Computer simulation of synchronous flashing of fireflies considering effect of random walk and dependence on interaction distance

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Introduction

Synchronous flashing of fireflies

- In Southeast Asia, fireflies flock in one tree and flash light in the same period all together.
- Complex emission patterns like a spiral and a propagating wave have been confirmed(1)

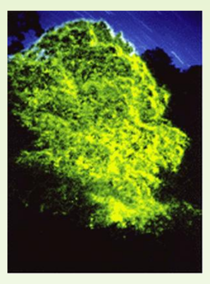


Figure 1 Firefly tree

http://www.mech.usp.ac.jp/~hnw/theme/bunnya_2007/hikikomi_hotal.htm

(1)[Symphony of Light tropical forest] 1st March 2004 NHK [Earth! Mysterious nature] Broadcasted by TV

Synchronization

- Repeat of the same process is called rhythm phenomenon, and entrainment that occurs between the rhythm and the rhythm is defined as SYNCHRONIZATION.
- Coherent phenomenon among individual oscillators occurs when more than two interacting oscillators couple.

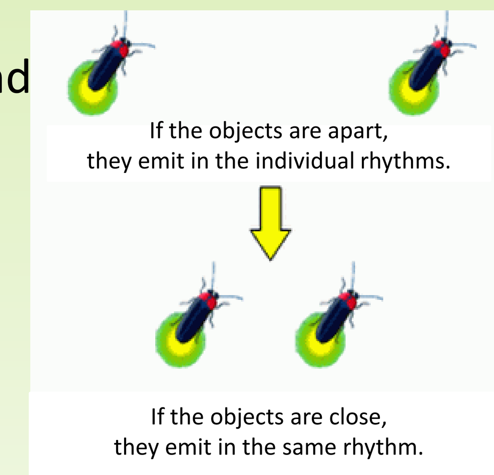
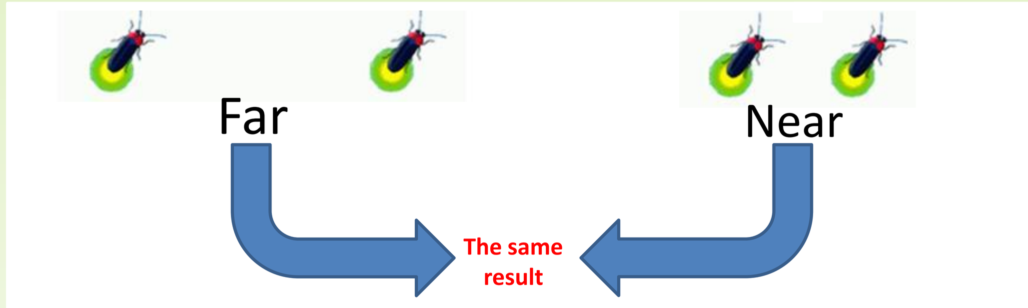


Figure 2 Synchronization

http://www.mech.usp.ac.jp/

Problems in Kuramoto model

- As conventional Kuramoto model ignores the distance effect, some problems occur.



- Using this model, emission patterns, such as a spiral and a propagating wave, can not be explained.

Purpose

To elucidate the mechanism for synchronous flashing of fireflies

1. To obtain information about the emission patterns, by introducing the coupling strength dependent on the distance into Kuramoto model
2. To consider the effect when the random walk is added to the model

Model of synchronization

Kuramoto model(2)

$$\frac{d\varphi_i}{dt} = \omega_i + \frac{K}{N}\sum_{j=1}^{N}\sin(\varphi_j - \varphi_i)$$

ω_i and φ_i are the natural frequency and the phase of the i-th oscillator, respectively.

New model

$$\frac{d\varphi_i}{dt} = \omega_i + \frac{K}{M}\sum_{j=1}^{N}\alpha_j \cdot \sin(\varphi_j - \varphi_i)$$

$$M = \sum_{j=1}^{N}\alpha_j$$

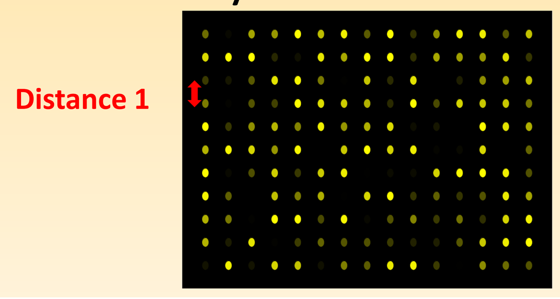
$\alpha_j = 1$ (if the distance between i and j is less than or equal to D)
$\alpha_j = 0$ (if the distance between i and j is longer than D)

D: Interacting distance

(2) Kuramoto Yoshiki (2007) About the so-called "Kuramoto model" 17(2), 175-177

Simulation Step 1

- Population of fireflies is 165 (11 × 15)
- Each individual which is given each specific frequency (1 ~ 1.25Hz)
- Initial state : Random phase (0 ~ 2π)
  Grid-like position
- Motion of firefly : Fixed and random walk

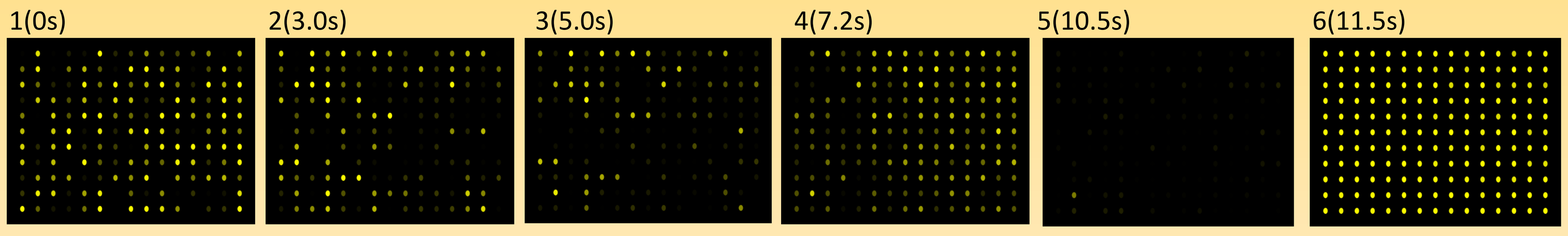


Simulation Step 1

Appearance of the synchronization

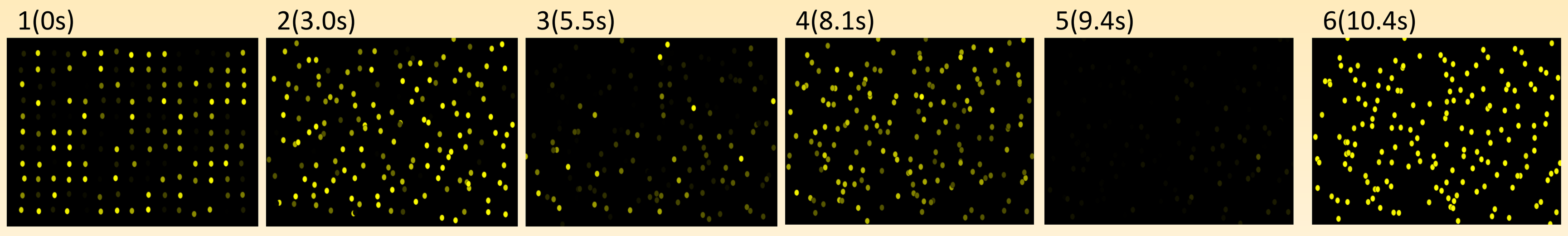
Fixed

1(0s) 2(3.0s) 3(5.0s) 4(7.2s) 5(10.5s) 6(11.5s)



Random walk

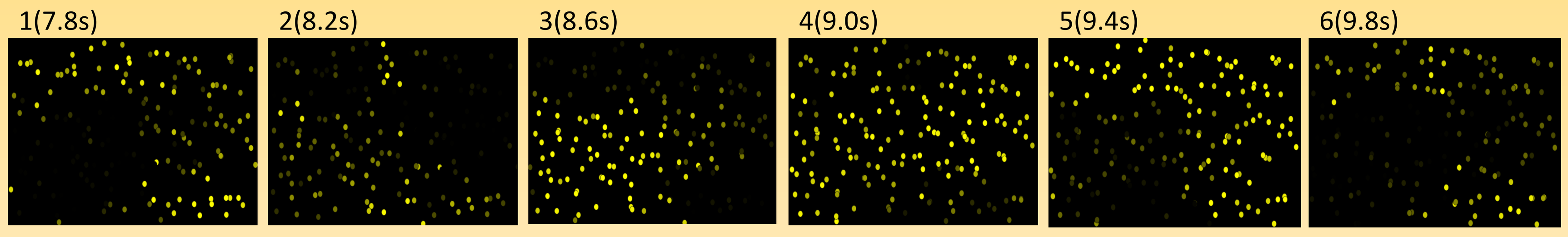
1(0s) 2(3.0s) 3(5.5s) 4(8.1s) 5(9.4s) 6(10.4s)



Spiral and Propagating wave (random walk)

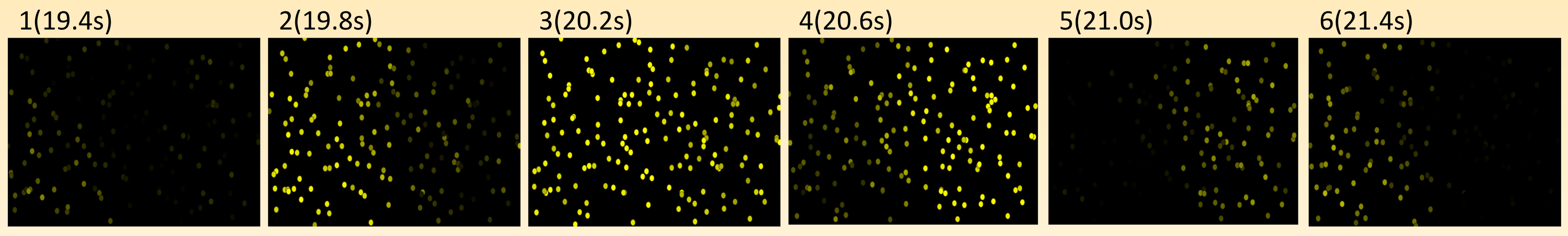
Spiral

1(7.8s) 2(8.2s) 3(8.6s) 4(9.0s) 5(9.4s) 6(9.8s)



Propagating wave

1(19.4s) 2(19.8s) 3(20.2s) 4(20.6s) 5(21.0s) 6(21.4s)



Result 1

Process up to the synchronous state (Fixed and Random walk)

Figure 3 Standard deviation versus time when D=5 (Fixed)

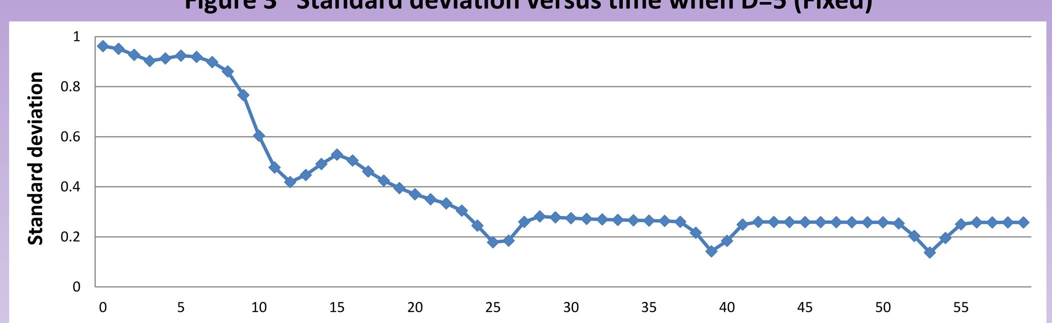
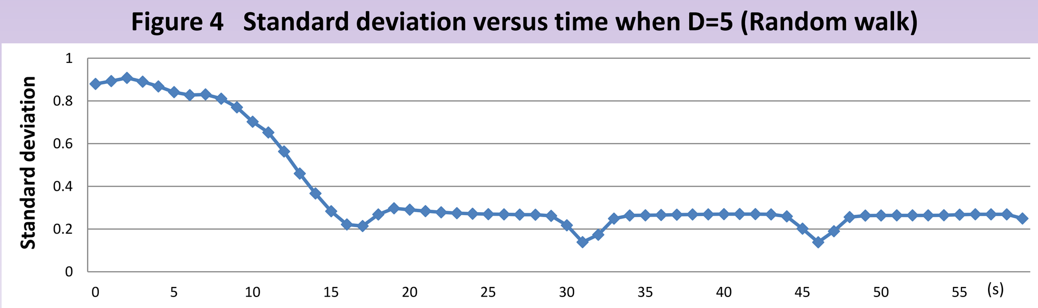


Figure 4 Standard deviation versus time when D=5 (Random walk)



Random walk effect in the process of synchronization

A statistical result (standard deviation <0.4) for time up to synchronous state

Distance of interaction	Degree of Difference
Short(D=2)	Significant difference (p=0.02)
Middle(D=5)	Some difference (p=0.66)
Long(D=8)	no difference (p=0.97)

Simulation Step 2

- Population of fireflies 165 (11 × 15)
- All individuals which are given one specific frequency (1Hz)
- Initial state : Random phase (0 ~ 2π)
  Grid-like position
- Motion of firefly : Fixed and Random walk
- Definition of the degree of synchronization

$$\sigma \exp(i\theta) = N^{-1}\sum_{j=1}^{N}\exp(i\varphi_j)$$

Result 2

Process up to the synchronous state 2 (Fixed and Random walk)

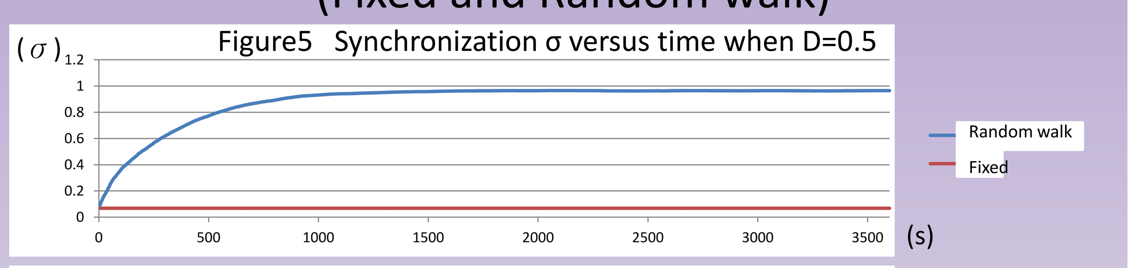


Figure5 Synchronization σ versus time when D=0.5

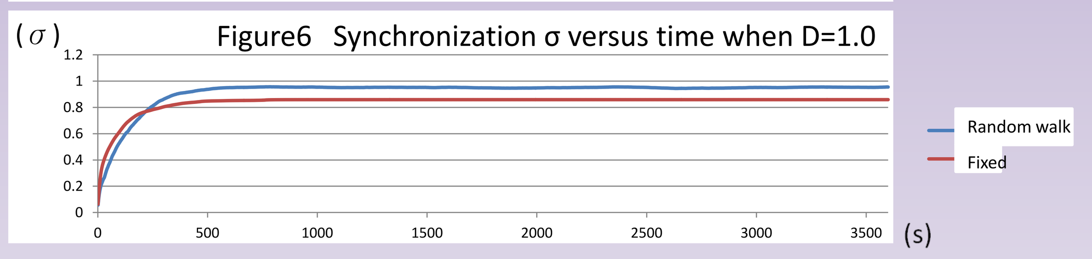


Figure6 Synchronization σ versus time when D=1.0

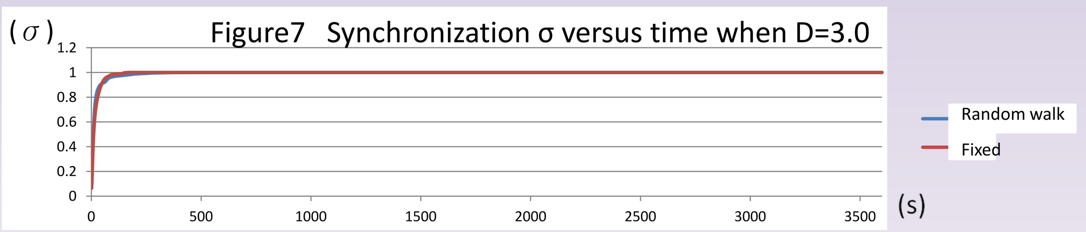


Figure7 Synchronization σ versus time when D=3.0

Discussion

- When D = 0.5, the effect of the random walk is clearly seen.
- As the interaction distance is smaller, more significant difference between the fixed condition and the random walk was shown.
- While it takes a longer time up to the synchronous state if the random walk is used, high reliability could be observed.

Summary

1. Complex emission patterns like a spiral or a propagating wave were obtained by introducing the coupling strength dependent on the distance into the model.
2. Significant difference was observed in the synchronization process by the addition of the random walk

Future tasks

1. Study of a movement different from a random walk
2. Investigation for the effects of a spiral or a propagating wave in the synchronization process