A Novel CPG controller of robotic fish: based on body wave function

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Abstract

The biomimetic robotic fish shows great potential of surveying of resource, military reconnaissance, the monitoring of water environment and so on, so the biomimetic robotic fish is a hot issue with great challenges. Although the current CPG controller of generating sine signals can also control the movement of robotic fish, but this kind of controller needs many parameters.According to the fish body wave function proposed by Lighthill we design a new CPG controller. This controller can efficiently reduce the parameters of controlling robotic fish movement and realize the simulation of the fish body wave curve. In order to test the feasibility and effectiveness of the CPG controller. We realized the virtual reality simulation and test it in a three joints of robotic fish.

Keywords: CPG, fish body function, biomimetic robotic fish

1 Introduction

Through million years of natural selection, fish show their capacity of high efficiently swimming, disturbing environment lightly and excellent mobility and performance underwater. This ability is great for underwater robots to complete surveying of resource, military reconnaissance, the monitoring of water environment task, and attract researchers's strong interest and enthusiasm [1, 2]. In order to imitate fish special capacity of motion underwater, we need to realize the coordinated control of robotic fish motion and this is a hot and difficult issue for robotic fish research.

In recent years with the development of CPG (central pattern generator) neural network, many researchers designned CPG controllers and apply them in the various robots. CPG is a kind of bionic method, and it is a basic component of vertebrate and invertebrate motor nerve loop [3, 4]. The major feature of CPG as a kind of locomotion system is the capability of producing coordinated patterns of rhythmic activity without any rhythmic inputs from sensory feedback or high_level control signals. High_level control signals can also conduct CPG controller and CPG controller has the advantages of simple structure and strong adaptability [3, 4]. This feature is especially suitable for controlling robotic locomotion, so these have been a number of robots using CPG controllers for controlling, such as legged robots [5-7], amphibian robots [8-10] and underwater robots [11], etc.

In the literature [11] Wang proposed a kind of CPG controller based on sine wave, and this controller can effectively control the robotic fish's motions. However, the parameters are too many, so controlling fish is hard. What's more, it cannot simulate the natural fish swimming body curve well. In order to realize the simulation of the fish body wave function and simplify the control of robotic fish, we design a new CPG controller based on the fish body function proposed by Lighthill [12, 13]. The CPG controller can control the robotic fish locomotion in a straight line using just only four parameters (literature [11] needs 2N+1 variable, N is the joint number of the robotic fish). In the literature we will introduce the establishment of CPG controller through dispersing fish body wave function and test the CPG controller's feasibility and effectiveness through simulation and an actual three joints robotic fish.

2 Fish body function

In 1960s, Lighthill proposed the fish body wave function according to the study of fish swimming wave curve [12, 13]. The function as follows:

$$y_{body}(x,t)=(c_1x+c_2x^2)\sin(kx+wt)\,. \qquad (1)$$

y_{body} denotes the offset from the axis of fish body and is a function of the fish body axial position x and time t; c_1 and c_2 is the first gain and second gain of the amplitude; k is the body wave number ($k=2\pi/\lambda$, λ is the wavelength of the fish body wave). w is the fish body wave frequency ($w=2\pi f=2\pi/T$). In one moment the curve which the function presents is called fish body wave. As shown in Figure 2-1.

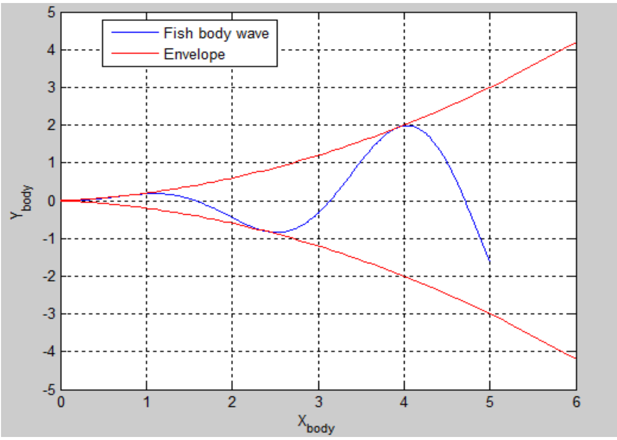

FIGURE 2-1 The diagram of fish body wave

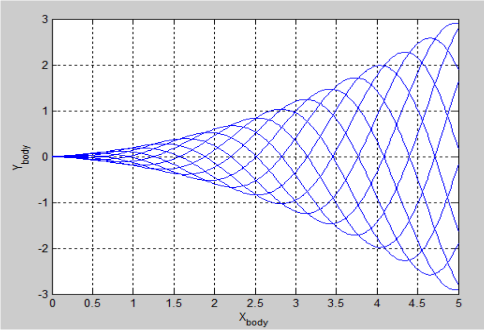

FIGURE 2-2 The diagram of discrete fish body wave

In fact, different fish swimming presents completely different shapes and the waveform they present may be only a part of overlap. For example, eel fish propagates from head to tail when swimming, but Carangidae fish is only part of the tail.basing on the different shape and size of fish, we should choose different parameters (c_1, c_2, k, w) .

In order to use biomimetic robotic fish to simulate the real wave when fish swimming presents, we need to do two things: (1) the discrete fish body wave in time; (2) fitting the fish body wave in space, that is to say, the fish body is comprised by many same length rod [14]. The more times of the discrete fish body wave in time,the more accurately control the robotic fish;The more ideal fit in space,the more accurately reflect the characteristics of fish swimming.

Supposing the robotic fish swimming locomotion is divided averagely into M equal parts in a period, then the variable of time is

$$wt_i = i * \frac{2\pi}{M}; i = 0,1..M-1.$$

The fish body function at the moment is:

$$y_{body}(x,i) = (c_1 x + c_2 x^2)\sin(kx + \frac{2\pi}{M} i). \quad (2)$$

If M=10, the discrete fish body wave present as Figure 2-2.

3 CPG controller based on fish body function

In most vertebrates even including of a part of invertebrates, controlling limbs and body to produce rhythmic motions, such as breathing, the beating of heat,swimming, is produced by CPG neural circuits.Taking into account that the fish body swing is a typical rhythmic locomotion,we can design a CPG controller to control robotic movement by the frequencies and amplitudes of fish body swing.

3.1 CPG CONTROLLER

In order to make the robotic fish body swing curve more similar to the fish body function, the common method is making the top of joints falling in the fish body wave curve, generally calling this kind of method "endpoint location method" [15]. This method is to solve the problem of finding appropriate joint angle φ_{ij} to make the end of each joint falling in the fish body wave curve, which requires each endpoint of joint satisfying the following conditions:

$$(x_{i,j} - x_{i,j-1})^2 + (y_{i,j} - y_{i,j-1})^2 = l_j^2, \quad (3)$$

$$y_{i,j} = (c_1 x_{i,j} + c_2 x_{i,j}^{\ 2})\sin\left(kx_{i,j} + \frac{2\pi}{M} i\right). \quad (4)$$

In the function, (x_{ij}, y_{ij}) denote the coordinate value of the j endpoint at the i moment, and $x_{i,0} = 0, y_{i,0} = 0;\ 1 \le j \le N;\ 1 \le i \le M-1$. N denotes the number of rods composing of the fish body. M denotes the discrete number in a period of the fish swimming action. So we use the iterative method to calculate the required rotational angle of each joint at each moment. Composing the angle list can also control the robotic fish's locomotion [15, 16]. But this method needs new angle list when we change the robotic fish locomotion,and it needs a large amount of calculation.So we design a new CPG controller in the paper which can solve the troubles.

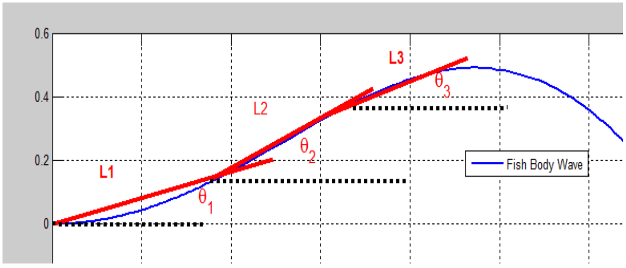

FIGURE 3-1 The diagram of joints falling in the fish body wave curve

The fish body wave function curve makes us know the fish body waveform when swimming and the Equations (3) and (4) require the robotic fish to meet the two Equations when swimming. So we design a new CPG controller to meet the requires.The i rod (i.e.oscillator) at the t moment meets the equations as following:

$$\theta_{0,i}(t) = \alpha_i\left[\alpha_i(\theta_{0,i} - \theta_{0,i}(t)) - 2\theta_{0,i}(t)\right], \quad (5)$$

$$x_i(t) = x_{i-1}(t) + L_i \cdot \cos(\theta_i(t-1)), \quad (6)$$

$$y_i(t) = (c_1 x_i(t) + c_2 x_i(t)^2)\sin(kx_i(t) + wt), \quad (7)$$

$$\theta_i(t) = \theta_{0,i}(t) + \arcsin\left(\frac{y_i(t) - y_{i-1}(t)}{L_i}\right) - \theta_{i-1}(t). \quad (8)$$

$\theta_{0,i}(t)$ denotes the offset of the i rod when time is t; $x_i(t)$ denotes the abscissa of the i rod when time is t; $y_i(t)$ denotes the ordinate of the i rod when time is t; $\theta_i(t)$ denotes the rotation angle relative to the previous joint and the first joint rotation angle is relative to the horizontal axis; $\theta_{0,i}$ denotes the offset of rotation angle set at the first beginning; L_i denotes the length of the i rod. Just as Figure 3-1 showing.

Equation (5) denotes a critically damped second order linear system, and the output $\theta_{0,i}(t)$ asymptotically and monotonically converges to the input $\theta_{0,i}$. In Equation (6) $\theta_i(t-1)$ denotes a rotation angle from the previous action, an approximate quantity, used to replace the rotation angle $\theta_i(t)$. $x_{i-1}(t)$ denotes the sum of the front (i-1) rod(oscillator) abscissa. Equation (7) is used to calculate the ordinate of the rod (i.e.oscillator) by the fish body wave function. Equation (8) is used to calculate the rotation angle of each joint to control the robotic fish locomotion. The schematic diagram of the CPG controller is just showing as Figure 3-2. c_1 and c_2 is from the fish body wave function, and they is mainly used to control the the amplitude of the oscillator. k is mainly used to control the phase difference. $\theta_{0,i}$ is the set offset used to control the direction.

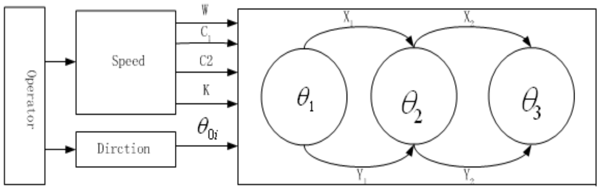

FIGURE 3-2 The diagram of locomotion control architecture

3.2 SPEED CONTROLLER

The locomotion speed of the robotic fish (only discuss swimming forwards in the section) is influenced by the frequency *w*, amplitude, phase difference and the surrounding environment.if we take all factors into account, it is very hard to control the speed. Through a lot of experiments we discovered that when the other parameters are fixed,the speed increases with the frequency *w*. When fixing the other parameters, increasing the value of C1 and C2 can make the amplitude increase and swim faster.But the two ways are restricted by the steering gear and the length of rods, and the corresponding relationship between them is nonlinear.

3.3 DIRECTION CONTROLLER

Direction controller used to control the direction of robotic fish is related to the offset $\theta_{0,j}$ of the oscillator. The different offsets of oscillators cause different direction of robotic fish swimming. We set $\theta_{0,1} = \theta_{0,2} = \theta_0$ and $\theta_{0,N} = 0$ to control the amplitudes of oscillators. θ_0 is the only variable to control the direction.Setting $\theta_{0,N} = 0$ is used to obtain enough driving force through robotic fish body swing. Now we set $\theta_0 > 0$ to control robotic fish move left, and $\theta_0 < 0$ is corresponding right.

4 Experimental tests

In order to test the effectiveness of the CPG controller based on fish body wave function, firstly we carried on the simulation experiment and then realized the CPG controller in the three joint robotic fish.

4.1 SIMULATION EXPERIMENTS

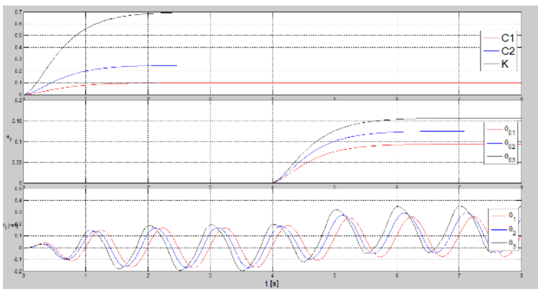

FIGURE 4-1 The waveform of output signal

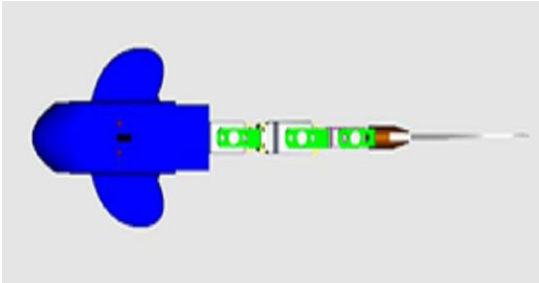
FIGURE 4-2 The three joints fish of virtual simulation

In Figure 4-1, C1 and C2 denote the coefficient of the fish body function envelope. K denotes the body wave number, that is to say, the ratio of length of the fish body swing to the length of fish body. In order to make the output signal θ_i more smooth,we use the critically damped second order linear system of Equation (7) to gradually increase to the ideal value C1, C2 and K. θ_{01}, θ_{02} and θ_{03} denote the set values of the offset angle.and also are used the critically damped second order linear system to increase to set valve. θ_i is the output rotating angle of the joint.The abscissa denotes the time t, and the unit is second. In Figure 4-1, we know the initial offset angle is zero, and the plus_minus amplitudes of the output signal θ_i are same, that is to say, the robotic fish is swimming straightly. θ_i increase from 0 to the maximum value smoothly, and that can meet the requirements of mechanics.When the time t is 4s, we set different offset angles,so the output signal θ_i increases smoothly. The enclosed area of the curve of output signal θ_i and abscissa axis is a positive value, meaning that the robotic fish swim towards a direction, which can be used to control the robotic fish direction. Virtual three joints fish can be driving by the rhythm signal generated by the CPG controller, just as Figure 4-2 showing.

4.2 ROBOTIC FISH

In this paper, the robotic fish is a three joints robotic fish made by the Intelligent Control Laboratory in Peking University. The robotic fish generates power by the tail swing, and change the amplitude and frequency of the tail swing to control the robotic fish locomotion (as shown Figure 4-3). The head and pectoral fins are streamlined to reduce the resistance of the water effectively. The tail is made up of three independent steering gear to provide the power for the robotic fish. The caudal fin is made of flexible rubber, presenting crescent.

FIGURE 4-3 Robotic fish

The robotic fish swims in a pool. There is a camera above the pool to capture the robotic fish and send data to a computer. And we can control the robotic fish by the compute sending commands to the robotic fish through the wireless. Through the experiments we corroborate that the CPG controller can effectively control the speed and direction of robotic fish swimming. Now the straight speed of the robotic fish can reach 37.8cm/s, which is 0.84 times the length of the fish body. The speed is a little slow, and next we will optimize the parameters to improve the speed of robotic fish.

FIGURE 4-4The robotic fish is swimming forward

FIGURE 4-5 The robotic fish is turning left

5 Conclusions

CPG controller basing on neural networks can generate rhythm signals to control the robotic fish locomotion.In the paper we designed a new CPG controller based on the fish body wave function to control the robotic fish locomotion.The experimental results show that this CPG controller can control the robotic fish, at the same time reduce the number of parameters and controlling becomes more simple and effective.What's more, this method can realize more simply and smoothly switching in different locomotion modes.

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