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

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Synchronization is a universal nonlinear phenomenon. Such synchronization is also observed in the flashing of fireflies inhabiting in the mangrove area of the Southeast Asia. The oscillations for the emitting lights of the individual fireflies synchronize when they flock in one tree. It is a very intriguing phenomenon, however, the mechanism is still unclear.

In this study, to clarify the mechanism of the synchronous oscillation of the fireflies, we developed a new model, based on the "Kuramoto model [1]" describing the phase synchronization of the rhythm of nonlinear oscillators. In our model, dependence on the distance of the phase entrainment between the oscillators doing the random walk is added, which is not considered by Kuramoto model. If the fireflies are located within the specific interaction distance, they entrain their phases of the oscillating flashing each other. On the other hand, if the fireflies are far beyond the specific interaction distance, they do not entrain their phases. The simulation condition realizes the situation where the fireflies flock in one tree and move randomly there. As a result of our computer simulation, we have reproduced the collective synchronous emission behavior of the fireflies. Especially, in the intermediate range of the interaction distance, we observed the spiral and propagating waves during the transient state to the collective synchronous condition. In reality, it was reported that the spiral and propagating waves emerge in the synchronous flashing of the fireflies swarming in one tree.

The result showed the clear difference in the order parameter of the synchronization r between the conditions when the fireflies are fixed in evenly assigned positions and when the fireflies are doing the random walk, especially, if the interaction distance is shorter than the average distance between the neighboring fireflies. In this condition, if the fireflies are fixed in evenly assigned positions, they do not synchronize forever and r is always zero. On the other hands, if the fireflies are doing random walk, they definitely show the entire synchronization and r finally reaches 1, although it takes long time. It indicates that random walk have the reliable effect to the goal [2]. The other systems also might utilize such an effect of the random walk or noise, for example, the development of typhoon. Typhoon expands, unifying the multiple typhoons as time passes. It is a kind of collective synchronizations. By adding the attractive force in the close range and the repulsive force in the long range into the present model, we would like to discuss analogy from collective synchronous emission of the fireflies into the development of the typhoons.

1. Hidetsugu Sakaguchi and Yoshiki Kuramoto, *Prog. Theor. Phys.*, **76**, 576 (1986).
2. Shun Takemoto, Yuko Nagamine, Hidetoshi Miike and Atsushi Osa, *Effect of random walk and dependence on coupling length for synchronous flashing of fireflies in computer simulation* (Poster presentation No.9), in Spatio-temporal Organization in Non-equilibrium Systems, 23rd February 2013, Fukuoka, Japan.