Tree Growth Simulation using Iterative Optimization for Maximized Sunlight Exposure

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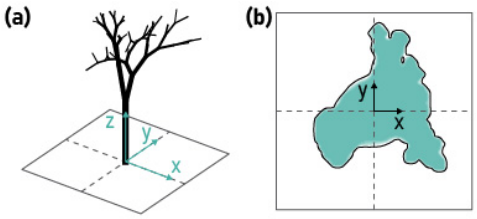
Abstract

Nature is a great optimizer; plants and animals have optimized their structures through evolution and adaptation to survive in their environment within the constraints of their limited resources. A common optimization problem that plants and animals have solved is to maximize the nutritional benefits while minimizing the risks. The science and rationale behind nature's intricate structures have survived the test of time yet are not fully understood. The intricate tree branch structure has been an interest of scientists and engineers for a long time, including Leonardo Da Vinci [1].

Sunlight is the source of energy for photosynthesis, and plants increase their exposure to the sunlight by modulating their branch lengths and angles using information from their photosensory receptors [2]. Branch growth therefore benefits the tree. At the same time, however, the branch growth increases the risk of failure due to the increased stress and bending moment on the branches.

The tree branch structure is an optimized form that has successfully balanced this tradeoff between nutritional benefit and structural stability. This paper presents a simulation of a tree growth that optimizes its effective leaf area throughout the growth process. An iterative optimization process is used to simulate the tree growth by adding a finite amount of volume to the volume constraint each time. An approximation of the structural analysis and the effective leaf area calculation were developed to expedite the computation.

The parameters that decide the tree form include: material parameters (Young's modulus, maximum strength, etc.), geometrical parameters (branch length, angle, number of branches, etc.), and other parameters (loads, sunlight angle, etc.). The simulation, as a form-finding tool, can generate bio-inspired structures that are optimized for maximizing the effective sunlight area in different conditions. The structures can be applied for designing canopies or solar cell panel structures since the maximum roof area is desired in both structures.



(a) An example of the optimized tree structure

(b) The effective leaf area projected on the xy-plane

References

[1] C. Eloy, "Leonardo's rule, self-similarity, and wind-induced stresses in trees," *Phys. Rev. Lett.*, vol. 107, no. 25, pp. 1–5, 2011.

[2] A. S. Fiorucci and C. Fankhauser, "Plant Strategies for Enhancing Access to Sunlight," *Curr. Biol.*, vol. 27, no. 17, pp. R931–R940, 2017.