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Visualization and Feature Extraction of the Surface Morphology of the Abdomen of Red Swamp Crayfish

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Abstract

This paper demonstrates a method for visual reconstruction and feature analysis of the surface morphology of red swamp crayfish in CATIA (Computer Aided Three Dimensional Interactive Application) and Microsoft Excel. Red swamp crayfish, *Procambarus clarkii*, with efficient burrowing activities and coupling propel pattern of abdomen with tail, was selected to study the feasible methods in the visual reconstruction and feature analysis of the surface morphology of living things. The digital measurements of surface of the red swamp crayfish were carried out using a three-dimensional laser scanner. Point clouds, the scanning digital data of the surface of the red swamp crayfish, were processed by deleting unwanted data, reconstructing surface in CATIA. There was a perfectly shape character similarity between the digital picture of the abdomen with corresponding point clouds shown in CATIA, and transverse curves which shown the surface morphology of abdomen in the cross section along the red swamp crayfish were obtained and saved as files of ASCII format in CATIA. Feature analysis of the abdomen of red swamp crayfish were carried out after files of single transverse curve were imported into Microsoft Excel, results shown that, the first row in file of single transverse curve was the number of rows after it, and those other rows stored coordinate values of measured points of the abdomen in the preset three-dimensional coordinate system, shapes of the abdomen in different cross sections were similar, and quadratic polynomial regression equation was able to effectively express surface morphology of the abdomen of red swamp crayfish.

Methods and results presented in this paper prove to be potentially useful for analyzing the feature of biological prototype, optimizing the mathematical model and affording deformable physical model to bionic engineering, those works would have great implications to the research of biological coupling theory and technological creation in bionic engineering.

Key words: Visual reconstruction; Feature analysis; Surface morphology; Red swamp crayfish

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INTRODUCTION

Bionics is a science for studying the structures, characters, elements, behaviour and interactions of biological systems in order to provide new design schemes, working principles and system structures for engineering (Ren, *et al.,* 2001; Vincent, *et al.,* 2002; Lu, 2004). Results of biological coupling research show that, earthworms and other soil animals such as dung beetles can move efficiently in mud or moist soil without soil sticking to them; the lotus leaf can repel water, remove contaminants and clean its surface (Ren, *et al.*, 2001; Yan, *et al.*, 2008). Biological functional surfaces of those living things are formed from the synergy of many factors including biological surface morphology, structure in surface layer, and the materials to obtain the best adaptability to the environment. Bionic

engineering takes the results of the evolution of living things as references for technological creation, imitates not directly duplicates features and characteristics of living things (Qian, *et al.,* 2009).

Red swamp crayfish, *Procambarus clarkii*, may inhabit a wide variety of freshwater habitats including rivers, lakes, ponds, streams, canals, and seasonally flooded swamps and marshes. Red swamp crayfish has 2 pairs of sensory antennae, compound eyes, 2 large pincers or claws called chelipeds, 8 jointed walking legs, a segmented body, and tail. Its body has three body regions: head, thorax, and abdomen. The head and thorax are closely joined together, or fused, to form the cephalothorax. A shield-like carapace covers the cephalothorax. The carapace also covers the sides of the body and protects the breathing organs, or gills. At the end of the abdomen is a pair of slender biramous appendages, the uropods. In between the uropods is a tail-like segment called the telson. The telson is not tightly joined with, or fused, to the last abdominal segment. The telson and uropods work together to form a fanlike tail. Red swamp crayfishes snap their abdomens with fanlike tails forward underneath their bodies to propel themselves backward through the water. Chelipeds are usually used for burrowing, feeding, mating, and defensing. The burrowing activities and coupling propel pattern of abdomen with tail could be references for technological creation to Bionics.

Biological prototype, mathematical model and physical model are three inter-related aspects in bionics. Visual reconstruction and feature analysis of the surface morphology of a biological prototype would not only play an important role in building and optimizing the mathematical model of biological prototype, but also be useful to study the influences of morphology, structure and the materials on the biological function, reveal multifactor coupling law and mechanism, build the deformable physical model and design principle of biological coupling.

In recent years, significant progresses have been made on visual reconstruction and feature analysis of the three-dimensional surface of living things (Xu, *et al.*, 2008; Zhang, *et al.,* 2008; Wu, 2006; Li, *et al.*, 2011). The reverse engineering technology was adopted to obtain the surface geometrical information of the head of wild boar and tergum of Mole cricket. Software, Surface, CATIA (Computer Aided Three Dimensional Interactive Application), AutoCAD and MATLAB, have been used to reconstruct and analyse the three-dimensional surface of those living things.

In present paper, red swamp crayfish, with efficient burrowing activities and coupling propel pattern of abdomen with tail, was selected to study the feasible methods in the visual reconstruction and feature analysis of the surface morphology of living things. The digital measurements of surfaces of the red swamp crayfish were carried out using a three-dimensional laser scanner. Point clouds, the scanning digital data of the surface of the red swamp crayfish, were processed using CATIA and Microsoft Excel, typical software of reverse engineering, which involved deleting unwanted data manually, surface reconstruction and feature analysis.

MATHEMATICAL AND METHODS

Acquisition of Point Clouds

Digital measurements of the surface of the red swamp crayfish were carried out by using the LSV 50 laser scanner, a non-touch three-dimensional laser scanner. Samples of red swamp crayfish were set at the scanning platform of this laser scanner, and the body of red swamp crayfish were kept paralleled to the lateral moving direction of the two CCD cameras (Figure 1). The maximum scanning range of length, width and height in this laser scanner was 80 mm × 70 mm × 30 mm, and the scanning precision was 0.05 mm.

In order to analyse the detail information in the point clouds, a three-dimensional coordinate system was preset to reconstruct and analyse the point clouds of the surface morphology of the red swamp crayfish, the origin point, *X*-axis and *Y*-axis were on the scanning platform of the laser scanner, *Z*-axis was in the vertical direction the scanning platform. The origin point was the start point of scanning; *X*-axis and *Y*-axis were point to the lateral and longitudinal moving and scanning direction of two CCD cameras.

Figure 1
Laser Scanner and Red Swamp Crayfish

For simplicity, only a limited region of the body of red swamp crayfish were scanned and analysed. Point clouds, the scanning data of the three-dimensional surface of red swamp crayfish, were saved as files of ASCII format. Point clouds consist of (x; y; z) coordinate values of measured points in the surface of red swamp crayfish. Figure 2 shows the point clouds of the abdomen and tail

of red swamp crayfish which was imported and displayed in the software of Surface. Rich information about the point clouds can be received by viewing and analysing, such as noise data introduced from extraneous vibration and specular reflection, data correspond to the scanning platform contained in point clouds.

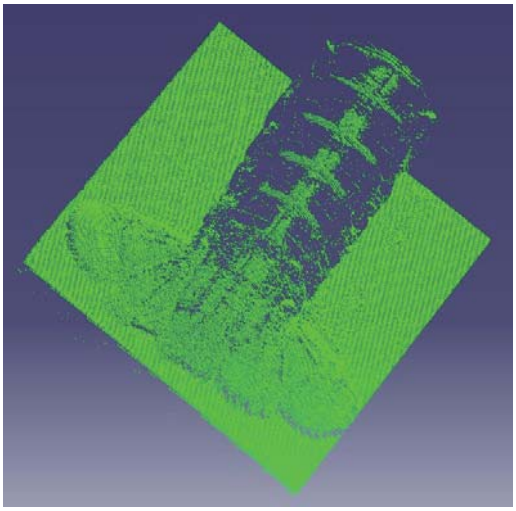


Figure 2
Point Clouds of Red Swamp Crayfish

Figure 3
Digital Picture of Red Swamp Crayfish

Compare with the digital picture of the abdomen and tail of red swamp crayfish in Figure 3, point clouds in Figure 2 shows a good coincidence with real shape of the abdomen and tail of red swamp crayfish. It could be used in the visual reconstruction and feature analysis of the abdomen of red swamp crayfish.

Surface Reconstruction of the Abdomen of Red Swamp Crayfish in CATIA

CATIA, Computer Aided Three Dimensional Interactive Application, is mostly used for 3D scanning, reverse engineering, design and computer-assisted design (CAD), digital manufacturing and medical applications. Elimination of unwanted data, such as noise, scanning platform, and tail of red swamp crayfish in point clouds, were curried out in CATIA. Point clouds were imported the module of "Digitized Shape Editor" in CATIA. "Adaptative" filtering type was selected to hide and delete the unwanted data of noise, scanning platform, and tail of red swamp crayfish could be deleted by setting parameters in the "Remove" dialog box. Point clouds of the abdomen of red swamp crayfish after filtering and deleting was shown in Figure 4.

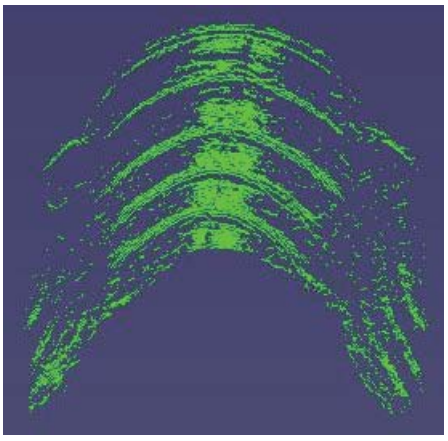


Figure 4
Point Clouds of the Abdomen

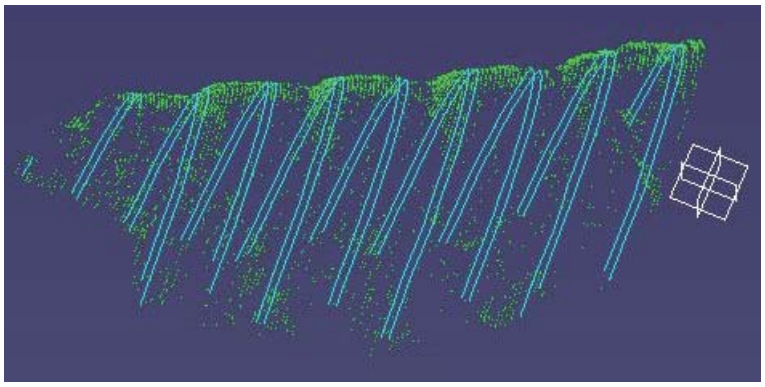


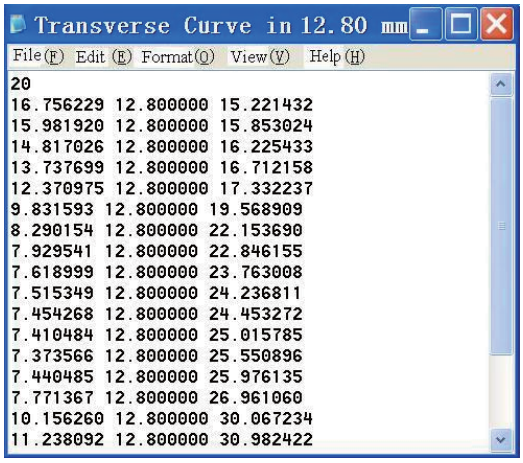
Figure 5
Point Clouds with Transverse Curves of the Abdomen

In addition, Group of transverse curves that approximate to the point clouds were obtained by setting parameters in the "Planar Sections" dialog box. Point clouds after processing operations and its transverse curves were shown in Figure 5.

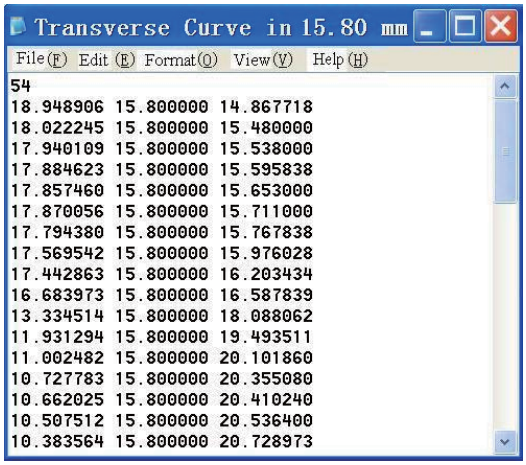
Those transverse curves were parallel to *XZ* plane and perpendicular to *YZ* plane with 3 mm space between them in the preset three-dimensional coordinate system. Point clouds of each transverse curve were also saved as file of ASCII format. Each file of ASCII format stored the point clouds respond to single transverse curve which shown the surface morphology of abdomen in the cross section along the red swamp crayfish. Features of those transverse curves were also characters of the surface morphology of abdomen in different cross sections, *YZ* plane of preset three-dimensional coordinate system.

Feature Analysis in Microsoft Excel

One file of ASCII format which stored the point clouds respond to single transverse curve opened in the program of Windows NotePad were shown in Figure 6 (a) and (b).



(a) Numerical Value in the Second Column is 12.80



(b) Numerical Value in the Second Column is 15.80

Figure 6
File of Single Transverse Curve Opened in Microsoft NotePad

Numerical values, 20 and 54 in the first row of Figure 6(a) and (b), was the number of rows after it in the file of single transverse curve, and each of those rows had 3 columns. All of the numerical values in the second column of each transverse curve were the same number, such as 12.80 and 15.80 in Figure 6(a) and (b). Associating fixed numerical values 12.80 and 15.80 with 3 mm space between each transverse curve before-mentioned, the result that numerical values in the second column were *x* coordinate values of measured points of the abdomen could be easily deduced. In other words, 12.80 and 15.80 were the coordinate values, locations of the transverse curves in the *X*-axis.

File of single transverse curve (Figure 6(a), *x*=12.80 mm) was imported into Microsoft Excel, and relationship between the first and third column were shown as scatter diagram in Figure 7.

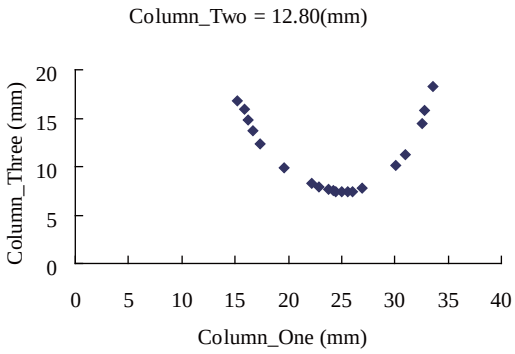
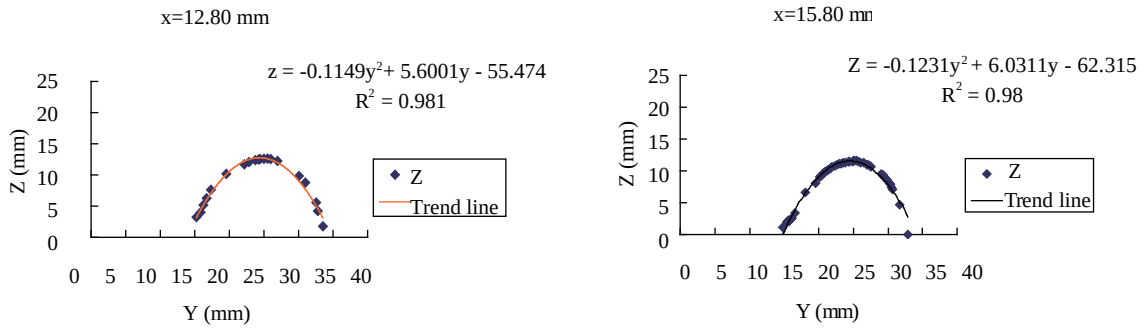


Figure 7
Scatter Diagram of Transverse Curve (x=12.80 mm)

Comparing with Figure 4 and 5, results that numerical values in the first and third column were *y* and *z* coordinate values of measured points of the abdomen also could be easily obtained. Associating Figure 5 with the

aforementioned fact that the maximum scanning range of height in this laser scanner was 30 mm, we would knew that, the graph in Figure 5 was inverted outline of the abdomen, and the third column of transverse curves stored the distance between the distances between the highest point that the scanner could measured and the surface of red swamp crayfish. It means that numerical values in the third column of each single transverse curve must be subtracted by an appropriate numerical value, such as 20 in this paper. Scatter diagrams similar with Figure 7 would be upside down and show the true shape of the outline of the abdomen of red swamp crayfish.

Based above deductions, files in Figure 6 were in imported into Microsoft Excel, and numerical values in the third column of each file were subtracted by 20. Scatter diagrams corresponding to different cross sections of the abdomen were shown in Figure 8(a) and (b). Trend lines and quadratic polynomial regression equations were also shown in Figure 8 (a) and (b).



(a) Coordinate Value in *X*-axis is 12.80 **(b) Coordinate Value in *X*-axis is 15.80**

Figure 8
Surface Morphologies and Regression Results of Abdomen in Different Cross Sections

Quadratic polynomial regression equation of the surface of abdomen in the cross section (x=12.80 mm) was derived as Eq. (1).

$$z = -55.474 + 5.6001y - 0.1149y^2 \quad (1)$$

In the meanwhile, quadratic polynomial regression equation of the surface of abdomen in the cross section (x=15.80 mm) was derived as Eq. (2).

$$z = -62.315 + 6.0311y - 0.1231y^2 \quad (2)$$

Where, y and z were coordinate values in X-axis and Y-axis of the preset three-dimensional coordinate system.

Comparing polynomial coefficients of those three terms in Eq. (1) and (2), conclusions that Eq. (1) and (2) was similar could be obtained. It indicated shapes of the abdomen in different cross sections were similar, and quadratic polynomial regression equation was able to effectively express surface morphology of the abdomen of red swamp crayfish.

RESULTS AND DISCUSSION

Visual reconstruction and feature analysis of the t surface morphology of the red swamp crayfish were carried out on CATIA and Microsoft Excel. Point clouds, the scanning data of the surface of the red swamp crayfish, were carried out by using the LSV 50 laser scanner and saved as ASCII format file. Surface of the abdomen of red swamp crayfish was reconstructed in CATIA after file of point clouds imported into CATIA. For the reason that there was a perfectly shape character similarity between the digital picture of the abdomen with corresponding point clouds shown in CATIA, transverse curves which shown the surface morphology of abdomen in the cross section along the red swamp crayfish were obtained and saved as files of ASCII format in CATIA.

Feature analysis of the abdomen of red swamp crayfish were carried out after files of single transverse curve were imported into Microsoft Excel, Results shown that, the first row in file of single transverse curve was the number of rows after it, and those other rows stored coordinate values of measured points of the abdomen in the preset three-dimensional coordinate system, shapes of the abdomen in different cross sections were similar, and quadratic polynomial regression equation was able to effectively express surface morphology of the abdomen of red swamp crayfish. CATIA and Microsoft Excel were suitable to the visual reconstruction and feature analysis of the surface morphology of the living things.

CONCLUSION

Visual reconstruction and feature analysis of the surface morphology of the abdomen of the red swamp crayfish were realized in CATIA and Microsoft Excel. Results shown that there was a perfectly shape character similarity between point clouds and surface shape in corresponding situation of the abdomen, and quadratic polynomial regression equation was able to effectively

express surface morphology of the abdomen of red swamp crayfish. CATIA and Microsoft Excel were suitable to the visual reconstruction and feature analysis of the surface morphology of the living things. Methods and results presented in this paper are of great use to analyze the feature of biological prototype, optimize the mathematical model and provide deformable physical model to bionic engineering; they promise great implications to the research of biological coupling theory and technological creation in bionic engineering.

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