Effect of Entrainment Phenomena to Intimacy of Firefly Robots

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Abstract: When nonlinear self-oscillatory system is coupled, synchronization phenomenon called "entrainment" occurs. Usage of the entrainment phenomena is very efficient for intimate interaction between human and agent. In this study, a firefly robot inspired by synchronized flashing of fireflies was designed. The firefly robot has the blinker light which is controlled by van der Pol equation and synchronizes with the other firefly's blinker light each other by their entrainment phenomenon. To investigate intimate effect of the entrainment phenomenon, pulse wave was recorded during the subject watch the firefly robots and subjective evaluation was done by the subject after all trials. As the result, the robots has intimate effect by applying synchronization such as the entrainment phenomenon by coupling of nonlinear oscillators.

1 Introduction

It has been known that swarm of fireflies in Southeast Asia shows synchronous flashing around a tree [1]. The people who look the synchronous flashing of a huge swarm of fireflies are amazed at the scene and are drawn into its coordinated mood. Also we often see that huge ovation after good performance in concert hall quite suddenly turns into synchronized clapping [2]. These synchronization phenomena attract attention to the progress of synchronization and induce feelings of unity and comfortable harmony among the people who experience the phenomenon. Even in our body, for example, the brain, the neuron and the hart, we can find self-organization of rhythmic activity, which is one of the most important characteristic of biological systems. Generally, in the field of nonlinear dynamics, mechanisms of the synchronization and the self-organization have been explained as an entrainment phenomenon of nonlinear oscillations [3], [4]. When we couple the nonlinear oscillators each other, even though these natural frequencies are different each other, they gradually synchronize with shifting their own frequency from their original natural frequency. Brainwaves have also been shown to synchronize with external stimuli [5]. Therefore, synchronization processes in entrainment phenomena can affect people's psychological states. Especially, since the flashing of fireflies have sweet mood, synchronous flashing of fireflies have the potential to relax the people who look at it.

There have been many studies to simulate characteristics of synchronous flashing of fireflies. The authors paid attention to the nature of distributed autonomous systems and discussed an issue of self-organizing behavior [6], [7]. Hence we thought such firefly like robots would have highly intimacy using the entrainment phenomenon. It is thought that usage of the entrainment phenomena is very efficient for intimate interaction between human and agent. Therefore, in this study, a firefly robot inspired by synchronized flashing of fireflies was designed. We developed a trial model of the robots imitating a firefly. The firefly robot has the blinker light which is controlled by van der Pol equation and synchronizes with the other firefly's blinker light each other by their entrainment phenomenon. To evaluate intimate effect of the entrainment phenomenon, pulse wave of subject was recorded during the subject watch the firefly robots and subjective evaluation was done by the subject after all trials.

2 Proposed System

We got an idea of this robot based beauty of synchronous flashing of swarming fireflies and immersive feeling like people are attracted to the beauty. Fig. 1 shows the firefly robot. It has the blinker light which is controlled by van der Pol equation and synchronizes with the other firefly's blinker light each other by their entrainment phenomenon. The robot is used on a wall as shown in Fig. 2.

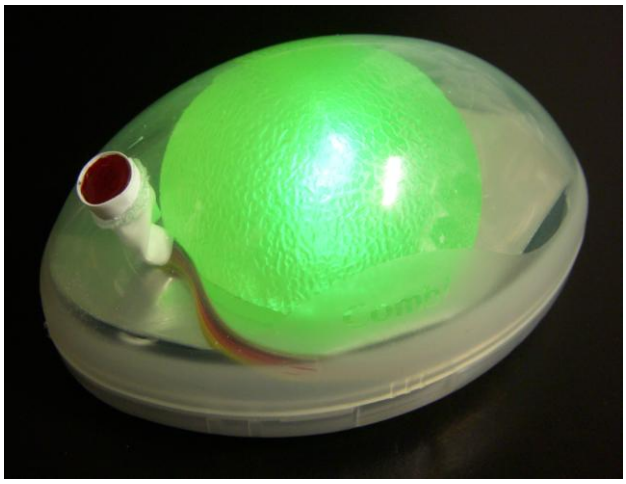

Fig. 1 Firefly Robot

Fig. 2 Firefly robot set on a wall

2.1 Architecture of firefly robot

The robot has domical shaped translucent case like exoskeleton of insects. Inside of the case, there is a LED covered with hemispherical silicone rubber as a light diffuser to express soft light like firefly luminescence. For the silicone rubber, green was selected as the impression of firefly luminescence.

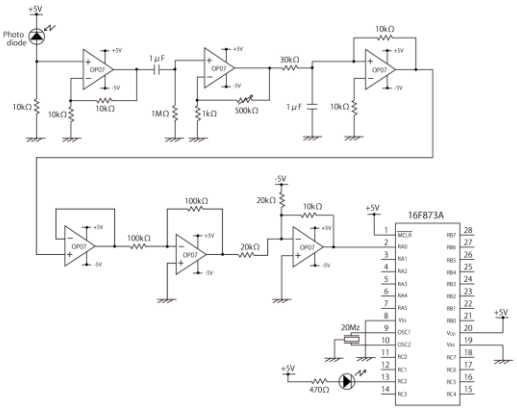

Fig. 3 Diagram of electro circuit in the firefly robot

For controlling light intensity of LED in the robot, PIC microcomputer (Microchip, 16F873A) was employed as shown in Fig. 3.

2.2 Synchronisation model

For the synchronous flashing of firefly robots, nonlinear oscillator was embedded into the microcomputer. We considered the synchronous flashing between two fireflies as coupled two pendulums driven by van der Pol equation as shown in Fig. 4.

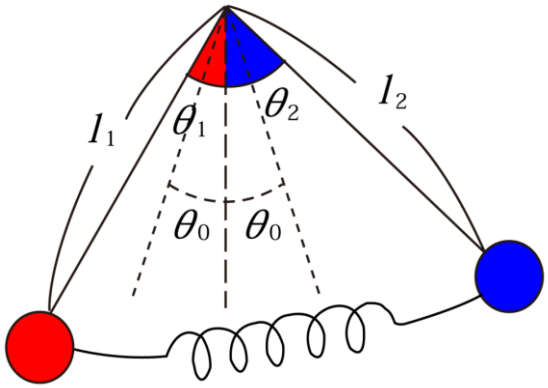

Fig. 4 Coupled two pendurums as model of the synchronous flashing between two fireflies

For example, in the case of coupling of only two pendulum, the model is wrote down as following equations.

$$\frac{d^2\theta_1}{dt^2} = -\frac{g}{l_1}sin\theta_1 - \varepsilon\frac{d\theta_1}{dt}(\theta_1^2 - \theta_0^2) - k(\theta_1 - \theta_2) \quad (1)$$

$$\frac{d^2\theta_2}{dt^2} = -\frac{g}{l_2}sin\theta_2 - \varepsilon\frac{d\theta_2}{dt}(\theta_2^2 - \theta_0^2) - k(\theta_2 - \theta_1) \quad (2)$$

where g is gravity acceleration, l_1, l_2 are length of pendurum, θ_1, θ_2 are angle of pendurum, θ_0 is the angle that restoring force is replaced with compelling force of the pendulum and ε, k are appropriate constant.

We implemented equation (1) in the robot by 4th order Runge-Kutta method. θ_1 and θ_2 are assigned to intensity of flashing light of the robott and other robot's light intensity detected by photo diode.

2.3 Behavior of actual firefly robots

We mede firefly robot actually. We examine the

synchronization phenomenon using two firefly robots. Fig. 5 shows the results under the condition $\theta_0 = 15$, $\theta_1 = 20^\circ$, $\theta_2 = 30^\circ$, $l_1 = l_2 = 0.15$ (aproximately 1.46 Hz), $\varepsilon = 2$ and $k = 20$. Fig. 5(a) shows the result of numerical simulation. Fig. 5(b) shows the result of synchronization between two actual firefly robots. Both of them, two oscillators synchronized finally, even thogh each initial angle was defferent.

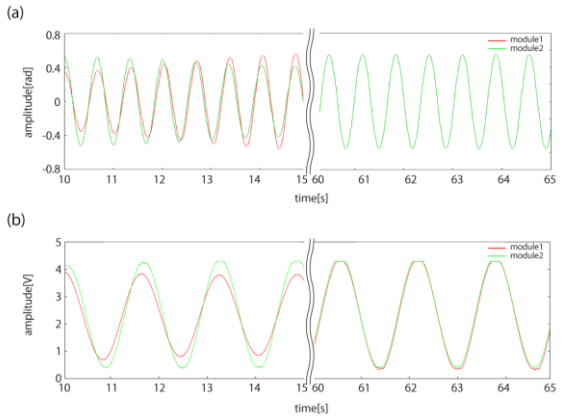

Fig. 5 Results under the condition $\theta_0 = 15$, $\theta_1 = 20^\circ$, $\theta_2 = 30^\circ$, $l_1 = l_2 = 0.15$ (aproximately 1.46 Hz), $\varepsilon = 2$ and $k = 20$. (a) numerical simulation. (b) synchronization between two actual firefly robots.

On the other hand, Fig. 6 shows the result under the condition $\theta_0 = 15$, $\theta_1 = 20^\circ$, $\theta_2 = 30^\circ$, $l_1 = l_2 = 0.15$, $\varepsilon = 2$ and $k = 1$. Fig. 6(a) shows the result of numerical simulation. Fig. 6(b) shows the result of synchronization between two actual firefly robots. Under this condition, reversed phase synchronization occurred.

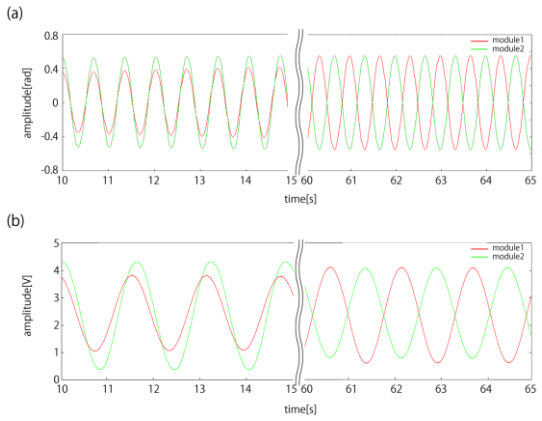

Fig. 6 Results under the condition $\theta_0 = 15$, $\theta_1 = 20^\circ$, $\theta_2 = 30^\circ$, $l_1 = l_2 = 0.15$ (aproximately 1.46 Hz), $\varepsilon = 2$ and $k = 1$. (a) numerical simulation. (b) synchronization between two actual firefly robots.

3 Experiment

To evaluate intimacy of the robot, we made experiment for evaruation.

Ten firefly robots are randamly dispersed on the wall every 30 cm in a dark room (270cm×180cm×180cm). Healthy 22-24 years old students consisting of two men and three women were selected as the subjects. They were instructed to enter the room and to stare these blinking LEDs without body movement in a comfortable position on a chair. Subjects experienced three demonstrations, single sign wave mode, double sign wave mode and van der Pol oscillator mode. With the single sign wave mode, all robots blinked as same sinusoidal wave. With the double sign wave mode, each half of robots blinked as same sinusoidal wave. With the van der Pol oscillator mode, all robots blinked as individual vander Pol oscillator.

Finally, following two kinds of evaluation were made.

3.1 Evaluation of sympathetic nervous system

It is known that activity of sympathetic nervous system is estimated with fluctuation of pulse wave. First, time series of R-R intervals of pulse wave are calcurated. Then, by FFT of the time series, power of high-frequency component (HF) and power of low-frequency component (LF) are calculated respectively. LF/(LF+HF) is usualy used as the index of activity of sympathetic nervous system.

While a subject see the robots, his/her pulse wave was detected from an ear sensor (Senoh). It has a photo diode to sense intensity of infrared light and infrared LED. They are opposed each other and are coupled by a clip like structure to pinch an ear lobe. The sensor can detect the pulsation of blood noninvasively by converting the intensity of transmitted infrared light through the ear lobe depending on the hemoglobin content of the blood into electrical signal.

3.2 Subjective evaluation

Subjects made subjective evaluation about intimacy by answering a questionnair after all trials. Subjects were asked a question which mode the subject liked most and which mode the subject calmed most.

4 Result and Disscuttion

Fig. 8 shows LF/(LF+HF) as an index of activity of sympathetic nervous system under the each condition.

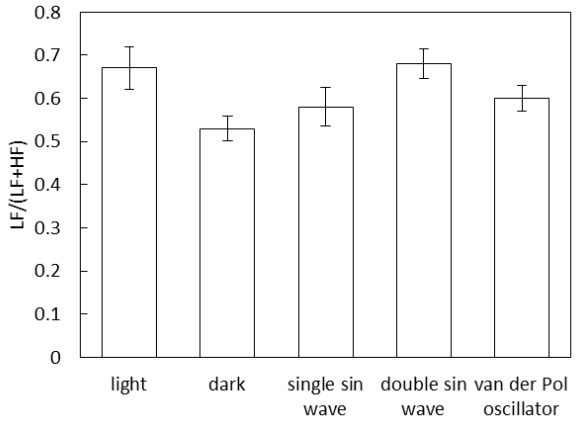

Fig. 8 LF/(LF+HF) as an index of activity of sympathetic nervous system under the each condition.

The activity of sympathetic nervous system is active under conflict situation. The smaller the index is, the more intimate with the robots. The index became the minimum in dark room. In three modes demonstrated here, van der Pol oscillator mode was relatively small along with single sine wave mode. It could be said that subjects were relatively relaxed and felt intimacy.

Fig. 9 shows the result of the questionnaire. Numbers of the voting “most favorable” and “most calm” were displayed.

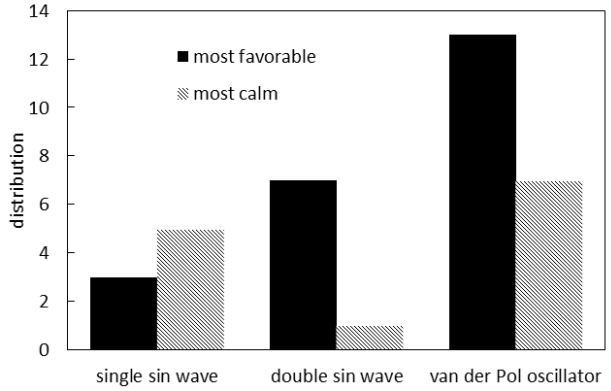

Fig. 9 Result of the questionnaire

For both “most favorable” and “most calm”, many subjects voted van der Pol oscillator mode.

From these results, it can be said that synchronization of coupled nonlinear oscillators is sufficiently effective for intimate interaction between human and agents.

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