Midterm Report of Spider Web Simulation

Changrui Cai, and Jiahua He

***Abstract*—This study explores the deformation of elastic materials from a bionics perspective, with a focus on the deformation of spider silk upon impact by a flying insect. Through simulation of the stress response of an octagonal spider web structure under central loading, we want to replicate and analyze the deformation characteristics of spider silk threads under impact conditions. By understanding these interactions, we hope to learn the mechanical properties of spider silk and contribute to the design of elastic materials.**

I. Introduction

With the rapid development of technology, the application of elastic materials in various fields is becoming increasingly widespread and has become one of the hot directions in science research due to their unique advantages including high dynamic bending elasticity, stretchability and high mechanical strength [1]. Elastic materials, with their excellent features have shown great potential for applications in multiple different fields, such as aerospace, medical devices and bionic robots.

With the rapid development of technology, the application of elastic materials in various fields is becoming increasingly widespread and has become one of the hot directions in science research due to their unique advantages including high dynamic bending elasticity, stretchability and high mechanical strength [1]. Elastic materials, with their excellent features have shown great potential for applications in multiple different fields, such as aerospace, medical devices and bionic robots.

In recent years, the development of bionics has further inspired the innovation of elastic materials. By drawing inspiration from the unique structure and function of biomimetic material, scientists continuously design high-performance elastic materials. These materials not only enable complex deformation, but also maintain excellent mechanical properties under impact and extreme conditions, providing a new approach for engineering applications [2]. Therefore, research on the performance of elastic materials in biomimetic scenarios has become an important topic in the field of materials science and engineering.

In this project, the goal is to study the deformation of spider silk. Due to the unique mechanical properties and excellent energy absorption ability of spider silk. Spider silk not only has high strength and ductility, but also exhibits excellent impact resistance in complex dynamic environments, providing an ideal model for the design of high-performance elastic materials.[3]

This study focuses on the deformation behavior of spider silk when flying insects collide with it from a biomimetic perspective. We simplify the spider web model into an octagonal structure. Through computer simulation, we want to study the deformation characteristics of the spider web structure under impact conditions. By simulating and analyzing the deformation characteristics of spider silk under impact conditions, we hope to learn the mechanical properties of spider silk and contribute to the design of elastic materials.

II. Current Progress

Figure 1 below is the initial state of the web simulation.

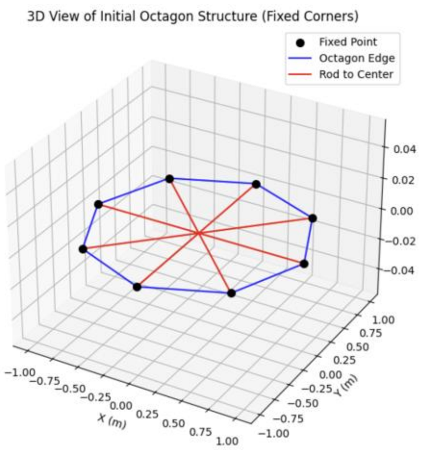

Fig. 1 Initial state of the web simulation

Changrui Cai, University of California Los Angeles, Los Angeles, CA 90024 USA (e-mail: changrui05@ ucla.edu).
Jiahua He, University of California Los Angeles, Los Angeles, CA 90024 USA (e-mail: Jiahua22@ ucla.edu).

The simulation consists of 16 rods in total. The 8 blue rods are identical, each with a length of 1 cm and a radius of 0.3 mm. All rods have a Young's modulus of 5 GPa. The blue rods form a regular octagon, with each vertex fixed in place (boundary condition). Moreover, each vertex is connected to the center by a red rod, which is also identical with a radius of 0.3mm.

The final state of the simulation is shown below:

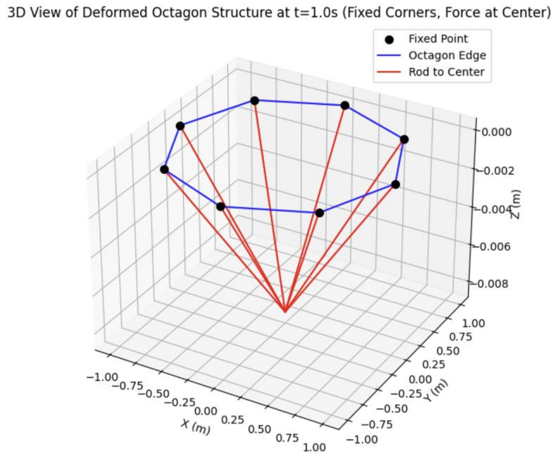

Fig. 2 Final state of the web simulation

The time interval is 2 seconds in this simulation, and delta_t = 0.02s. Our team decided to use the gradient and Hessian of elastic energy to compute the displacement of the rods. In the simulation, the gradient is calculated using the following formula, which represents the residual force in the system under the current state:

$$\text{gradient} = (\text{elastic\_modulus*area/length})\text{*displacement} - \text{force} \tag{1}$$

The Hessian is calculated by using the formula below:

$$\text{Hessian} = (\text{elastic\_modulus*area/length})1 \tag{2}$$

The Hessian represents the system's second derivative, which describes the rate of change in elastic energy. With the calculation of these parameters, our group applied the Newton-Raphson approach here: Gradient generates the system's displacement from equilibrium, and the Hessian changes the step size to determine the location of the equilibrium state, or minimum elastic energy.

In this simulation, the force is continuously applied in the center of the web, which is 50N. In the future plan, the force will be adjusted to one that gradually decreases with acceleration, reflecting realistic conditions.

References

[1] M. Chen, Z. Wang, K. Li, X. Wang, and L. Wei, "Elastic and Stretchable Functional Fibers: A Review of Materials, Fabrication Methods, and Applications," Advanced Fiber Materials, vol. 3, no. 1, pp. 1–13, Jan. 2021, doi: https://doi.org/10.1007/s42765-020-00057-5.

[2] Maria Gessica Ciulla, Alessio Massironi, Michela Sugni, M. A. Ensign, S. Marzorati, and Mahdi Forouharshad, "Recent Advances in the Development of Biomimetic Materials," Gels, vol. 9, no. 10, pp. 833–833, Oct. 2023, doi: https://doi.org/10.3390/gels9100833.

[3] A. Powers, "Spider Silk: Sronger than Steel? Nature's Supermaterial," Berkeley Scientific Journal, vol. 18, no. 1, 2013, doi: https://doi.org/10.5070/bs3181020651.

[4] K. M. Babu, "Spider silks and their applications," *Silk*, pp. 235–253, 2019, doi: https://doi.org/10.1016/b978-0-08-102540-6.00010-3.

[5] M. K. Jawed and S. Lim, *Discrete Simulation of Slender Structures*. 2022.

[6] O. M. O'Reilly, "Kirchhoff's Rod Theory," *Interaction of mechanics and mathematics*, pp. 187–268, Jan. 2017, doi: https://doi.org/10.1007/978-3-319-50598-5_5.