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Design of Ultra-Light and Ultra-Stiff Lattice Structure for Performance Improvement of Robotic Knee Exoskeleton

Authors : Bing Chen, Xiang Ni, Eric Li

Abstract : With the population ageing, the number of patients suffering from chronic diseases is increasing, among which stroke is a high incidence for the elderly. In addition, there is a gradual increase in the number of patients with orthopedic or neurological conditions such as spinal cord injuries, nerve injuries, and other knee injuries. These diseases are chronic, with high recurrence and complications, and normal walking is difficult for such patients. Nowadays, robotic knee exoskeletons have been developed for individuals with knee impairments. However, the currently available robotic knee exoskeletons are generally developed with heavyweight, which makes the patients uncomfortable to wear, prone to wearing fatigue, shortening the wearing time, and reducing the efficiency of exoskeletons. Some lightweight materials, such as carbon fiber and titanium alloy, have been used for the development of robotic knee exoskeletons. However, this increases the cost of the exoskeletons. This paper illustrates the design of a new ultra-light and ultra-stiff truss type of lattice structure. The lattice structures are arranged in a fan shape, which can fit well with circular arc surfaces such as circular holes, and it can be utilized in the design of rods, brackets, and other parts of a robotic knee exoskeleton to reduce the weight. The metamaterial is formed by continuous arrangement and combination of small truss structure unit cells, which changes the diameter of the pillar section, geometrical size, and relative density of each unit cell. It can be made quickly through additive manufacturing techniques such as metal 3D printing. The unit cell of the truss structure is small, and the machined parts of the robotic knee exoskeleton, such as connectors, rods, and bearing brackets, can be filled and replaced by gradient arrangement and non-uniform distribution. Under the condition of satisfying the mechanical properties of the robotic knee exoskeleton, the weight of the exoskeleton is reduced, and hence, the patient's wearing fatigue is relaxed, and the wearing time of the exoskeleton is increased. Thus, the efficiency and wearing comfort, and safety of the exoskeleton can be improved. In this paper, a brief description of the hardware design of the prototype of the robotic knee exoskeleton is first presented. Next, the design of the ultra-light and ultra-stiff truss type of lattice structures is proposed, and the mechanical analysis of the single-cell unit is performed by establishing the theoretical model. Additionally, simulations are performed to evaluate the maximum stress-bearing capacity and compressive performance of the uniform arrangement and gradient arrangement of the cells. Finally, the static analysis is performed for the cell-filled rod and the unmodified rod, respectively, and the simulation results demonstrate the effectiveness and feasibility of the designed ultra-light and ultra-stiff truss type of lattice structures. In future studies, experiments will be conducted to further evaluate the performance of the designed lattice structures.

Keywords : additive manufacturing, lattice structures, metamaterial, robotic knee exoskeleton
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