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Research Article

Simulation Study of Snake-like Robot's Serpentine Locomotion Based on Recurdyn

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Abstract: The snake-like robot is composed of nine joints and the robot is proposed in this study. The serpentine locomotion mechanism of snake-like robot is studied and its moving model is established in the multi body system dynamics simulation the Software Recurdyn. The joint angle functions of serpentine locomotion are set up. We add some restrictions for model in Recurdyn and set moving functions. The simulation introduced the input of the joint angle function's influence on the winding movement of the snake-like robot. The simulation results show that the snake-like robot can complete the serpentine locomotion set before.

Keywords: Recurdyn simulation, serpentine locomotion, snake-like robot

INTRODUCTION

The snake-like robot redundancy is extremely high, with many degrees of freedom movement ability, make it imitate a variety of the biological snake movement patterns in movement, the snake-like robot has a good stability and a strong ability to adapt to the terrain in the process of marching and the snake-like robot has a wide foreground of application in many fields.

At present the developed snake-like robot has a variety of structures (Hirose, 1993; Ma and Tadokoro, 2006; Li *et al*., 2004), achieve a variety of sports models (Sun *et al*., 2008; Wang, 2004; Ye *et al*., 2009; Wu and Ma, 2010), the winding sports as biological snake is the most typical movement, which is a snake-like robot motion mode is the key issue of study. The study developed nine snake-like robot joints is the research object, the snake-like robot winding motion mechanism is studied, the multi body system dynamics is simulated by the software Recurdyn and a snake-like robot motion model is simulated, the simulation results are analyzed and illustrated.

LITERATURE REVIEW

Simplified serpentine locomotion curves: The snake-like robot serpentine locomotion is usually adopt the Serpenoid curve (Hirose, 1993) to carry on the analysis, as shown in Fig. 1.

A cycle, the Serpenoid curvature of a curve equation is:

$$\rho(s) = -\frac{2K_n\pi\alpha}{l}\sin\left(\frac{2K_n\pi}{l}s\right) \tag{1}$$

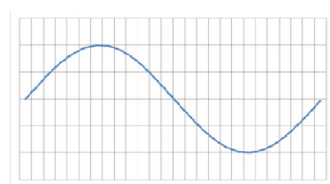

Fig. 1: Serpenoid curve

where,

- l = The total length of the snake-like robot
- K_n = The transfer wave's number of the snake-like robot
- α = Serpenoid curve for the initial corner
- s = The snake-like robot displacement along the axis direction of the Serpenoid curve

Based on the simplified Serpenoid curve (Ma and Tadokoro, 2006), the snake robot gaits generation way, arc length is defined as the curvature of the s:

$$\rho(s) = -\alpha b \sin(bs) \tag{2}$$

where,

- α = Serpenoid curve for the initial corner
- b = Constant

Type (2) on the s integral can get Serpenoid curve, which is arc length for s in tangential direction and horizontal direction angle. The Serpenoid curve approximation for length l line set, in the endless approach, two adjacent lengths l is line, the arc length is s place for angle:

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$$\varphi(s) = -2\alpha \sin(bl)\sin(bs) \tag{3}$$

Practicing a snake robot module length may be not infinitesimal, l can't approach in the endless to module actual length, to fit Serpenoid curve. It still can simulate serpentine locomotion.

The generation of winding movement gait: Modular joint length of a snake robot is 2l, when s = 0, 2l, 4l, ..., a snake robot in the modular joints for the corner:

$$\varphi(i) = -2\alpha \sin(bl)\sin(2(i-1)bl) \tag{4}$$

where, i is each joint serial number.

The relative angle of each joint is determined, which can make the snake-like robot establish static winding configuration. In the serpentine locomotion, each joint of a snake robot should be along the Serpenoid curve dynamic to move, the s valuable should be changing with sequence of time, suppos s = ct, ct + 2bl, ct + 4bl, …, A = -2αsin (bl), ω = bc, where c is constant. The corner of dynamic circumstances in the modular snake-like robot joints is:

$$\varphi_i(t) = A\sin(\omega t + (i-1)\beta) \tag{5}$$

MODELING AND SIMULATION

The model structure of a snake-like robot: A snake-like robot model as shown in Fig. 2, the structure use the modular joint design, its overall mechanical structure is become by nine the same module series, each module size: diameter of 65 mm, length of 238.5 mm. The modular joint of a snake-like robot is similar to a universal joint mechanism, with transverse longitudinal freedom of 2º direction, we can drive and control the composed of their motor and control system. Through the modular joint connection a snake body with high redundancy, can make a snake robot achieve a variety of postures and movement modes.

The simulation environment settings: The initial attitude of snake-like robot use 3 d design software to adjust the joints of paragraphs, to achieve universal joint Angle and then import Recurdyn to set parameters in the virtual simulation, as shown in Fig. 3 after the introduction of model (a). The Recurdyn simulation environment Settings are as follows: the robot joint and ground use physical Contact (Solid Contact), the parameter Settings as shown in Fig. 3b.

The constraints of the joints and universal Joint use rotating vice (Joint), serpentine bionic robot by setting movement (motion) of the rotation vice (Joint) simulate the motor to drive cases each Joint movement. The motion (motion) choose displacement mode, to set displacement time function of each rotation vice. With rotational vice displacement time function of ground level of is set to zero, in the movements of the winding, rotating vice of under horizontal don't participate in the movement. The each rotation vice displacement time function of ground vertical is set to:

(a) The whole plan

(b) The modular joint

Fig. 2: Simulation model of the snake-like robot

$$step(time, 0, 0, 5, A*\sin(\omega*(time-5)+n*\beta)) \tag{6}$$

where, n is accord to each rotation deputy position in turning to 0~8, participate in the movement of each joint rotation vice phase lag in order to produce winding motion.

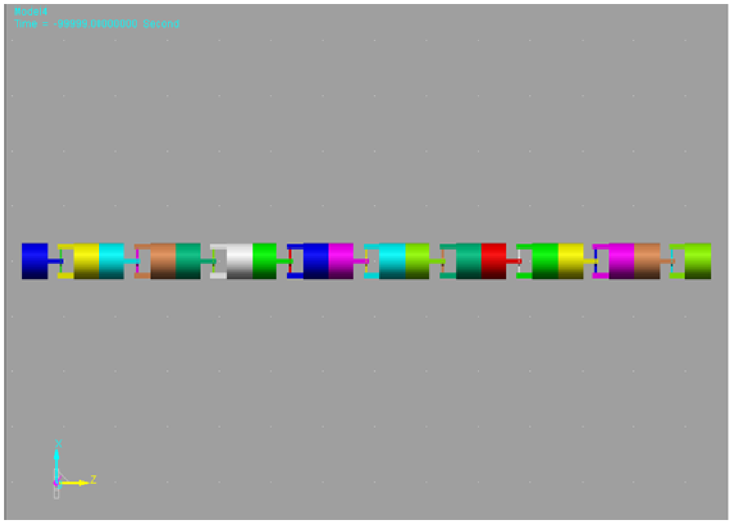
In Recurdyn, step function is 3 times polynomial approximation step function, which can be used to define a smooth step function.

The simulation: In formula (6), the parameters determine the winding curve of snake-like robot, the size of the snake-like robot body determines number of the formation wave. Setting up the simulation time is 30s, the steps is from 1000, so that motion of model is stability. The simulation includes follows situations:

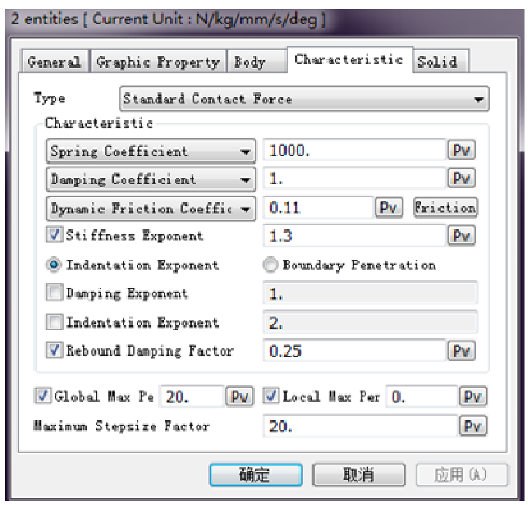
- **Maintain the value of ω and β, change the value of A:** In formula (6), suppose ω = 1, β = 0.7. Every time the simulation changes the value of A. The movement of the snake-like robot in different amplitudes is shown in Fig. 4.
  The forward speed of the snake-like robot in different amplitudes is shown in Table 1:
- **Maintain the value of A and β, change the value of ω:** In formula (6), suppose A = 1, β = 0.7. Every time the simulation changes the value of ω. The movement of the snake-like robot in different frequencies is shown in Fig. 5.

Table 1: The forward speed of the snake-like robot in different amplitudes

Amplitude/m	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
The forward speed/ (mm/s)	2	9	21	39	62	87	109	136	156



(a) The initial attitude snake-like robot



(b) A snake robot simulation model

Fig. 3: Simulation environment settings

Table 2: The forward speed of the snake-like robot in different frequencies

Frequency/Hz	0.5	1	1.5	2	2.5	3	3.5
The forward speed/ (mm/s)	52	109	169	220	249	288	339

Table 3: The forward speed of the snake-like robot in different wave numbers

Wave number	0.5	0.75	1.0	1.25	1.5	1.75	2.0
The forward speed/ (m/s)	418	249	109	35	12	7.4	5.2

The forward speed of the snake-like robot in different frequencies is shown in Table 2.

Fig. 4: The movement of the snake-like robot in different amplitudes

- **Maintain the value of A and ω, change the value of β:** In formula (6), suppose ω = 1, β = 0.7. Every

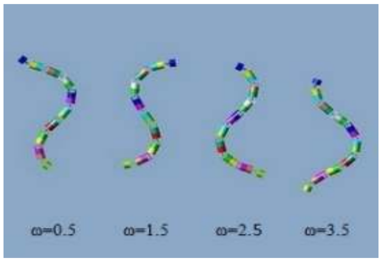


Fig. 5: The movement of the snake-like robot in different frequencies

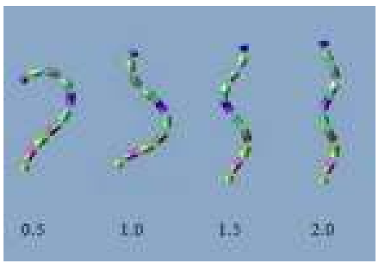


Fig. 6: The movement of the snake-like robot in different wave numbers

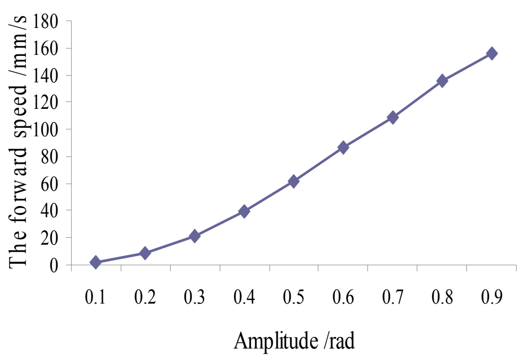
time the simulation changes the value of A. The movement of the snake-like robot in different wave numbers is shown in Fig. 6.

The forward speed of the snake-like robot in different wave numbers is shown in Table 3.

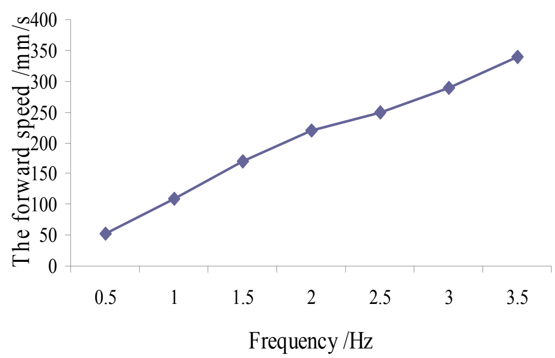
SIMULATION RESULTS

According to the simulation data draw curve is shown in Fig. 7:

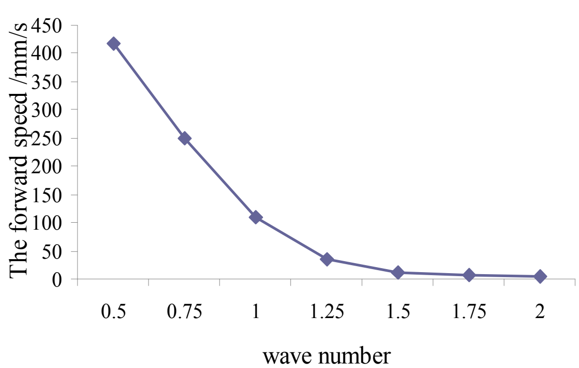
- The relationship of the forward speed and amplitude is shown in Fig. 7a, which can be seen from the graph, with the increase of amplitude, the forward speed of serpentine robot has obvious increasing, in fact, snake robot modular joint Angle function amplitude by joint, the design of the maximum Angle limit, the biggest optimal magnitude is 0.7 rad.
- The relationship of the forward speed and frequency is shown in Fig. 7b, which can be seen from the graph, with the joint Angle function



(a) Graph showing the relationship of the forward speed and amplitude



(b) Graph showing the relationship of the forward speed and frequency



(c) Graph showing the relationship of the forward speed and wave number

Fig. 7: Simulation analysis

frequency increasing, the speed of the advance has been increased, in fact, a snake robot modular joint Angle function by the frequency of the selected motor restrictions.
- The relationship of the forward speed and wave number is shown in Fig. 7c, which can be seen from the graph, with a snake robot body formation wave number increasing, the forward speed snake-like robot is more and more small, but the number of wave is too little words, which will influence the orientation of the snake-like robot, it can't form a complete Serpenoid curve.

CONCLUSION

Through the analysis and simulation can get the following conclusion:

- With the joint Angle function amplitude, frequency, the increasing of the snake-like robot serpentine locomotion forward speed is increasing. But in practice, the joint angle function amplitude by joint design of the maximum angle limits, the frequency of the joint angle function by the selection of motor limit, so through the reasonable design modular joints, choose joint machine, can enhance the snake-like robot serpentine locomotion performance.
- When a snake robot modular joint number and Serpenoid curve length, in formation wave number forming winding curve, which reduce the formation of the snake-like robot Serpenoid curve wave number, which is beneficial to improve the snake-like robot forward speed.

Proposed a snake robot in the simulation environment complete scheduled serpentine locomotion, the further prototype experiment has important guiding significance. The next step to a snake robot movement gait planning further perfect, make its trajectory smooth and more complicated for the natural environment.

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