

Visual Reconstruction and Feature Analysis of the Three-Dimensional Surface of Earthworm¹

LI Yin-wu²

ZHAO Guang-sheng³

WANG Jing-chun⁴

SUN Xiu-wen⁵

PENG Hua-xin⁶

QIN Fa-xiang⁷

Abstract: This paper demonstrates a method for visual reconstruction and feature analysis of the three-dimensional surface of earthworm in CATIA (Computer Aided Three Dimensional Interactive Application) and IDL (Interactive Data Language). The earthworm, with a relatively simple surface morphology and good capability in reducing soil adhesion and resistance, was selected to study the feasible methods in the visual reconstruction and feature analysis of the three-dimensional surface of living things. The digital measurements of surfaces of the earthworm were carried out using a three-dimensional laser scanner. Point clouds, the scanning digital data of the surface of the earthworm, were processed by screening unwanted data, reconstructing surface and analysing feature in CATIA. In order to get more detail information about the point clouds, IDL, which integrates a powerful, array-oriented language with numerous mathematical analysis and graphical display techniques, was adopted for the visual reconstruction and feature analysis of three-dimensional surface of the earthworm.

Importing of point clouds and reconstruction of the surface of earthworm were conducted in CATIA. Analysis feature of the scanning data and reconstructing surface were carried out in IDL, which provides a high level of flexibility to access, analyse and

¹ The authors are grateful for the financial support by the National Natural Science Foundation of China (Grant No.50635030).

²Corresponding Author, Key Laboratory of Engineering Bionics Jilin University, Ministry of Education, Changchun, 130022, P. R. China; Department of Aerospace Engineering, Faculty of Engineering, University of Bristol, Bristol, BS8 1TR, UK. Address: Nanling Campus of Jilin University, 142 Renmin Street, Changchun, 130025, P. R. China. E-mail: lyw@jlu.edu.cn

³ Key Laboratory of Engineering Bionics, Jilin University, Ministry of Education, Changchun, 130022, P. R. China

⁴ Key Laboratory of Engineering Bionics, Jilin University, Ministry of Education, Changchun, 130022, P. R. China

⁵ Key Laboratory of Engineering Bionics, Jilin University, Ministry of Education, Changchun, 130022, P. R. China

⁶ Department of Aerospace Engineering, Faculty of Engineering, University of Bristol, Bristol, BS8 1TR, UK.

⁷ Department of Aerospace Engineering, Faculty of Engineering, University of Bristol, Bristol, BS8 1TR, UK.

* Received 16 May 2010; accepted 29 July 2010

visualize the data using different methods. Polynomial regression equation of the surface of earthworm in the longitudinal plane was derived. In addition, point clouds were more easily displayed and analysed by resizing, rotating and zooming in IDL.

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.

Keywords: Visual Reconstruction; Feature Analysis; Three-Dimensional Surface; Earthworm; CATIA; IDL

1. 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 & Mann, 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 & JI, 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).

Biological prototype, mathematical model and physical model are three inter-related aspects in bionics. Visual reconstruction and feature analysis of the three-dimensional surface 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 et al., 2006). 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.

IDL, the Interactive Data Language, is a self-contained computing environment for the interactive analysis and visualization of data. IDL integrates a powerful, array-oriented language with numerous mathematical analysis and graphical display techniques, thus providing a high level of flexibility, and supporting OpenGL-based hardware accelerated graphics (LI, 2007; TANG et al., 2005; Neicu et al., 2005; Marschallinger, 2001; Chatziioannou, 1994).

In present paper, the earthworm, with a relatively simple surface morphology and good capability in reducing soil adhesion and resistance, was selected to study the feasible methods in the visual reconstruction and feature analysis of the three-dimensional surface of living things. The digital measurements of surfaces of the earthworm were carried out using a three-dimensional laser scanner. Point clouds, the scanning digital data of the surface of the earthworm, were processed using CATIA, typical software of reverse engineering, which involved deleting unwanted data manually, surface reconstruction, feature analysis. Point clouds obtained were then imported to IDL to attempt more effective visual reconstruction and feature analysis of the three-dimensional surface of the earthworm.

2. MATHEMATICAL AND METHODS

2.1 Acquisition of point clouds

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

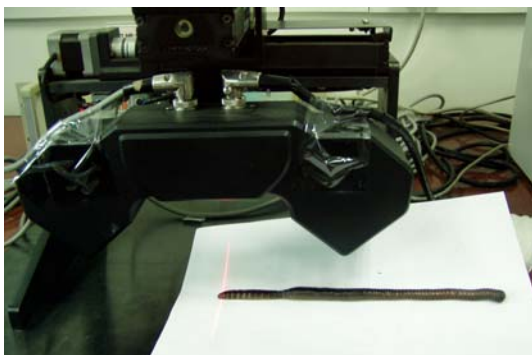


Fig. 1: Laser scanner and the earthworm

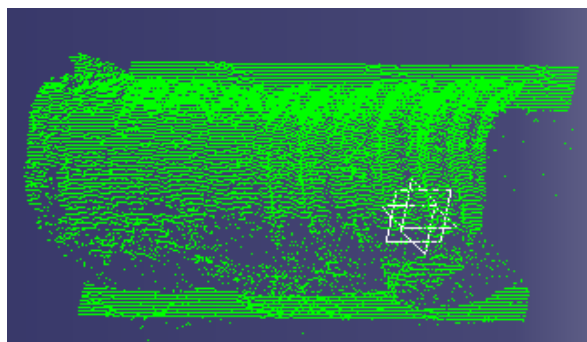


Fig. 2: Point clouds of body of the earthworm

A three-dimensional coordinate system was set up to reconstruct and analyse the three-dimensional surface of the earthworm: with the origin point, X-axis and Y-axis were on the scanning platform; 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.

For simplicity, only a limited region of the body of earthworm were scanned and analysed. Point clouds, the scanning data of the three-dimensional surface of the earthworm, were saved as files of ASCII format. Point clouds consist of $(x; y; z)$ coordinate values of measured points in the surface of the earthworm. Fig. 2 shows the point clouds of the body of earthworm 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 vibrations and specular reflections, data correspond to the scanning platform contained in point clouds.

2.2 Surface reconstruction in CATIA

CATIA, Computer Aided Three Dimensional Interactive Application, is mostly used for three-dimensional scanning, reverse engineering, design and computer-assisted design (CAD), digital manufacturing and medical applications. Elimination of unwanted data, such as noise and scanning platform data in point clouds, were carried 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 noise data, and data of scanning platform could be deleted by setting parameters in the "Remove" dialog box. In the meantime, Group of transverse curves that approximate to the point clouds were obtained by setting parameters in the "Planar Sections" dialog box. Those curves were parallel to YZ plane and perpendicular to XY plane with 1 mm spacing between them. Point clouds after processing operations and its transverse curves were shown in Fig. 3. Transverse curves of point clouds in Fig. 3 were used as the guide curve in the module of "Quick Surface Reconstruction" in CATIA, and the reconstructed surface was shown in Fig. 4.

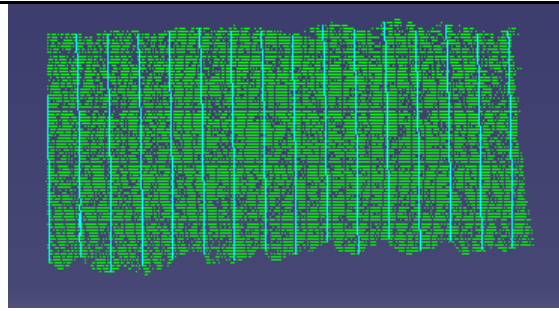


Fig. 3: Curve frame of surface of earthworm

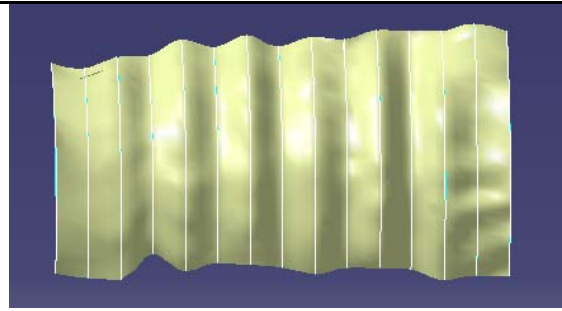


Fig. 4: Reconstructual surface of earthworm

2.3 Feature analysis in CATIA

Complexities of the surface of living things and limitations of the software restricted that only few features of the surface of earthworm could be analysed in CATIA. Curvature Analyses of those curves in Fig. 3 were conducted in the module of "Digitized Shape Editor". Further feature analyses about the surface of living things were also attempted. Regression equation of curves was derived by exporting the coordinates of the curves similar to curves in Fig. 3 and importing and calculating in CAD and MATLAB. Curvatures and second derivatives of those curves could also be calculated in MATLAB.

Point clouds consist of $(x; y; z)$ coordinate values of measured points in the surface of earthworm. But storage format and size of point clouds were paid less attentions in processing procedure of CATIA. To a certain extent, visual reconstruction of the surface of the earthworm is a process whereby the point clouds were transformed into a visual form to augment the process of discovery and analyse the feature of the three-dimensional surface of the earthworm. Visual study of the point clouds would be helpful to reconstruct and analyse the surface of earthworm.

3. VISUAL RECONSTRUCTION AND FEATURE ANALYSIS WITH IDL

3.1 IDL environment

IDL, the Interactive Data Language, is an ideal computing environment for the interactive analysis and visualization of scientific and engineering data. It integrates a powerful, array-oriented language with numerous mathematical analysis and graphical display techniques, thus providing a high level of flexibility to access, analyse and visualize the data by different methods, such as programming in editor window or calling iTools, the IDL Intelligent Tools directly. IDL programs run across all major platforms: UNIX, Macintosh and Microsoft Windows.

3.2 Accessing the point clouds

IDL provides built-in support for the data sources, data types, file formats, and file sizes. IDL was used to access common formats like TIFF, JPEG, and DXF, hierarchical scientific data formats like HDF, HDF-EOS, CDF, and netCDF, as well as custom binary and ASCII formats.

Point clouds consist of $(x; y; z)$ coordinate values of measured points in the surface of earthworm. In order to learn more information about the storage format and size of point clouds, Point clouds were opened with Notepad, and the measured points were arranged by three columns and 62388 rows. Three columns correspond to x ; y and z coordinate values of measured points.

The IDL Intelligent Tools (iTools) are a set of pre-built visualization tools that combine data analysis and visualization with the task of producing presentable quality graphics. Based on the IDL Object Graphics system, the iTools are designed to maximize the utilization efficiency of the data. The iTools

allows one continue to benefit from the control of a programming language, while enjoy the convenience of a point-and-click environment.

Point clouds can also be imported using the “ASCII Template Dialog” windows and defining type and range of ASCII data in iTools. Point clouds would be selected to import into IDL, more time would be wasted in clicking “Get next 50 Lines” optional button for the 62388 rows in it.

Being an array-oriented language, IDL could import aforementioned point clouds entirely (without using loops) into an array, such as *Bio_ASCII* [3, 62388], with 3 columns and 62388 rows. This work was carried on “editor window” with the volume of column and row being set in advance.

3.3 Reconstructing the surface

Three columns of the original point clouds, *Bio_ASCII* [3, 62388] were plotted in IDL and shown in Fig. 5. By comparing with Fig. 2 and Fig. 4, we received the corresponding relationship between three columns of the *Bio_ASCII* [3, 62388] and with (x; y; z) coordinate of measured points in the surface of the earthworm. The first, second and third columns of the *Bio_ASCII* [3, 62388] stored the z, y and x coordinate values of the measured points. Unwanted data, including data of the noise and scanning platform, were shown as those data of which volumes were larger than 13 mm in “Column_One” of Fig. 5. This conclusion could also be confirmed by analysing the first and second columns of original point clouds which being plotted in IDL (Fig. 6). Fig. 7 was the scatter plot of measured points in IDL, which is similar with Fig. 2, point clouds of body of the earthworm shown in CATIA.

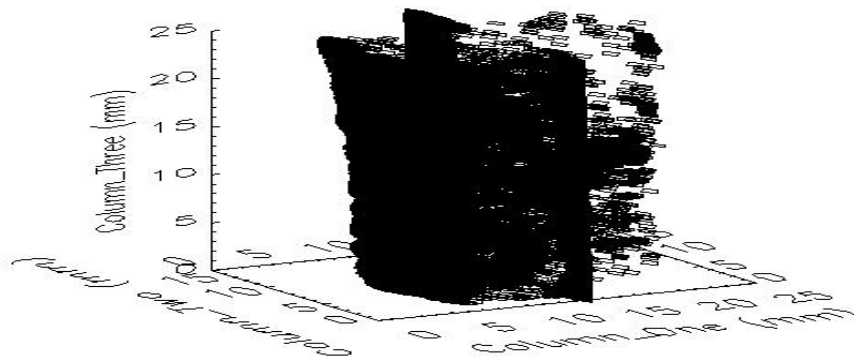


Fig. 5: Original point clouds being plotted in IDL

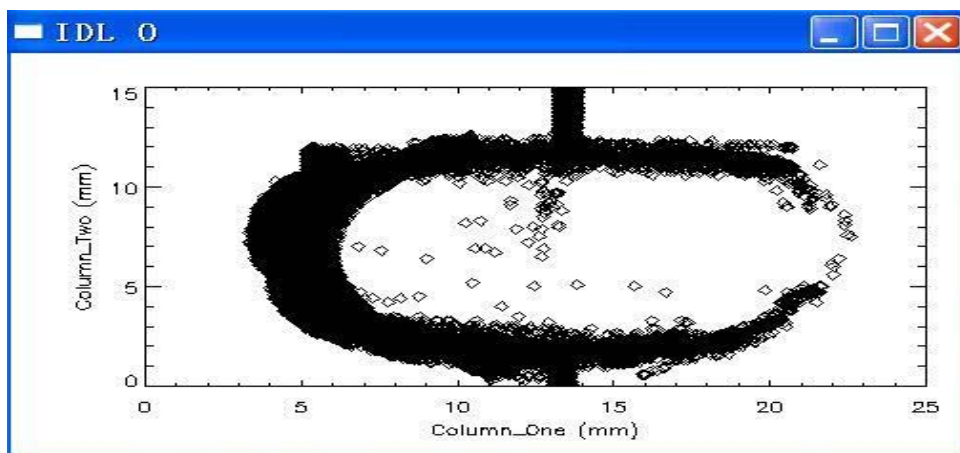


Fig. 6: First and second columns of original point clouds being plotted in IDL

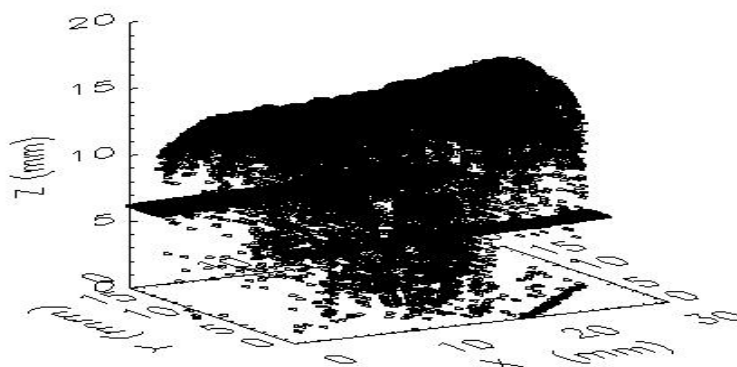


Fig. 7: Scatter plots of the measured points in IDL

The iPlot tool in iTools could be used for any type of two- or three-dimensional plot, including scatter plots, line plots, polar plots, and histogram plots. Point clouds, stored in the array of *Bio_ASCII* [3, 62388], can be displayed and analysed with great flexibility. Scatter plot, similar with Fig. 7, can be modified by adding elements such as error bars, legends, and axis titles. The data range can be altered in the data space properties of iTools if the data contained more data than wanted. After removing those unwanted data, such as data of the noise and scanning platform, three-dimensional surface of the body of earthworm was reconstructed in IDL. Fig. 8 was the scatter plot of the surface being reconstructed in iPlot tool. In the processing of surface reconstruction, the data used for feature analysis were selected and stored in the array. On the other hand, array subscripting syntax of IDL can be used to simply limit the range of data when the plot display is created in analysing the feature of the surface.

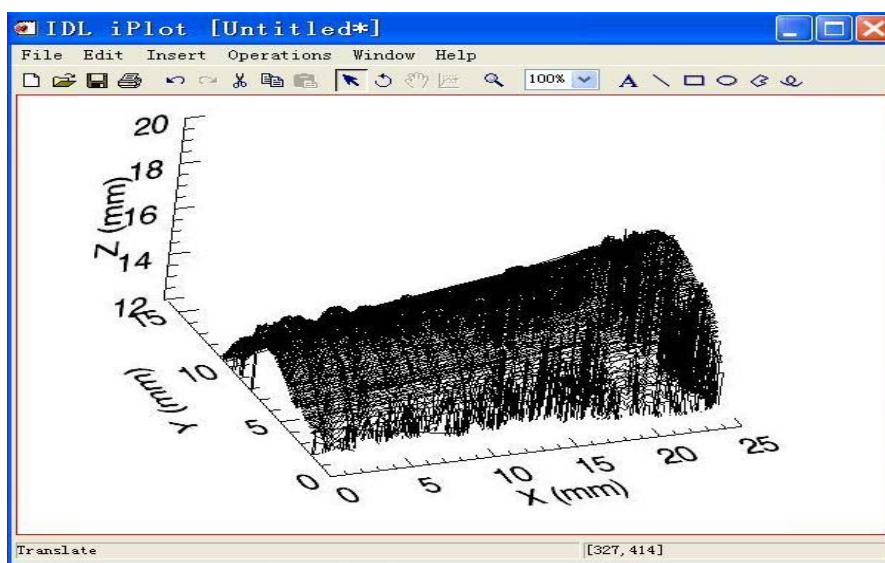


Fig. 8: Scatter plots of the surface being reconstructed in the iPlot tool of IDL

3.4 Analysing feature of the surface

After reconstructing the surface and getting the array for feature analysis in IDL, we had the option to resize them, change colour tables and plot style, rotate the surfaces, zoom, print or save the plots in several graphic file formats.

IDL has an extensive library of built-in math and statistics routines. Additional mathematical and statistical functionality can be added quickly and easily to an IDL application with the aid of the IDL Advanced Math and Stats Module. By calling the “poly fit” function with a subset of the *Bio_ASCII*

[3,62388]. Polynomial regression equation of the surface of earthworm in YZ plane (the longitudinal plane) was derived as Eq. (1).

$$z = 11.4206 - 1.9022y + 0.1227y^2 + 0.0014y^3, R^2 = 0.9926 \quad (1)$$

where, y and z are coordinates of the measured points in the three-dimensional coordinate system.

4. RESULTS AND DISCUSSION

Visual reconstruction and feature analysis of the three-dimensional surface of the earthworm were carried out on CATIA and IDL. Point clouds, the scanning data of the three-dimensional surface of the earthworm, were saved as ASCII format file. CATIA is commercial software widely being used for three-dimensional scanning and reverse engineering, those works, such as importing of point clouds and reconstruction of the surface of earthworm, were easily conducted in CATIA. But the rest of present work, such as analysis of the scanning data and feature of the scanning surface, would be more suitable to do in IDL, the ideal computing environment for the interactive analysis and visualization of scientific and engineering data.

In general, the choice of a quality software depends strongly on the purpose of the research problems addressed, the methods and approaches used, and the personal interest of the researcher or engineer. Users may also have different purposes, such as exploration, detailed analysis, or presentation. Therefore, the aim of researchers decided which technique, CATIA or IDL, was the most suitable to the visual reconstruction and feature analysis of the three-dimensional surface of the living things.

To a certain extent, the purpose of a surface reconstruction is to analyse the features of the surface. IDL provides a high level of flexibility to access, analyse and visualize the data by different methods, such as programming in "editor window" or calling iTools directly. Polynomial regression equation of the surface of earthworm in the longitudinal plane was derived. Point clouds can be more easily displayed and analysed by resizing, rotating and zooming in IDL.

5. CONCLUSION

Visual reconstruction and feature analysis of the three-dimensional surface of the earthworm were realized both in CATIA and IDL. With powerful capabilities of visualization and interactive analysis, IDL proves to be more suitable to carry out the research of visual reconstruction and feature analysis. 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.

REFERENCES

- A Chatziioannou, PK Banerjee, KA Gardner, M Dahlbom. (1994). Visualization of whole body PET images. *Proceedings of the 1994 Nuclear Science Symposium and Medical Imaging Conference, Norfolk, USA*, 1399–1402.
- LI Xin-wu. (2007). The Design and Realization of a Medical Image Management System Based on the IDL Platform. *Proceedings of the International Conference on Service Systems and Service Management (ICSSSM 2007), Chengdu, China*. 1–5.
- LU Yongxiang (2004). Significance and Progress of Bionics. *Journal of Bionics Engineering*, 1: 1–3.
- Marschallinger R.. (2001). Three-dimensional reconstruction and visualization of geological materials with IDL—examples and source code. *Computers & Geosciences*, 27(4), 419–426.

- Neicu Toni, Khaled M Aljarrah and Steve B Jiang. (2005). A software tool for 2D/3D visualization and analysis of phase-space data generated by Monte Carlo modelling of medical linear accelerators. *Physics in Medicine and Biology*. 50, N257–N267.
- Pomarede, D.; Audit, E.; Brun, A.S.; Gautard, V.; Masset, F.; Teyssier, R.; Thooris, B. (2007). Visualization of astrophysical simulations using IDL Object Graphics. *Proceedings of the 4th International Conference on Computer Graphics, Imaging and Visualization (CGIV 2007), Bangkok, Thailand*.471–480.
- QIAN Zhi-hui, HONG Yun, XU Cheng-yu, REN Lu-quan. (2009). A Biological Coupling Extension Model and Coupling Element Identification. *Journal of Bionics Engineering*, 6(2), 186–195.
- REN L Q, TONG J, LI J Q, CHEN B C. (2001). Soil adhesion and biomimetics of soil-engaging components: A review. *Journal of Agricultural Engineering Research*, 79, 239–263.
- REN Luquan, CONG Qian, TONG Jin and CHEN Bing-cong. (2001). Reducing adhesion of soil against loading shovel using bionic electro-osmosis method. *Journal of Terramechanics*, 38(4), 211–219.
- TANG Li-yu, WANG Qin-min, CHEN Chong-cheng. (2005). Interactive 3-D visualization of construction of geothermal field with IDL. *Proceedings of the 2005 International Geoscience and Remote Sensing Symposium (IGARSS 2005)*, Seoul, Korea, 3645–3647
- Vincent J F V, Mann D L. (2002). Systematic technology transfer from biology to engineering. *Philosophical Transactions of the Royal Society A*, 360, 159–173.
- WU Na, TONG Jin, CHEN Dong-hui, ZHANG Shu-jun, CHEN Bing-cong. (2006). Measurement of Geometrical Configuration of Dung Beetle *Copris ochus* Motschulsky Using Reverse Engineering Methods. *Transactions of the Chinese Society for Agricultural Machinery*, 37(5), 117–121. (in Chinese)
- XU Liang, LIN Min-xu, LI Jian-qiao, WANG Zhao-liang, Chirende B. (2008). Three-Dimensional Geometrical Modelling of Wild Boar Head by Reverse Engineering Technology. *Journal of Bionics Engineering*, 5(1), 85–90.
- YAN Y.Y., JI C.Y.. (2008). Molecular Dynamics Simulation of Behaviours of Non-Polar Droplets Merging and Interactions with Hydrophobic Surfaces. *Journal of Bionics Engineering*, 5(4), 271–281,
- ZHANG Yan, ZHOU Chang-hai, REN Lu-quan. (2008). Biology Coupling Characteristics of Mole Crickets' Soil-Engaging Components. *Journal of Bionics Engineering*, 5(1), 164–171.

LIST OF FIGURE CAPTIONS

- Fig. 1 Laser scanner and the earthworm
Fig. 2 Point clouds of body of the earthworm shown in CATIA
Fig. 3 Curve frame of surface of earthworm shown in CATIA
Fig. 4 Reconstructional surface of earthworm shown in CATIA
Fig. 5 Original point clouds being plotted in IDL
Fig. 6 First and second columns of original point clouds being plotted in IDL
Fig. 7 Scatter plots of the measured points in IDL
Fig. 8 Scatter plots of the surface being reconstructed in the iPlot tool of IDL