Literature Review: Natural Surface Pattern Analysis and Its Engineering Applications

Natural surfaces exhibit complex patterns and textures that reflect both biological processes and physical constraints. These micro- and macro-scale structures inspire engineering designs because of their efficiency, adaptability, and functionality. Quantitative analysis of such surface features is essential for applications in tribology, materials science, and surface manufacturing. Recent studies emphasize connecting natural texture formation with measurable engineering parameters.

Pawlus et al. [1] classified surface texture parameters into height, spatial, hybrid, functional, and feature groups, establishing a framework to quantify topography and its effect on friction, wear, and optical behavior. Ruzova et al. [4] further highlighted that three-dimensional measurements yield more realistic characterizations than traditional 2D roughness metrics. Together, these studies form the foundation for translating natural surface observations into engineering-grade data.

From a design standpoint, surface texture strongly determines performance. Kouediatouka et al. [2] reviewed texture design strategies, showing how dimples, grooves, and ridges control lubrication and wear. Gopal et al. [3] described texture management as a multidisciplinary approach linking mechanical, chemical, and electrical functionality. These insights parallel the naturally optimized surfaces of leaves, skin, and shells, where geometry governs function.

Biomimetic approaches extend these ideas by replicating nature's designs for engineering use. Guo et al. [5] reported micro- and nano-patterns that enhance lubrication and corrosion resistance in industrial materials. Xu et al. [6] demonstrated tribological improvements in ceramics using bio-inspired microtextures, and Sheng et al. [9] summarized how micro–nano textures reduce friction and extend wear life. Such findings reveal the technological value of natural pattern replication.

Computational analysis also plays a growing role in quantifying surface complexity. Seck et al. [7] advanced 3D texture modeling through high-resolution normal-field reconstruction, while Yesilli and Khasawneh [8] introduced a data-driven framework using persistent homology to capture surface irregularity beyond conventional metrics. These methods strengthen the link between experimental texture data and predictive modeling.

Despite these advances, most studies focus on machined or synthetic surfaces, whereas natural patterns—such as leaf textures—remain underexplored in engineering contexts. Translating biological surface data into engineering parameters like anisotropy, fractal dimension, and surface energy could reveal new principles for biomimetic texture design. The present research aims to address this gap by quantitatively analyzing leaf surface patterns as natural models for engineered surfaces.

References

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