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Study and Simulation of Control Method Based Biped Robot Walking On Water

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Abstract: In this paper the control method about biped robot walking on water is mainly developed. As the complexity of the water environment, biped robot walking on water encounter many difficulties when walking such as external environment modeling, gait planning, water interference and so on. The traditional model-based exact kinematic solution method is not applied. This article studies control algorithm that combine CPG neural networks and fuzzy control. The control algorithm is used for robot process control. The nonlinear model of the robot is got from electro-mechanical system co-simulation. In order to verify the validity of the algorithm, biped robot control system is established. Simulation results show that the algorithm can meet the control requirements of walking biped robot biped robot walking on water.

Key Words: Biped robot; walking on water; CPG (Central Pattern Generator) neural network; CPG-fuzzy control; co-simulation

1 Introduction

The basilisk lizard is an animal that lives in tropical rainforest. This lizard is famous for its amazing ability to run on water. In this paper, we introduce a novel biped robot which can run on the surface of water in a manner similar to basilisk lizards. The ultimate aim of this study is to develop a kind of amphibious biped robot. The biped robot can play an important role in military investigation, water quality testing, wetland detection and flood relief.

Existing walking research about biped robot focuses on the terrestrial environment. In order to maintain the balance of robot, compensatory control based on ZMP (Zero Moment Point) and other criteria is developed. This method need to establish a precise mathematical model about the robot body and the environment. It also requires appropriate path planning. The traditional model-based motion control method has some drawbacks, for example, complicated dynamics modeling, motion planning complexity, low environmental adaptability, poor robustness and so on. Biped robot walking on water and ground-based biped robot are very different. The ground-based biped robot is mainly to maintain its balance during walking. The water walking robot must maintain dynamic balance during walking and avoid sinking into the water. Biped robot walking on water has many difficulties in external environment modeling and motion planning effectiveness. The precise kinematics method is invalid.

The CPG-based motion control algorithm is a kind of intelligent control algorithms. CPG can spontaneously generate stable rhythmic movement without high-level control signals and external feedback. It doesn't require environment model. CPG can also reduce the workload of control systems and save working time. By adjusting the composition of CPG network connections and the internal parameters of each neuron, The CPG network can produce a series of signals with stable phase relationship. Since 1972, the fuzzy control has been great progress. Fuzzy control is easy to construct and it has a strong robustness.

In this paper, we use CPG neural networks and fuzzy control algorithm. The combination of these two algorithms is introduced to our biped robot walking on water control system.

Fig. 1: The basilisk lizard

2 Kinematic analysis on biped robot walking on water

Through analysis of basilisk lizard body structure and movement, the eventual bipedal walking robot virtual prototype model shown in Figure 2.

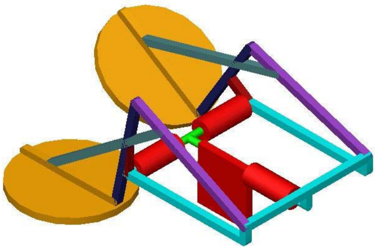

Fig. 2: The virtual prototype of biped water running robot

A robot's water running stride can be divided into three phases: slap, stroke and recovery. The lift from the slap

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phase is limited. Most of the lift comes from the stroke phase. During the stroke phase the force of robot's feet from water is:

$$F(t) = C[0.5S\rho \cdot v^2 + S\rho \cdot gh(t)]^{[1]} \qquad (1)$$

where $F(t)$ is the time varying drag force, $C \approx 0.703$ is the constant drag coefficient, S is the effective area over which drag is occurring, ρ is the density of water, v is the velocity of the foot, $h(t)$ is the time varying depth of the foot, and g is the acceleration due to gravity. The drag force according to formula (1) is shown in Fig. 3.

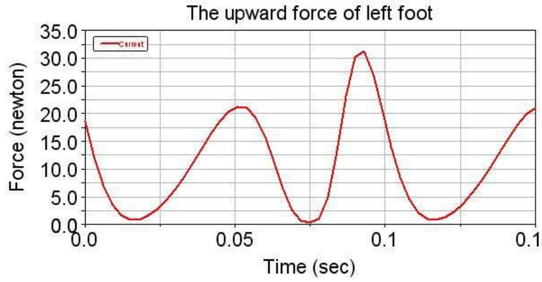

Fig. 3-a: The upward force of left foot

Fig. 3-b: The upward force of right foot

The upward force in the stroke phase is enough for biped robot to keep on the water.

3 CPG-fuzzy control on biped robot walking on water

When the robot is walking in water, we can keep the balance of the robot by regulating the plate on robot's body. The biped robot walking on water is controlled by CPG-fuzzy. The control block diagram is presented in Fig.4.

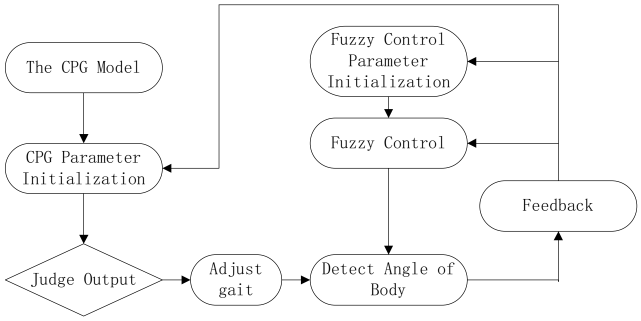

Fig. 4: CPG-Fuzzy control block diagram

If the CPG model output is high, then the robot's foot is in the slap and stroke phase. Likewise, if the CPG model output is low, then the robot's foot is in the recovery phase. We need to make real-time detection of the angle θ . Where θ is shown in Fig.5.

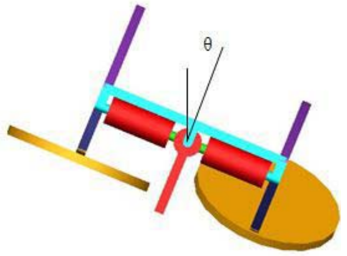

Fig.5: Rear view of the robot

The angle θ is used for fuzzy control. By fuzzy control, we can compensate biped robot's movement. Fig.6 is the CPG-Fuzzy control system of robot.

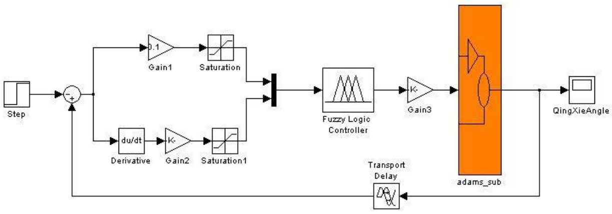

Fig. 6: CPG-Fuzzy control system of robot

3.1 The CPG model of biped robot walking on water

CPG neural network considers the coordination of each joint under different objectives and environmental. This method has a good adaptability and stability. How to select the appropriate mathematical model describing the neurons in the CPG neural network is important.

Japanese scholar Matsuoka put forward a neural oscillator model, which well expressed inhibition between neurons. By changing network structures and weights among neurons, we can produce a set of signals with different phases. Righetti and Ijspeert from Switzerland made use of the Hopf oscillator to establish CPG neurons. This model is relatively simple. We can easily control the amplitude and frequency of oscillator output signal. In addition, there are many other mathematical models. This article chooses Hopf oscillator as the mathematical model, Hopf oscillator mathematical equations are as follows:

$$x_i^{'} = (\mu_i - \gamma_i^2)x_i + \omega y_i + \sum_{j=1, j \neq i}^{n} a_j x_j \qquad (2.1)$$

$$y_i^{'} = (\mu_i - \gamma_i^2)y_i - \omega x_i \qquad (2.2)$$

$$x_{i+1}^{'} = (u_{i+1} - \gamma_{i+1}^2)x_{i+1} + \omega y_{i+1} + \sum_{j=1, j \neq i+1} a_j x_j \qquad (2.3)$$

$$y_{i+1}^{'} = (\mu_{i+1} - \gamma_{i+1}^2)y_{i+1} - \omega x_{i+1} \qquad (2.4)$$

where $\gamma_i = \sqrt{x_i^2 + y_i^2}$, $\gamma_{i+1} = \sqrt{x_{i+1}^2 + y_{i+1}^2}$, a_j is the weights among neurons, x_i and x_{i+1} are the oscillator output signals, μ_i affects the $\mathrm{i_{th}}$ oscillator output signal amplitude, μ_{i+1} affects the $\mathrm{(i+1)_{th}}$ oscillator output signal amplitude, ω determines the frequency of the oscillator, y_i , y_{i+1} is the oscillator's internal variables.

Fig. 7 is the Hopf oscillator model.

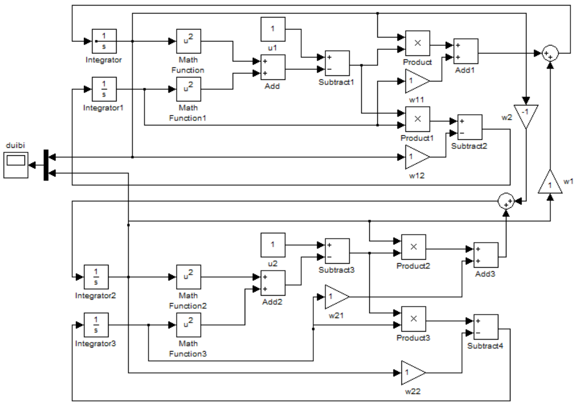

Fig.7: Hopf oscillator model

After the slap phase and the stroke phase, there is an air cavity in the water. The recovery stage must finish before the closure of the cavity. The time that the cavity is open is as followers:

$$T = 2.285\left({r_{ef}}/{g}\right)^{0.5[1]} \qquad (3)$$

where T represents the time that the cavity is open, r_{ef} is the effective radius of the foot, g is the acceleration due to gravity. When the effective radius of the foot r_{ef} is $20mm$, T is $0.103s$. The frequency of the foot is $10Hz$. The oscillator output shown in Fig.8.

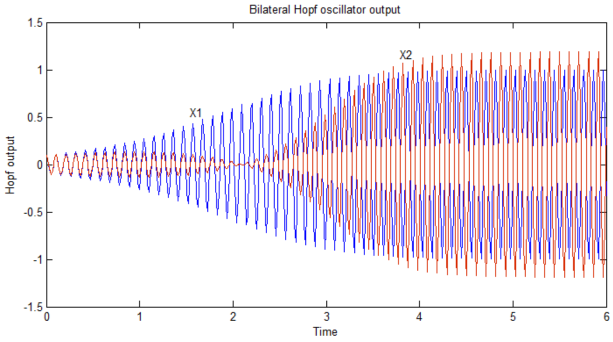

Fig. 8: 10HZ oscillator output

The phases between two output signals are opposite. After about four seconds, the oscillator generates two stable output signals. Fig.9 is the output with a comparator.

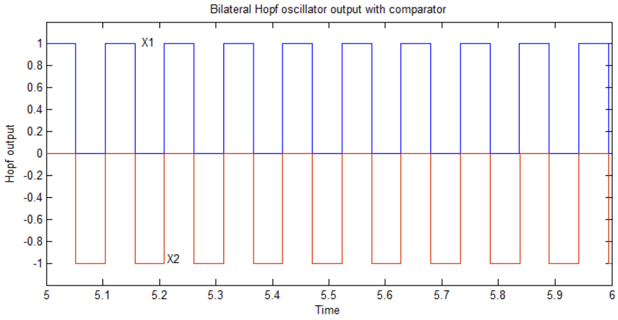

Fig. 9: 10HZ oscillator output with a comparator

Fig.9 shows that the Hopf oscillator can be used in biped robot walking on water. By adjusting the internal parameters ork, we can get a set of signals with different phases.

3.2 The CPG-Fuzzy control of biped robot walking on water

Most of the object model is a complex nonlinear model. In this paper, we use mechanical and electrical systems co-simulation. This approach helps us to build a nonlinear model of the biped robot walking on water. We mainly consider the robot's movement balance control in the horizontal plane. θ and $d\theta$ are the input linguistic variables of fuzzy control. θ and $d\theta$ are replaced by E and EC in our fuzzy control system. U is the output linguistic variables of fuzzy control. Definitions of membership functions are shown in Fig. 10.

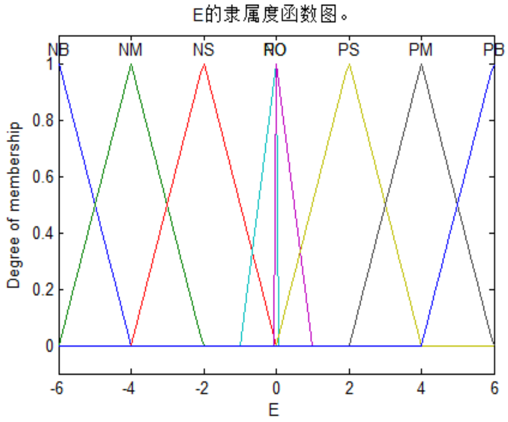

Fig. 10-a: Definition of error membership functions

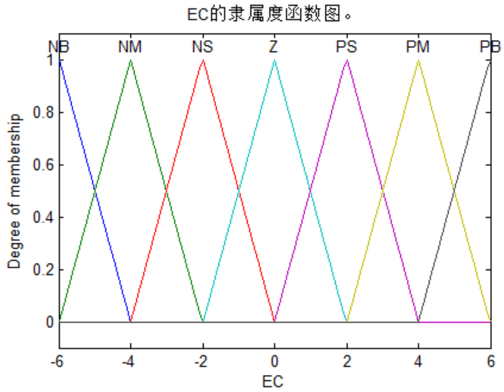

Fig. 10-b: Definition of error rate membership functions

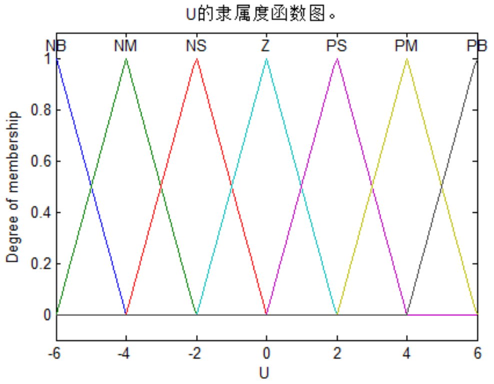

Fig.10-c: Definition of output membership functions

The CPG-fuzzy control system simulation result is as follows:

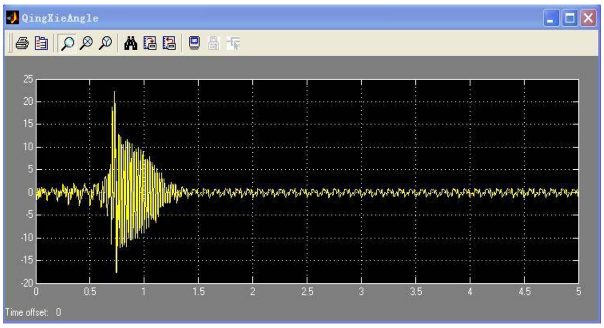

Fig. 11: The CPG-fuzzy control system simulation result

$t \approx 0.6s$, the concussion of biped robot walking on water intensified. $t \approx 0.7s$, the angle θ in the horizontal plane reaches its maximum. The maximum is 20° . Subsequently the concussion reduced. $t \approx 1.3s$, dynamic balance established.

4 Conclusion

By mechanical and electrical systems co-simulation, we get the nonlinear model of the biped robot walking on water. In order to achieve walking on water, CPG-Fuzzy control is introduced in this paper. Simulation results show that the algorithm can meet the control requirements of walking biped robot biped robot walking on water.

References

[1] Steven Floyd, Terence Keegan, John Palmisano and Metin Sitti. A Novel Water Running Robot Inspired by Basilisk Lizards[C]// International Conference on Intelligent Robots and Systems, 2006.

[2] Linsen Xu, Bing Li, Feng Xu, etc. Optimization Synthesis on Water Running Mechanism of Biped Robot[J].Advanced Materials Research, 2011, Vols.212, pp: 454-459.

[3] Jimmy or Institute of Human Performance Research Laboratories. A hybrid CPG-ZMP control system for stable walking of a simulated flexible spine humanoid robot[J]. Neural Networks, 2010, 23, 452-460.

[4] Xu Linsen, Zhao Jianghai, Li Bin, Xu Feng, Yu Shulin. Designing and Kinematics Analysis on Running Mechanism of Biped Robot for Water-Running[C]// Proceedings of 2011 3rd International conference on Mechanical and Electronics Engineering, vol.1, pp: 1-5.

[5] [5] J.Bush and D.Hu. Walking on Water: Biolocomotion at the Interface[J]. Annu. Rev. of Fluid Mech, 2006, 38, pp;339-369.

[6] [6] J. Glasheen and T. McMahon. A hydrodynamic model of locomotion in the Basilisk Lizard[J]. Nature, 1996, 380, pp:340-342