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Reconstruction of Geometrical Structure of Claw of Mole Rat (*scaptochirus moschatus*) and Finite Element Analysis of Claw against Soil

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Abstract. Mole rat, a typical soil-burrowing animal, has high working efficiency during digging procedure, its claws are good biomimetic prototypes, and the geometrical structure of its claws and its movement type during digging can provide certain foundation for improving the design of the tillage implement. In this paper, based on the reverse engineering, the original data points of the claw was collected by a 3D laser scanner, then the accurate surface of the claw was created by using special software of reverse engineering on the premise of point-curve-surface method. The reconstructed CAD model was established in Pro/E software, and the model of interaction between the claws of mole rat and soil was obtained. The finite element method (FEM) was utilized to simulate the interaction of the claw against soil. The simulated results showed that the movement type of claw of mole rate during digging could get lower cutting resistance and bigger impact to soil.

1 Introduction

Some soil-burrowing animals have excellent living ability and biological systems through the evolution upon millions of years for adapting their living surroundings. These soil-burrowing animals, such as pangolin, dung beetle and mole cricket, have better functions in biomechanics, which resulted in lower cutting resistance and reduced soil adhesion [1-5]. Mole rat is a typical soil-burrowing animal, and it is called as “living grab” because it can dig a long tunnel in length over 91m in one night [6, 7]. The claws of mole rats are its main digging organs, and the body length of mole rat is only 100mm-180mm, a 91m long tunnel is really a huge project for it [7]. Thus, the claw of mole rate is a good bionic prototype, and it is a new way to design of soil-cutting tool by imitating the shape of claw of mole rat [8, 9].

In this paper, the reverse engineering was used to obtain the detail information of geometrical structure of mole rat’s claw. Then, the reconstructed model of the claw of mole rat was formed on the basis of the collected data and software of Imageware and Pro/E. The finite element method (FEM) was utilized to simulate the interaction of the claw against soil. This research works would provide certain foundation for improving the design of the soil-cutting tool.

2 Reconstruction of geometrical structure of claw of mole rat

The living body of mole rat (*scaptochirus moschatus*) was captured in Yaojinzi pasture which located in Changling county, city of Songyuan, Jilin province, The claws of mole rat was excised from the animal before testes, and rinsed thoroughly with distilled water. Then the biological sample was preserved in ethanol solution, and the quality concentration of ethanol solution was 95%.

The geometrical characters of five claws were analyzed by optic stereoscope. The photograph of optic stereoscope of claws is shown in Fig.1. The geometric parameters of claws of mole rate were measured by vernier caliper. The results of observation and analysis showed that the values of lengths, widths and thicknesses of the middle three claws were larger than that of two outer claws, and the measurement values of claw-2 and claw-3 was very close. So, the claw-2 was taken as subsequent test specimen.

The detail information of geometrical structure of claw is difficult to measure by traditional methods because of the complicated surface character, and reverse engineering is a effective method to solve this problem [10]. In order to avoid the influence of reflectivity, color of the surface and the differences of curvature feature, the claw of mole rat was colored by the dye penetrate inspection material (DPT- 5 type) before data acquisition.

A 3D laser scanning system (LSV50 type) was used to measure the digital data of the claw of the mole rat, as shown in Fig.2. Three small steel balls with a radius of 1.47mm were utilized during the measurement to ensure that the data obtained from different scanning angle and at different time can be unified. The comparative analysis was conducted, because the varied scanning steps and the scanning direction could result in different number of point cloud data. In order to obtain the holistic shape data, the scanning step of 0.05mm was used in experiments by comprehensively considering the acquired data and scanning speed. The scanning results of mole claw toe as shown in Fig. 3.

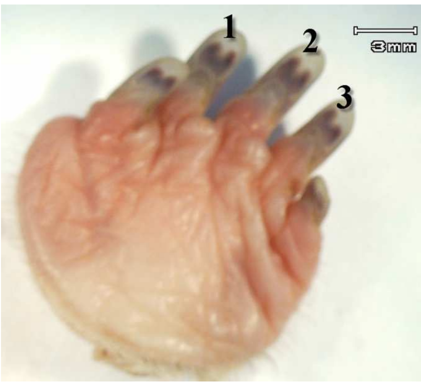
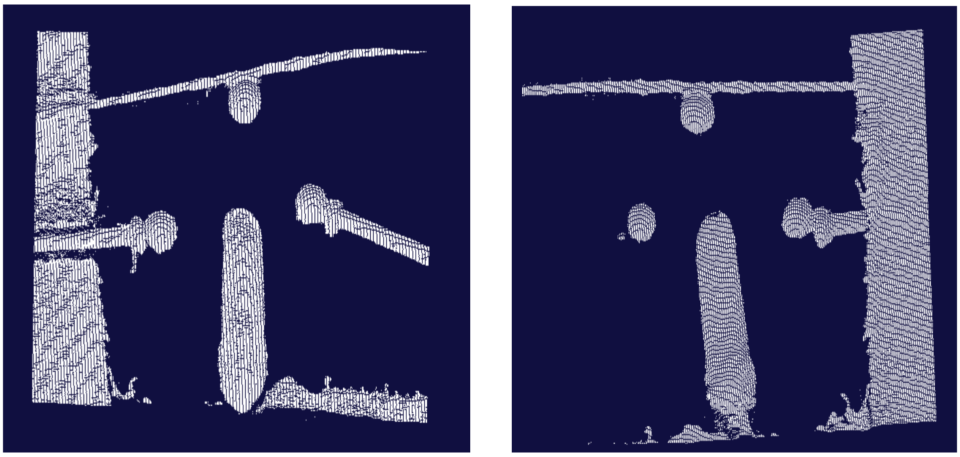


Fig.1 Claws of mole rat (*Scaptochirus moschatus*)

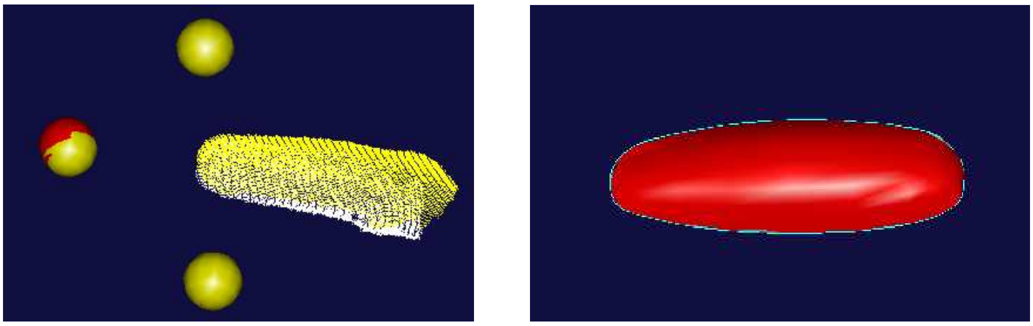
Fig. 2 The 3D laser (LSV50 type)



(a) (b)

Fig.3 The collected data of selected claw. (a) Point cloud data of back side; (b) Point cloud data of palm side.

The scanning data point clouds were processed by using software of Imageware which was a professional software for reverse engineering. The procedure included deleting error points manually, smoothing the scanning data and sampling characteristic points from the scanning point clouds. Gaussian filter was used for smoothing and chordal deviation method was used for sampling. Based on the reconstruction model of three placements, the scanning data obtained from different angle and different direction were positioned and conformed. The point-curve-surface method was used to reconstruct the geometrical configuration of the claws of the mole rat. The processing results of point cloud data by software of Imageware are shown in Fig. 4(a) and Fig. 4(b).



(a) (b)

Fig. 4 The processing results of point cloud data. (a) Aligned point cloud data; (b) Reconstructed surface of claw

Then, the quality of the reconstructed geometrical surface was evaluated, the difference between the original point cloud data and the reconstructed surface was analyzed. The analysis showed that precision of reconstruction was high for the low error, and the value of maximum negative error was only -0.158mm, the value of maximum positive error was 0.127mm. The negative error mentioned above meaned the point cloud data was at outside of the reconstructed surface, and the positive error indicated the point cloud data was at inside of the reconstructed surface correspondingly.

3 Finite element analysis of Claw of mole rat against soil

Table 1 The parameters of claw of mole rat and soil

	Parameter	Value
Claw of mole rat	Modulus of elasticity	0.82e+010Pa
	Poisson ratio	0.25
Soil	Density	1850kg/m
	Angle of internal friction	31.5°
	Cohesion	3.04e+004Pa
	Modulus of elasticity	1.25e+006Pa
	Angle of external fiction	24°
	Poisson ratio	0.15

The reconstruction model which obtained from software of Imageware was saved as IGS format, and imported into software of Pro/E to form a substantiated model and draw the soil model**.** The substantiated model is shown in Fig. 5. Then, the model of the claw of mole rat and soil was transferred into software of ANSYS, and a nonlinear analysis was conducted by finite element method (FEM). In the software of ANSYS, the element type, material and some parameters were defined, and the parameters of claw was got from Nanomechanics tests, the soil parameters was obtained from triaxial compression test, the parameters of claw of mole rat and soil used in ANSYS are listed in Table 1. Subsequently, the model of the claw and soil was meshed, limited conditions were added, and resolution parameters were set up. Afterwards, the procedure of the interaction of the claw of mole rat against soil was simulated. The simulation results were analyzed through post-process functions of software of ANSYS. The displacement nephogram and stress nephogram were obtained.

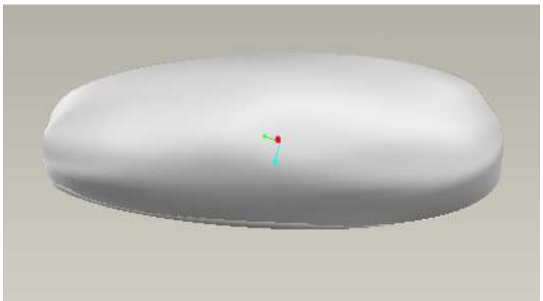


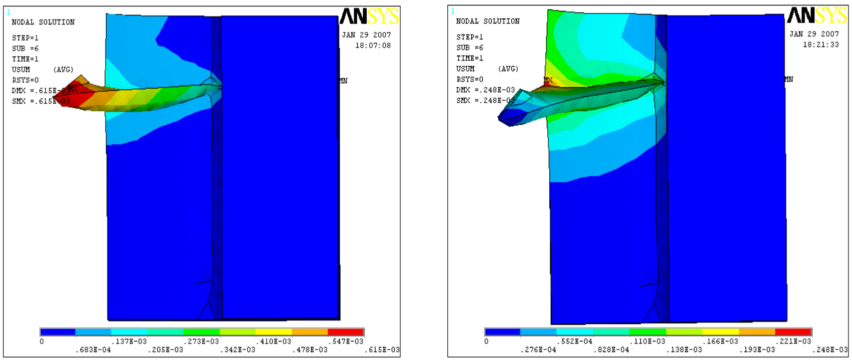
Fig. 5 Substantiated model of claw of mole rat

Two kinds of movement types of claw of mole rat were analyzed in this paper, and the interactions of the claw against soil during the different soil-cutting procedure were obtained. The movement types were translational motion and rotary motion. In addition, the mode of rotary motion was similar as the soil-cutting motion of mole rat [11].

The results of displacement nephogram from finite element analysis are show in Fig. 6. As seen in the Fig. 6, the displacement ranges of soil caused by claw of mole rat were different, and the scope of rotary motion was bigger than the translational motion's. Furthermore, when the claw was in translational motion, the value of displacement of claw was larger than that of rotary motion, which indicated that during translational motion process the claw of mole rat would receive a larger soil resistance.

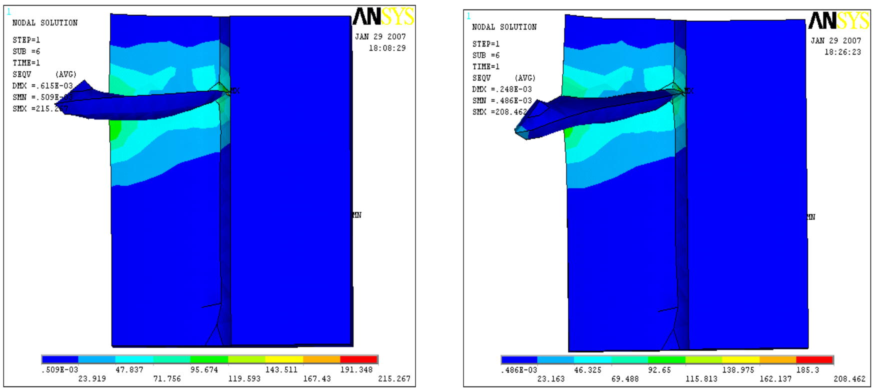
Fig. 7 shows the results of stress nephogram of the movement types of claw. The results showed that the stress distribution was almost same, but the values of stress existed differences, and the stress induced by the rotary movement of claw was slightly larger than that of translational motion.

As is mentioned above, when soil-cutting action of claw of mole rat was rotary motion, it could get the lower soil resistance and larger scope of influence to soil. Thus, the geometric structure of claw of mole rat would provide some useful information for improving the design of soil-cutting tools, especially for the rotating type.



(a) (b)

Fig. 6 The results of displacement nephogram. (a) Movement type of claw was translational motion and rotary motion; (b) Movement type of claw was rotary motion.



(a) (b)

Fig. 7 The results of stress nephogram. (a) Movement type of claw was translational motion and rotary motion; (b) Movement type of claw was rotary motion.

4 Summary

The detail information of geometrical structure of claw of mole rat was obtained by using reverse engineering. Then the reconstructed model of the claw of mole rat was formed on the basis of the collected data and software of Imageware and Pro/E. The quality of the reconstructed geometrical surface was evaluated, and the analysis result showed that precision of reconstruction was high. The finite element method (FEM) was used to simulate the interaction of the claw against soil, and the nonlinear analysis was conducted. The results of finite element analysis show that, when soil-cutting action of claw of mole rat was rotary motion, it could get the lower soil resistance and larger scope of influence to soil. This research works would provide certain foundation for improving the design of the soil-cutting tool.

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