Modeling Accoustic Synchronization of Crickets

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Abstract

In this report, we modified Strogatz model[1] and used electronic crickets to test the resultant behaviour. It turns out this model leads to synchrony in most cases. In addition, computer simulation is used to test the robustness when the system is subject to small and large noise. The result suggests that a large noise is needed to de-synchronize the system.

1 Introduction

Crickets can achieve synchronization by either lengthening or shortening their chirp intervals. However, this does not result in a perfect synchronization [2]. There will be an overlap between two signals, where one signal leads and the other one follows [3]. It is believed that male crickets vary their chirp intervals in an attempt to take the lead because female crickets have preference in the lead cricket[4]. Following crickets can use several strategies to compete with a lead cricket, such as calling louder, increasing distance from the lead, or calling when the lead is silent[5].The other thing that might stops the leader from leading is the ambient noise, since it can disturb the synchronization potentially [6]. So it is better to understand therir interacting mechanism and also investigate into how different noise would affect the synchronization.

In 1990, Strogatz[1] proposed a mathematical model to discuss the dynamics between the chirping crickets. However, the result is rather trivial because no matter what the parameters(internal chirping frequency and coupling strength) are, crickets will always synchronize at the end. This converging behavior results from the concave curve employed in the model as discussed by the authors. Based on the discussion above, he suggested that a linear response curve could possibly results in a different behavior, even chaos are possible. So we decide to follow this path.

In this paper, we will conduct two kinds of experiment. One is using electronic crickets to simulate the real chirping and help us understand their chirping pattern more intuitively by looking at specific interacting model. The other one is computer simulation for comparing the electronic cricket experiment and exploring the robustness of the model.

2 Electronic Cricket experiment

The experiment setup is very simple. An electronic cricket is composed of a microphone, a speaker and a USB soundcard controlled by a Matlab Program. Each cricket is controlled by an individual program. This is because the Matlab program is single thread so that it cannot simultaneously control different soundcards.The speaker plays sounds and the microphone acts as the ear of a cricket to receive sounds and transformed them into data. By analyzing the sound data, the program will judge this sound qualify as a stimulus or not and then perform the corresponding the function either to shorten or lengthen the interval of the chirp. The mathematical model can be described as follows

$$\frac{\partial x_i}{\partial t} = \omega_0 + \zeta(t) \tag{1}$$

also we have a response to the outside stimulus

$$x_i = 1, then, x_j(t^+) = x_j(t) + \eta, x_i(t^+) = 0 \tag{2}$$

Where x_i indicates the state of the i^{th} cricket. When the other crickets chirp, if the j^{th}cricket has not arrived at the threshold '1'(the threshold can be other value), then there will be a boost ,η, added to the j^{th}cricket. the i^{th} cricket will be reset. $zeta(t)$ is just a noise term that will be explored later on in the simulation.

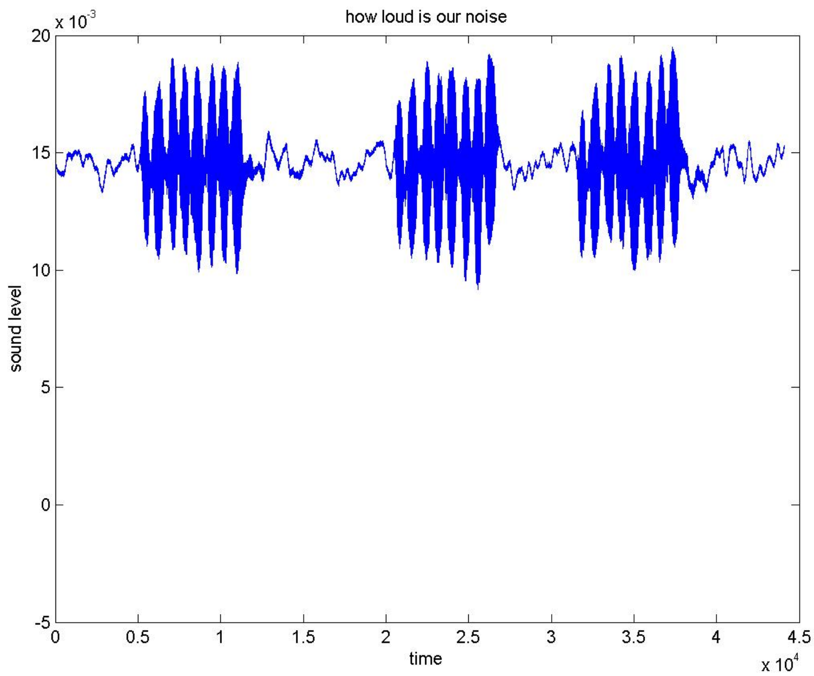

Figure 1: received noise level by the microphone

In our case, we used two crickets, one leader and the other follower , because it is easy to recognize and trace the follower. The two crickets have close natural frequency which is about 2 seconds. As discussed above, the following cricket is assigned with a state. The state evolves proportionally to ω. This function will trigger a chirp when it reaches a threshold and then returns to 0. The threshold is set to be one. The criterion to trigger a boost to enhance the state is that the amplitude of the received sound is larger than a specific value where we set it to be 0.1 , indicating that this cricket hears a chirp. We set it to 0.1 because from figure 1 , the amplitude of a chirp recorded down is 0.02.

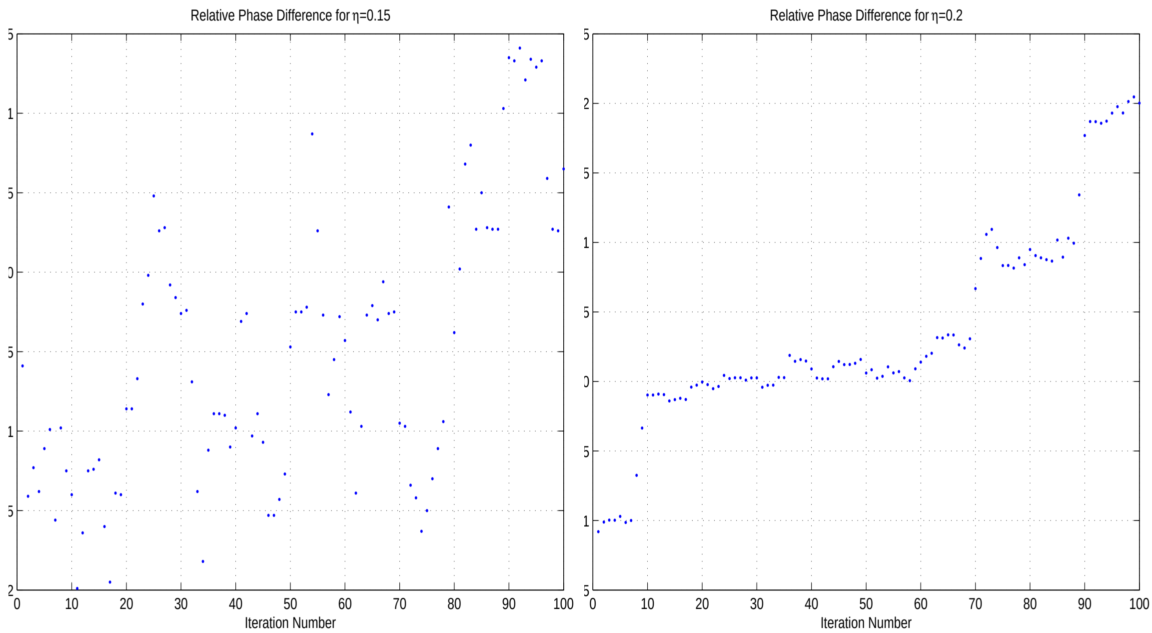

Figure 2: relative phase difference between two cricket with different boost. When boosts equals 0.15, they do not really have a phase difference. When it reaches 0.2, it is obvious that they demonstrate phase locking, especially the 180 degrees.

There are several terms need further explaination. The term relative phase difference is calculating the difference between the nth chirps of different crickets. This tells us that what is the time difference between two crickets. If it is fixed on a integer value of the leaders frequency, it implies synchronization. If it is fixed on other non-integer value of the leaders

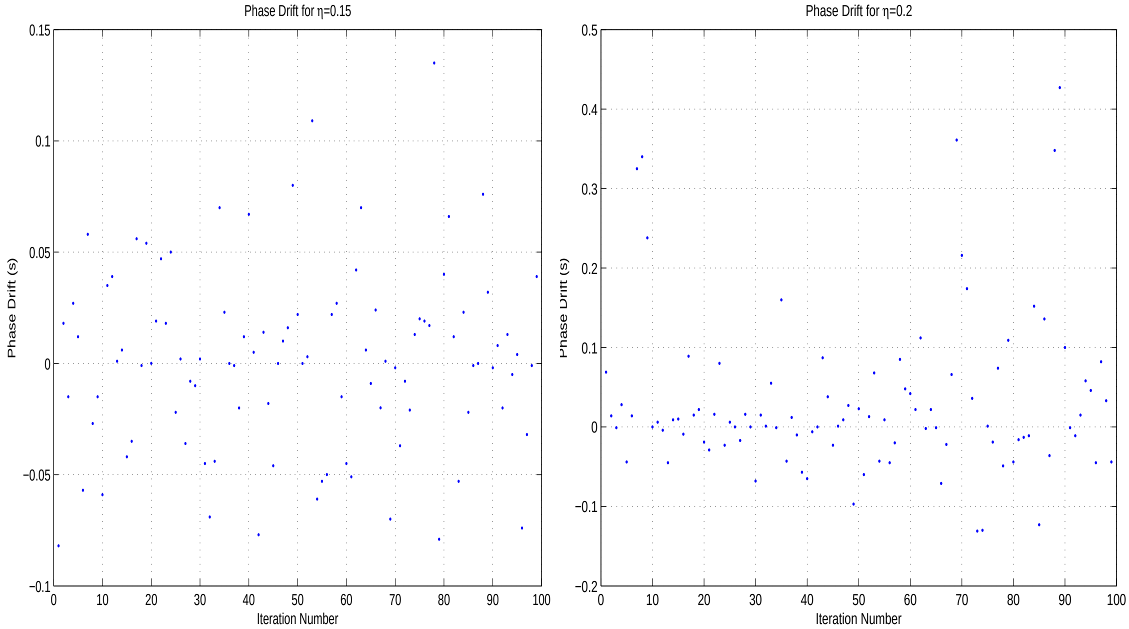

Figure 3: Phase drift between two cricket with different boost. a stronger boost results in a faster convergence of synchronization

frequency, it implies a phase lock. If we used this way to calculate the time difference of adjacent chirp from the same cricket, it tells you the period for a specific chirp. In addition, we calculate the difference of the relative phase difference, called phase drift here, or more precisely, phase difference drift. This value tells you whether the phase difference is either shortened or lengthened. It is obvious that if they lock into each other, then their difference of the relative phase would be 0. If it is a positive number, then it means the relative phase are getting larger, and vice versa.

The result is quite interesting. Not really expected by Strogatz prediction, even with the simple proportional evolvement, crickets show some phase lock and eventually synchronization behavior. Although the data looks rather scatter from figure 2, it did not spreads out 15 percents . Another interesting thing is that, if we look at the 20 percents boost graph in figure 2, there is a step like function. This shows that the crickets were catching up not in continuous but discrete manners. The last thing is that as the boost gets stronger, the phase difference and phase drift converges much more quickly. In figure 2 and 3, the 0.15 boost graph looks rather random, but the 0.2 boost graph starts to show clear pattern. This is possible because the larger the boost, the quicker they converge to the synchronization.

3 Computer Simulation and Result

In the simulation, we are also using the simplified Strogatz model. The idea is the same as above. Each cricket is assigned with a state function which will evolve proportionally to its internal frequency in the course of time. When the state function of a cricket reaches a threshold, the cricket will chirp, and the state function will return back to zero and start another cycle. The time a cricket fires will be recorded for future analysis. In the evolving of the state, there are two more things worth noticing. First, since we are using leader-follower configuration, the leader cricket never hears another cricket. However, to make things interesting, we add a disturbance from a random noise. The maximum of the noise can be the threshold value, and the minimum of the noise is 0. For the follower cricket, the same noise disturbion is applied and with a fixed boost as mentioned above.

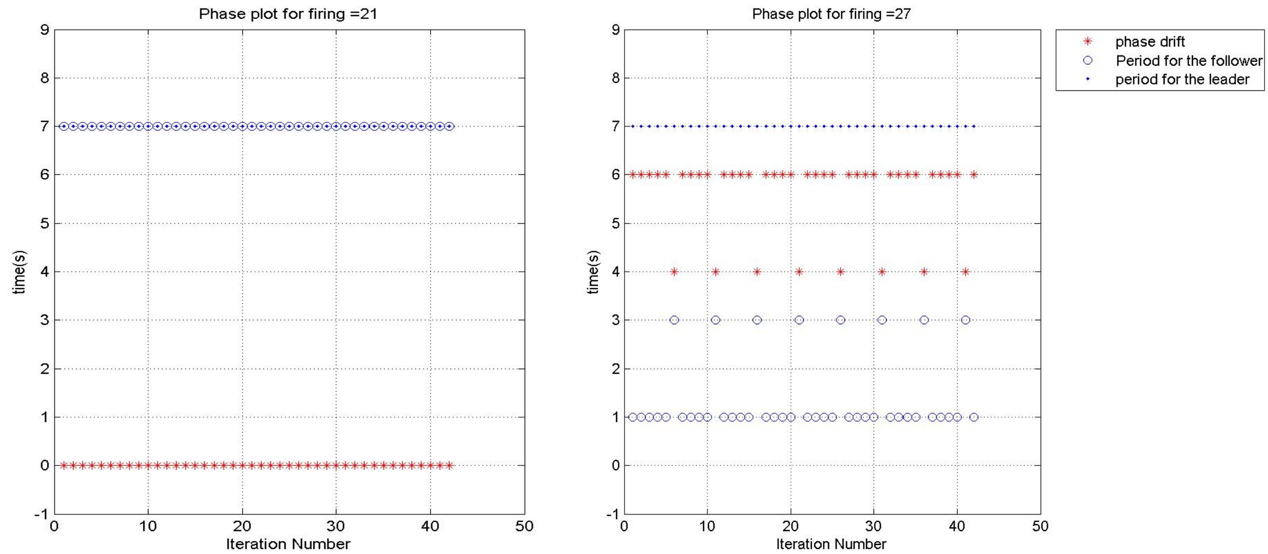

Figure 4: the boost is constant. boosts for these two situations are 21 and 27, respectively. a small devia tion is shown in the picture and also a clear pattern is also manifested.

First of all, we would like to compare this simulation with our experimental results. The condition of the crickets are the same in the sense that the ration between the set of parameters in the experiment is preserved in the simulation. In the experiment, the internal frequencies for the two crickets are very close, and it is around two seconds. So we set the internal frequency around 40 in the simulation and the two crickets differs only 1 percent of the threshold. The boosts for the state is about 30 percents of the threshold. We also

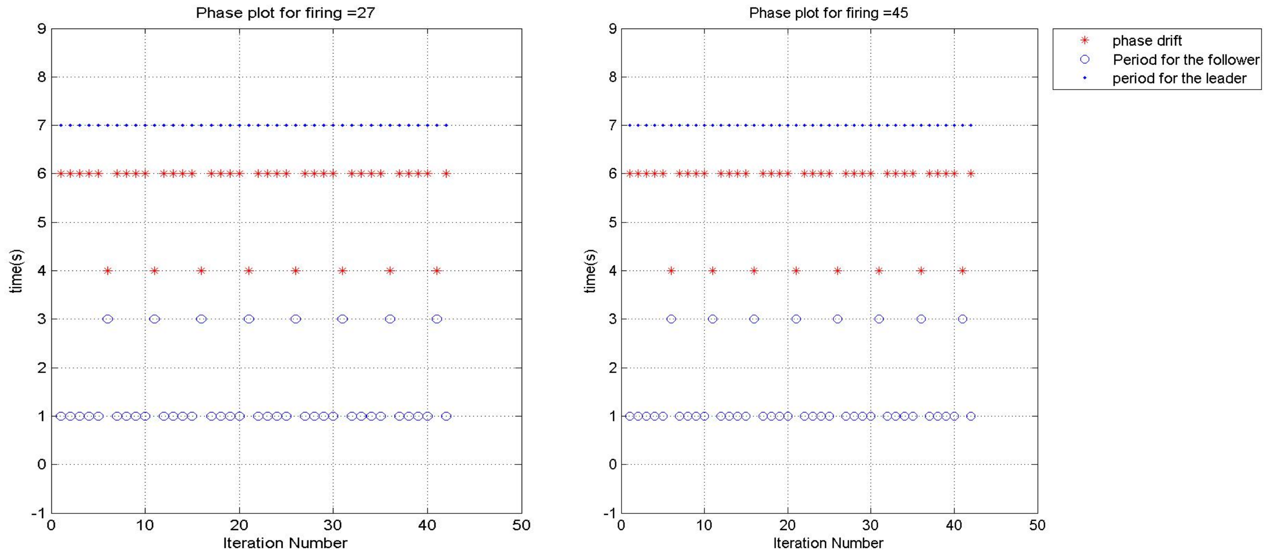

Figure 5: boosts are 27 and 45 respectively. Comparing this set of data with the data in figure 3, there is not much difference.It is possible to say that a stable boost will only results in stable pattern.

set the boosts for the state to be 30. In addition, this experiment did not employ the noise described above. From the results shown in figure 4, it is obvious that the leader is chirping at its internal frequency. Moreover, though the value in simulation might be different from experiment, its drift for the follower shows some deviation from, but mostly restricted within a line. This also applies for the phase drift for the two crickets in the experiment. This consistent pattern confirms that our simulation reflects some of the behavior of the experiment results.

Secondly, we would like to explore the stability of this coupling. We first apply noise on the follower cricket. The noise did not come into effect until the maximum of the noise reaches certain value. In figure 6, with approximately 40 percent of the threshold disturbtion, you can still see a clear stable period for the follower. Moreover, we apply noise on both of the crickets. In figure 7, it is obvious that the leader crickets is rather stable when the noise is as much as half of the threshold. However, for the following crickets, it gradually becomes chaos and cannot see a clear pattern or a stable behavior of its chirps.

All the result analysis above shows that this kind of the system is rather robust. Because it is rather difficult to imagine that a noise up to 50 percents of the threshold would exist in the existing network. The leader is pretty stable at its internal frequency, and the following crickets does not deviate much from its original frequency.

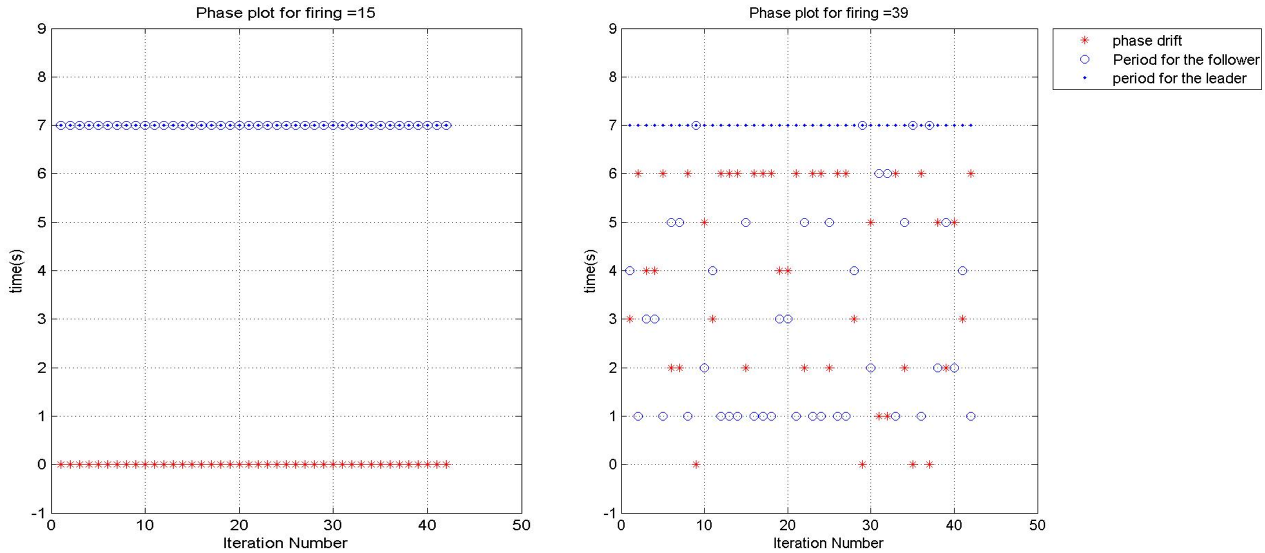

Figure 6: Period and phase drift for the two crickets when the follower cricket had a random boosts while the leader does not get boosted. The noise has to get to very big (30 percent of the threshold) in order to have random behaviour.

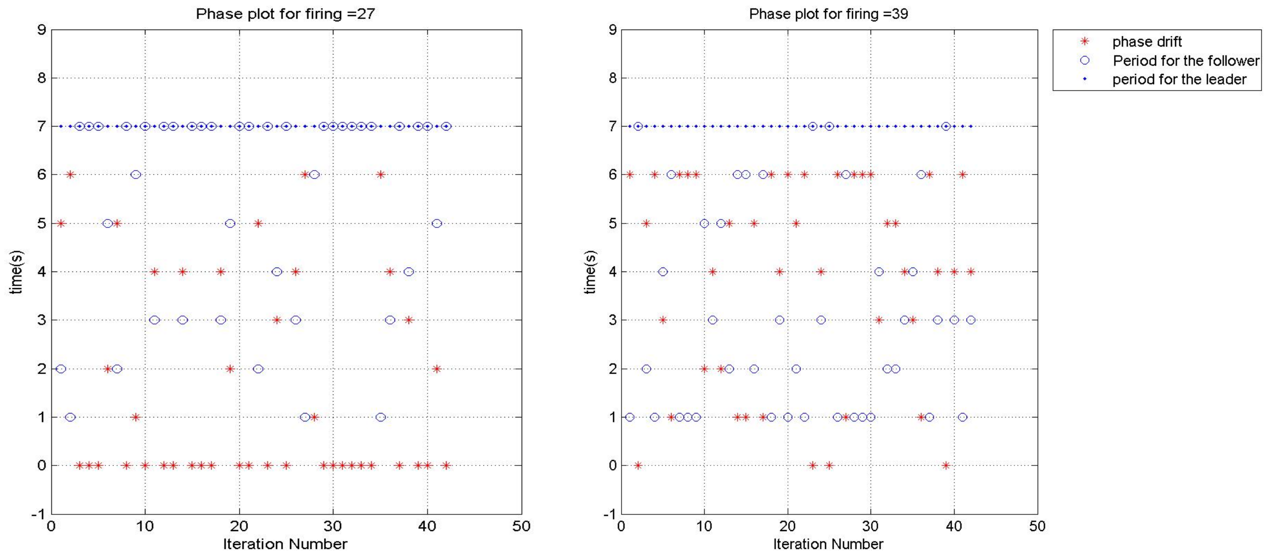

Figure 7: Period and phase drift for the two crickets when both the follower and the leader cricket had a random boosts. It is the same conclusion that noise has to get to very big (30 percent of the threshold) in order to have random behaviour.

4 Discussion

For the present model, the boost is a constant. It is easy to find that once the two crickets get close enough to each other, the constant boost will make one cricket jumps ahead of the other. Then it will start to catch up with the leading cricket again. So a certain cycle period should be expected. However, this seems to be rather contradictory to the real cricket behavior. Intuitively, the cricket should maintain some kinds of phase lock around the synchronization or a small phase oscillation. So we can consider the boosts function to be more phase difference dependent. The closer they are, the smaller the boost it is so that it is possible for crickets to maintain a very close synchronization rather than a repeated pattern.

There is also improvement needed in the experiment setup. In order to have a precise response, we use a very small time interval to record and listen to the other cricket. however, a chirp is longer than the recording time, which may results in multiple boosts. In fact, this induces a systematic error in our experiment. However, if the time scale is too long, then it might loss some of the information it should receive while it is chirping, Thus slowing down the boost process. This is also related to the slow processing ability of the sound card. It cannot record and play at the same time. So it still remains a problem that how to choose a proper time scale or use a different way of organizing the experiment to eliminate this problem.

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