufacture some materials designed with our inverse method, with the help of external collaborators experts in bio-materials.

Practical implementations will be performed in the Malia spectral rendering engine [6], enabling fast rendering in complex lighting environments that permit to assess the designed material appearance in realistic settings.

3 Required Knowledge and background

Apart from strong knowledge in Computer Science and Computer Graphics, which are mandatory, knowledge in Optics and Physics would be beneficial.

Expected Programming Skills:

- C++
- GPU (Cuda or equivalent)
- Matlab or Python with NumPy for prototyping aspects

References