Studies on Spinning Behavior of Silkworm for Developing Robot

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Abstract

Silkworms construct cocoons that are strong and resilient structure by their masterful behavior. Knowing the essentials of their skill, we could apply them to building many types of objects. In this research we focused on the some properties of silkworm's spinneret and body position in their cocoon construction process. Silkworm's spinning process was measured by two Video camera system and then analyzed to find out some appropriate statistical models representing the behavior. Furthermore, we interested in the locus pattern of spinneret based on "8" and "S" character. We modeled this pattern to the Lemniscate's curve function, and tried to make a design of plane surface.

Introduction

Spinning and cocooning behavior of silkworm is a interesting process, not only the process of generating silk which is superior natural fiber, but also the process of building the structure made with fiber. Especially, form the view of robotics, it is interesting that silkworm build the flexible structure, like dome and flat web, etc., and spin the fibriform material with a single stroke. This research analyzes the model of silkworm spinning behavior to develop the robot which can mimic the behavior and build the artificial flexible structures. A silkworm has a typical behavioral pattern of making continuous "8"shape spinning and cocooning with fixing the rear of the body and moving the front of the body artfully. In this research, We notice the "8"shape spinning locus and model it by Lemniscate's curvilinear function. Additionally, we studied the method of representing the spinning locus on two dimensional or in three dimensional spaces freely on the base of Lemniscate's Curvilinear Function.

Fig.1. Spinning process and Cocoons

Analysis of Spinning Behavior

We marked 15 points on the silkworms body immediately before spinning cocoons by a pen, and put them in a 40mm x 40mm x 40mm box. The silkworm's behavior was videoed from two different angles, and then we reconstructed them as three dimensional data by computer. And we've developed computer software for the visualization and statistical analysis of a silkworm's behavior. We have studied modeling the silkworm spinning and cocooning behavior to resolve the behavioral trait of silkworm by collecting the data of the position of its body and the spinneret. The spinning pattern can be categorized in two major phases. The first step is scaffold building and the second is cocooning. Fig.2 show the position of the spinneret at every second at 4 different spinning stages in the 'single cocoon'. Each windows shows the positions for about 2 hours.

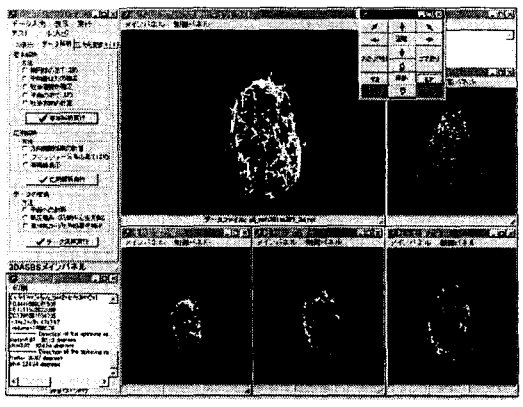

Fig.2. 3D Visualization and Analysis system

Fig.3. Spinning Locus in the process.

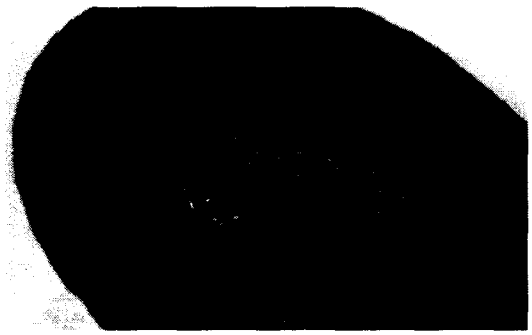

Fig.4. "8" shaped Locus on the cocoon.

Modeling the Spinning Locus

In the first step of spinning process for constructing scaffold, spinning locus doesn't make any fixed patterns. And the silkworm spins linearly on the wall and the flour mainly to framework for cocoon shell. Meanwhile, in cocooning step, spinning behavior in "8" or "S" shape is observed in forming a cocoon shell. In forming a cocoon shell, this characteristic spinning pattern makes a process that one-dimensional. One cocoon filament makes two dimensional flat surface or three dimensional oval sphere.

Fig.3 shows the typical "8" shaped silkworm spinning locus. This picture a silkworm is spinning on the acrylic board is taken from below. A silkworm, spinning in "8"shape with its front of body waving back/force and left/right, is recognized. Fig.4 shows the mark of spinning locus on the cocoon.

Lemniscate's curve is exercised as a function to model this "8" shape spinning pattern. Lemniscate's curve is inscribed as a special series of Cassinian oval as below. In this modeling, parameter function is exercised on the program constitution.

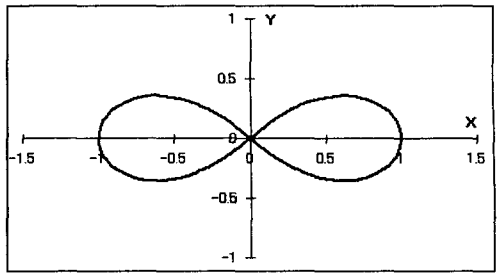

Fig.5. Lemniscate's Curvelinier Function.

$$\begin{cases} x = a \dfrac{\cos t}{1 + \sin^2 t} \\ y = b \dfrac{\sin t \cos t}{1 + \sin^2 t} \end{cases}$$

Changing the value of constant a and b, the size of Lemniscate's Curve is also changeable freely. Fig.5 shows the graph that constant a and b are 1, each other.

Development of Spinning Locus generating system

Programming the spinning locus pattern planimetrically the simulation of the movement of a silkworm spinneret in cocooning is programmed, exercising Lemniscate's Curve. Various kinds of locus can be drew by the method which moves the origin coordinates of Lemniscate's Curve. Furthermore, changing the movement speed, not only "8" shaped but also "S" shaped spinning locus can be simulated. Delphi 6, as development environment of simulation program and OpenGL, as graphics library, are exercised.

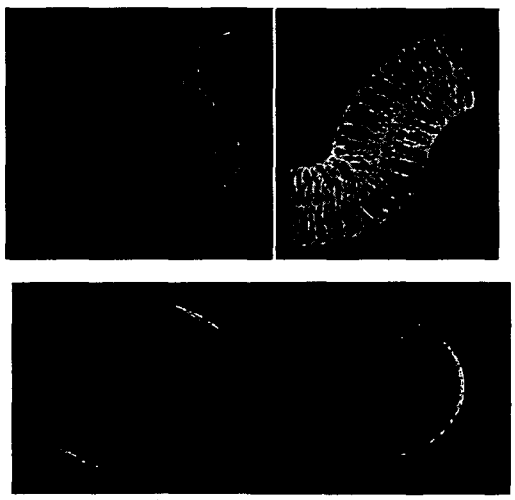

Fig.6. 2D and 3D Locus generated by the model.