A Preliminary Study on the Design of Compliant-based Pruning Shear

Sara Lee Kit Yee¹, * and Chong Chen Hoo¹

¹Center of Systematic Innovation Research, Department of Mechanical Engineering, Faculty of Engineering and Technology, Tunku Abdul Rahman University College, 53300 Kuala Lumpur, Malaysia.

*E-mail: leeky@tarc.edu.my

Abstract. Various forces ranging from 200 N to 350 N were applied on the compliant-based pruning shear for stress, strain, displacement and factor of safety analysis. A 3D-print prototype was also fabricated to verify the possibility of the metamaterial-based structure in the product design. The result shows that the maximum stress and strain distribution on this pruner is 44.25 MPa and 0.02121 respectively, with an applied force of 350 N. The minimum safety factor is reasonable, and the maximum displacement is 1.6 mm at the head of the pruner when force was applied at the handle.

1. Introduction
Compliant mechanisms give many intrinsic advantages, including low cost, zero backlash, manufacturing comfort and scalability due to their monolithic structure. The part count can be reduced by having flexible parts instead of the conventional pin, springs, and rigid hinges [1-3]. Metamaterials are artificial structures with repetitive cell patterns to attain macroscopic movement and offers different degrees of freedom [4]. Mechanical pruning shears were developed as an alternative to manual labour [5, 6]. Pruning shear is a cutting device used in gardening, farming and flower arranging. A typical pruning shear consists of two sharp blades to cut twigs and branches, where there is a spiral spring and several joints to connect with the handle. There are different types of pruning shears in the market, such as anvil pruners, bypass pruners and parrot-beak pruners. The limitation of the pruning shears includes wear and failure in the spring. Besides, It is essential to design ergonomic pruning shears to avoid occupational disorders, such as cumulative trauma disorders [7]. In particular, the action of pruning caused high biomechanical strains on the hand-write system due to the repetitive task [8]. This research aims to design an ergonomic, monolithic compliant-based pruning shear, with the combination of metamaterial as the main mechanism.

2. Methodology

2.1. Design Setup
There are numerous types of pruning tools available in the market. Generally, most of the manufacturers fabricated left-handed models and tools with ergonomic handles. The design criteria are part count reduction and reduction in weight. FlashForge Finder 3D Printer was selected as the printer for the prototype. Thermoplastic Polyurethane (TPU) filament with a diameter of 1.75 mm was
selected owing to its flexibility and adaptability to the 3D printer. A detailed setup detail is depicted in Table 1.

| Specification     | Details                      |
|-------------------|------------------------------|
| Software          | Ultimaker Cura Version 4.2   |
| Infill Pattern    | Hexagon (Honeycomb)          |
| Infill Density    | 100%                         |
| Printing Speed    | 30 mm/s                      |
| Extruder Temperature | 220º C                      |
| Bed Temperature   | 30º C                        |
| Shell Thickness   | 0.8 mm                       |

2.2. Product Design

The current product design (Figure 2) was compared with the compliant plier designed by Howell and co-authors (Figure 1) [9]. A demonstration of function for Howell’s design is explained in Figure 1(b). As the force was applied at the handles, the hinge will move upward as shown and the head of the pruner will be closed. The cutting function will be then performed with the blades located at the head of the pruner. As refer to Figure 2, the main mechanism in the current design was inspired by the flexible metamaterial mechanism [10]. This flexible metamaterial mechanism is also categorized under the family of compliant mechanism, which is beneficial in substituting the function of bolt and nuts of the pruner. When the force was applied at the handle, this mechanism would deform outward, as shown with the blue arrow in Figure 2(b). The energy was then transformed from the mechanism to the head of the pruner for cutting purposes.
3. Results and Discussion

The simulation was done based on non-linear deformation analysis using Autodesk Fusion 360. The design was drawn via SolidWorks and imported to Fusion 360 for simulation analysis as referred to Figure 3. Forces varied from 200 N to 350 N were set to apply at the handle for the simulation analysis. Mesh size was generated on the model as shown in Figure 4, with the average element size set to an absolute size of 1 mm. Parabolic shape (element order) and curved mesh element were also selected to generate precise meshing distribution, in particular at joint and edges.

Thermoplastic Polyurethane (TPU) was selected as the material with the Shore grade of 98 A due to the flexibility of the material. The stress and strain analysis for the model were presented in Table 2. Based on the results, maximum stress on the pruner is occurring at the flexible mechanism part of the pruner. This is because the flexible mechanism part undergoes a large area displacement when the handle is compressed. Nevertheless, it is clearly shown that the pruner may not incur excessive stress on the overall surface as referred in the analysis. The detailed analysis of stress and strain were displayed in Figure 7 and 8 for all the forces applied.

Displacement analysis was conducted, and the results were displayed in Figure 5. From Figure 5(d), it was observed that the maximum displacement occurred on the handle, which is 3.189 mm. The maximum displacement at the head of the pruner is 1.6 mm. As for the safety factor analysis, the overall minimum safety factor occurs at the flexible mechanism part of the pruner, in which the minimum safety factor is 1.29 when a maximum 350 N force was applied as referred in Figure 6. The overall safety factor for all forces ranging from 1.29 to 2.26, which are acceptable. The 3D-print prototype and demonstration of applied force at the handle and the compression are displayed in Figure 7.

| Force Applied | Maximum Stress (MPa) | Maximum Strain |
|---------------|----------------------|----------------|
| 200           | 25.31                | 0.01213        |
| 250           | 31.62                | 0.01516        |
Figure 5. (a) Displacement analysis with 200 N, (b) Displacement analysis with 250 N, (c) Displacement analysis with 300 N, (d) Displacement analysis with 350 N.

Figure 6. Safety Factor Analysis with 350N Applied Force.
4. Conclusion
In conclusions, various forces were applied on the pruning shears for stress, strain, displacement and factor of safety analysis, with a 3D-print prototype fabricated. The result shows that the maximum stress and strain distribution on this pruner is 44.25 MPa and 0.02121 respectively, with an applied force of 350 N. The minimum safety factor is reasonable, and the maximum displacement is 1.6 mm at the head of the pruner when force was applied at the handle. A compliant based pruner was successfully analyzed with a prototype to support the possibility of a metamaterial-based structure in the product design.

5. Acknowledgments
The authors express gratitude to Tunku Abdul Rahman University College for the financial support provided in this work.

6. References
[1] Pandiyan A and Gopal A, 2016 Istrazivanja i Projektovanja za Privredu 14 223-232
[2] Howell L L. 2013 Handbook of Compliant Mechanism
[3] Dearden J, Grames C, Jensen B D, Magleby S P, and Howell L L, 2017 J. Med. Devices 11
[4] Ion A, Frohnhofen J, Wall L, Kovacs R, Alistar M, Lindsay J, et al. 2016 UIST 2016.
[5] Nowakowski T, Dąbrowska M, Sypuła M, and Strużyk A, 2018 Sci. Hortic 242 30-35
[6] Giametta G and Zimbalatti G, 1997 J. Agric. Eng. 68 15-20
[7] Leppä nen M, Mattila M, and Kivistö-Rahnasto J, 2000 Proc. Hum. Factors Ergon. Soc. Annu. Meet. 44 .647-650
[8] Roquelaure Y, Dano C, Dusolier G, Fanello S, and Penneau-Fontbonne D, 2002 Int. Arch. Occup. Environ. Health 75 591-595
[9] Howell L, Midha A, and Murphy M, Proc. ASME 1994 Design Techn. Conf. 1994 509-515
[10] Bertoldi K, Vitelli V, Christensen J, and van Hecke M, Nat. Rev. 2017 2 17066