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Experimental Evaluation on Feasibility of Noise-Induced Synchronization by Natural Environmental Signals

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Abstract—Noise-induced synchronization is a phenomenon that the nonlinear oscillators synchronize by adding common noise to each of them. In our previous researches, we have already confirmed that synchronization of the oscillators also occurs even by adding natural environmental fluctuations obtained in close, which have high cross-correlation. In this paper, we investigate parametric dependence of noise input method by changing amplitude and interval of noise input. By our numerical experiments using real data and white Gaussian noise, it is confirmed that strong noise is effective for fast success of synchronization and weak noise is effective for long retention of synchronization. Futhermore, our experimental results show that there are optimal parameter settings to improve the performance of synchronization, even when using the natural environmental fluctuation.

1. Introduction

Noise-induced phase synchronization [1, 2] is a phenomenon that uncoupled nonlinear oscillators synchronize with each other only by adding common identical noise to each of them. Based on the noise-induced synchronization phenomenon, we propose a natural synchronization scheme for uncoupled wireless devices. We use natural environmental fluctuations, such as the humidity of the air, the temperature, environmental sounds and so on. Those natural environmental fluctuations obtained at the neighboring devices have high similarity. By adding such similar fluctuations to the devices, our proposed scheme realizes natural synchronization of those devices, without any interactions or exchanges of the signals.

One of application examples of this synchronization method is time synchronization of sensor nodes on wireless sensor networks. For wireless sensor networks, synchronization among the sensor nodes is important to reduce power consumption. Since it is hard task to exchange batteries of a large number of battery-powered wireless sensor nodes, it is important to develop low power consumption protocol. One of the approaches is intermittent data transmission with extending sleep time by synchronized sensor nodes. Simplest synchronization schemes are to exchange clock timing information between the sensor nodes, or to receive GPS time signals, and so on. However, those schemes have overheads in power consumption or in the necessary equipments. In our proposed method, it is possible to reduce the overhead because time synchronization can be achieved by using only data of natural environment that is obtained by each sensor. We have already clarified by experiments using real data, such as the temperature, humidity of the air that synchronization can be achieved by the proposed method [3]. However, in that case, it is found that it takes long time to achieve the synchronization. Considering the application, it should be as fast as possible to achieve synchronization, and maintaining long-term synchronization. Therefore, for the purpose of taking advantage of the faster fluctuations, we have confirmed that synchronization is possible even if using environmental sound [4].

In this paper, we will investigate the parameter dependence of the performance of this synchronization method in the noise input. We change the amplitude and interval of noise input as the parameter, and investigate the synchronization performance, using white Gaussian noise and actual measurement data of humidity and environmental sound as the input noises. We investigate synchronization performance by evaluating the success rate in within a certain period of time and the retention rate after achieving synchronization. As a result, we will clarify that there are the optimal parameters for fast and long-term synchronization.

2. Noise-Induced Phase Synchronization Theory

This section shows the theory of the noise-induced synchronization phenomenon, which is the base of our proposed natural synchronization scheme. At first, an ordinary differential equation of the dynamics of the oscillator is defined by the following equation,

$$\dot{\mathrm{X}}(t) = \mathrm{F}(\mathrm{X}). \tag{1}$$

The dynamics of its phase can be defined as follows using the angular frequency ω,

$$\dot{\theta}(t) = \omega. \tag{2}$$

Here, we consider synchronization of two limit cycle oscillators, which have common noise input to both. The dynamics of limit cycle oscillators with the Gaussian white

noise $\xi(t)$, as the common noise, are expressed as follows,

$$\dot{X}_1(t) = F(X_1) + \xi(t), \quad (3)$$
$$\dot{X}_2(t) = F(X_2) + \xi(t). \quad (4)$$

The phase dynamics of these oscillators with the common noise can be expressed as follows,

$$\dot{\theta}_1(t) = \omega + Z(\theta_1)\xi(t) \quad (5)$$
$$\dot{\theta}_2(t) = \omega + Z(\theta_2)\xi(t), \quad (6)$$

where $Z(\theta) = grad_X \theta(X)|_{X=X_0(\theta)}$, which is called the phase sensitivity function. Here, we define the difference of the phases of these two oscillators as $\phi = \theta_1 - \theta_2$.

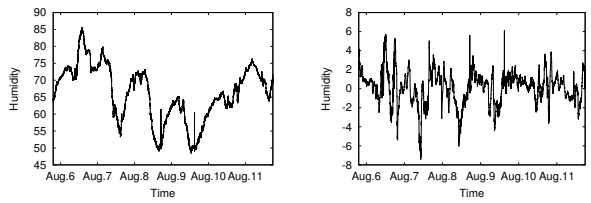
Analyzing the linear growth rate (Lyapunov exponent average) of the phase difference, Λ, is calculated as follows,

$$\begin{aligned} \Lambda &= \left\langle \frac{d}{dt} ln|\phi(t)| \right\rangle = \epsilon^2 \langle Z''(\theta(t))Z(\theta(t)) \rangle \\ &\cong \frac{\epsilon^2}{2\pi} \int_0^{2\pi} Z''(\theta)Z(\theta)d\theta \quad (7) \\ &= -\frac{\epsilon^2}{2\pi} \int_0^{2\pi} Z'(\theta)^2 d\theta \leq 0. \end{aligned}$$

Since the linear growth rate of the phase difference dynamics is smaller than 0 for the limit cycle, the phase difference always decreases. Thus, two limit cycle oscillators can be synchronized by adding a common noise for both.

3. Time Synchronization Method Using Natural Environmental Fluctuations as the Additive Sequences of Noise-Induced Synchronization

In our proposed scheme, we apply natural fluctuations to the nonlinear oscillators as the common noise of noise-induced synchronization phenomenon. As the natural environmental fluctuations, we use temperature or humidity of the air, environmental sounds and so on. Even if the input noises are not completely common, noise-induced synchronization can be achieved if the noises have high cross-correlation within them. It is shown that the fluctuation among the neighborhood in the natural environment satisfies such conditions [3].

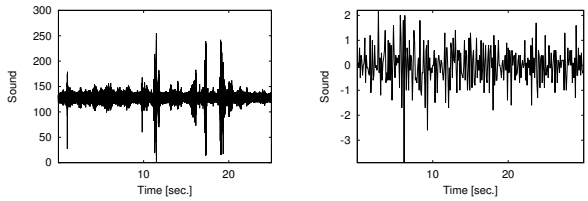


(a) raw data (b) normalized data

Figure 1: Time series of humidity data and its normalized data.

In our experiments, we measure the real natural environmental fluctuations, such as humidity and environmental sound. For obtaining of humidity data, we use 8 sensor nodes of the wireless sensor network nodes, MICAz [5]. The sensor nodes located in very small area at outside corridor of Kudan Building of Tokyo University of Science and the distances between the nodes are is around 10 to 30m. For obtaining of environmental sound, we use a voice recorder. The recorder located at a park in Katsushika, Tokyo and the distance is within 2m. Fig. 1(a) and 2(a) show one of examples of obtained data.

From Figs. 1(a) and 2(a), we found that the mean, standard deviation, and fluctuation period is different depending on the data type. In the theoretical proof of Noise-induced Synchronization, the input noise is assumed that they have constant average and arbitrary period. Therefore, it is necessary to normalize the amplitude of noise and adjust the sampling frequency when using the environmental data. And also this normalization must be one of online processing technique when considering of implementation. In this paper, for humidity, we use the time-averaged value and the moving average value. We calculate the average of environmental data acquired in the given time interval to calculate the time-averaged value. It also calculates the moving average value, it is used as a new data value the difference between the moving average value and the time average value. For environmental sound, we use difference of zero crossing method that counts the number of times that the value of data is changed from positive to negative to calculate the new time series.



(a) raw data (b) normalized data

Figure 2: Time series of environmental sound and its normalized data.

As an example, we use processing of moving average and time average for the humidity data in Fig. 1(a), and zero-crossing method for environmental sound in Fig. 2(a). Figs. 1(b) and 2(b) show the result of the normalization and adjustment of the sampling frequency.

Fig. 3 shows time series of the phase difference between the oscillators when using normalized humidity data as input of environmental data. From Fig. 3, it can be seen that the phase difference between the oscillators is reduced even in the case of using the environmental data, and synchronization can be achieved within the oscillators. Therefore, it indicates that Noise-induced Synchronization of using the environmental data is possible.

In our proposed synchronization system, each device

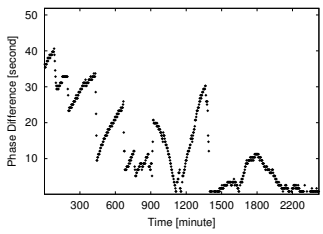


Figure 3: Time series of phase difference of oscillators adding normalized humidity data.

calculates the nonlinear oscillators in themselves. Each device input the environmental data that are obtained by their own sensors to oscillator as a common noise. If the devices place in close area and environmental data obtained by them have high correlation, the oscillators equipped on devices will achieve phase synchronization by noise-induced synchronization. Thus, each device for adjusting the internal clock by the phase of the nonlinear oscillators is able to achieve time synchronization. By using this technique, autonomous time synchronization between devices is possible without any signal exchange. Here, in this paper, we set the time of the period of the oscillator to be 150 minutes per cycle in the case of using humidity, and 36 seconds per cycle in the case of using environmental sound. At the time of implementation, it is assumed to be appropriately changed oscillator period depending on the frequency of the environmental fluctuation and accuracy required in the system to apply.

4. Effectiveness of Parameters to the Performance of Synchronization, and Optimal Parameter for Fast and Long-Term Synchronization

When adding the fluctuation of the natural environment, it is assumed that the parameter of amplitude and interval of input is set arbitrarily, but the value of parameter have affect on the synchronization performance. In addition, it is necessary to adjust the parameter settings depending on the type of environmental fluctuations. We investigate parameter dependence of synchronization performance to confirm the parameter values that is intended to set that can improve the synchronization performance depending on the usage situation.

At first, we investigate relationship of synchronization performance with input interval and amplitude, when using white Gaussian noise. We use FitzHugh-Nagumo oscillators as the oscillators, and calculate the state of the oscillators in a discrete manner by the four following Runge-Kutta method. Each environmental data is normalized, and set the standard deviation same as the oscillator. Synchronous state is defined that keeping synchronization in accuracy of 0.5% with respect to time of the period of the oscillator. Synchronization performance is assessed by the success rate and retention rate of synchronization. Synchronization success rate is defined as the percentage that can

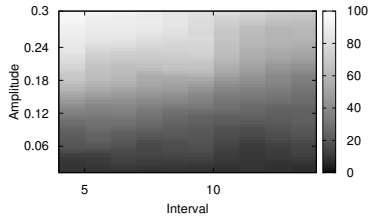


Figure 4: Relationship of success rate of synchronization with input interval and amplitude, when using white Gaussian noise.

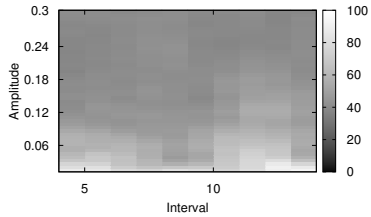


Figure 5: Relationship of retention rate of synchronization with input interval and amplitude, when using white Gaussian noise.

achieve synchronization at least once in a period of half of the data acquisition time. Retention rate is defined as the percentage of time that can keep state of synchronization after achieving synchronization. We define the time as the number of calculations of the Runge-Kutta method, when using white Gaussian noise.

Figs. 4 and 5 represent the relationship between the parameter setting with success rate and retention rate of synchronization. From the figs. 4 and 5, we can see that the success rate is high when the amplitude is high, and retention rate is high when the amplitude is weak. Therefore, it is confirmed that there are the optimal parameter set in order to obtain the appropriate achievement rate, maintenance rate.

Secondly, we examine the relationship between the synchronization performance and parameter setting in the case of using the natural environmental fluctuations of sound and humidity. We evaluate the synchronization performance as in the case of using the white Gaussian noise. We use humidity data of 30 days which obtained by wireless sensor networks that have been installed in 6 outdoor point of Kundan building of Tokyo University of Science as input to oscillator. And, we use environmental sound of 3 hours which obtained by voice recorder that have been installed in 8 outdoor point of a park in Katsushika, Tokyo.

Figs. 6-9 shows the success rate and retention rate when the interval and amplitude changes respectively about humidity and environmental sound. The amplitude of noise input is varied from 0.002 times to 0.1 times the standard deviation ratio. Further, the intervals of input is varied 133 seconds to 400 seconds in the case of humidity, and is varied from 0.5 seconds to 1.5 seconds in the case of environmental sound. We can see that the success rate is high

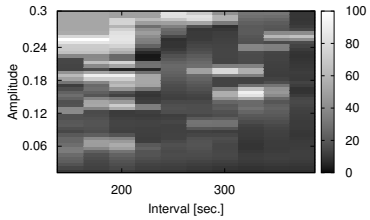


Figure 6: Relationship of success rate of synchronization with input interval and amplitude, when using humidity data.

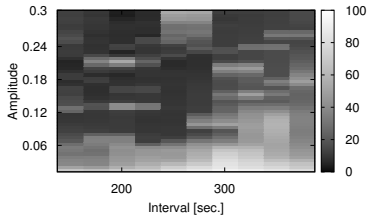


Figure 7: Relationship of retention rate of synchronization with input interval and amplitude, when using humidity data.

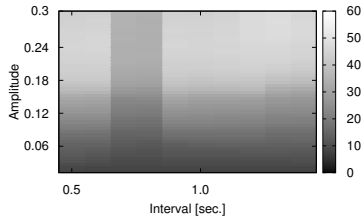


Figure 8: Relationship of success rate of synchronization with input interval and amplitude, when using environmental sound.

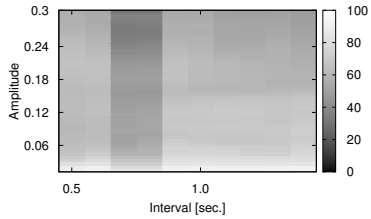


Figure 9: Relationship of retention rate of synchronization with input interval and amplitude, when using environmental sound.

when the amplitude is high, and retention rate is high when the amplitude is weak, like as in the case of white Gaussian noise. From figs. 6 and 7, achievement ratio and retention rate is higher values in the case of that the amplitude set to 0.1 and the interval set to 266 seconds. It was found that higher synchronization performance can be obtained when set the value of parameter like this settings. Identically, from fig 8 and 9, synchronization performance can be improved when the value of amplitude set to 0.1 and the interval set to 1.3 seconds, in the case of using environmental sound. From the above, it is shown that there is possibility that the parameters depend on the synchronization performance, even if using environmental fluctuation. Moreover, the results show that optimal parameter exists to achieve higher synchronization performance in this case.

5. Conclusion

In this paper, we investigate the noise input parameter dependence of synchronization performance in Noise-induced Synchronization using real-world fluctuations. We examined the dependence of synchronization performance on amplitude and interval of the noise input. Our results show that there are optimal settings on parameters of amplitude and interval of input, and it is confirmed that synchronization performance depends on parameters in the noise-induced synchronization using the natural environmental fluctuation. In addition, we confirmed that strong noise is effective for fast success of synchronization, and weak noise is effective for long-term retention of synchronization.

As our future work, in order to realize the synchronization with higher accuracy, we will consider about other natural environmental signals that have high cross-correlation and higher frequencies. We will clarify the optimal parameter adjustment method in each state of the oscillator and the type of fluctuation. In addition, we aims to establish a method to enhance the synchronization performance of noise-induced synchronization using environmental fluctuations.

References

[1] J. Teramae and D. Tanaka, “Robustness of the Noise-Induced Phase Synchronization in a General Class of Limit Cycle Oscillators,” *Physical Review Letter*, vol. 93, 204103, 2004.

[2] H. Nakao, K. Arai, and Y. Kawamura, “Noise-induced synchronization and clustering in ensembles of uncoupled limit-cycle oscillators,” *Physical Review Letter*, vol. 98, 184101, 2007.

[3] M. Harashima, H. Yasuda and, M. Hasegawa, “Synchronization of Wireless Sensor Networks using Natural Environmental Signals Based on Noise-Induced Phase Synchronization Phenomenon,” *Proc. IEEE Vehicular Technology Conference Spring,*, 2012.

[4] Y. Honda, H. Yasuda, M. Hasegawa, H. Nakao and K. Aihara, “Time Synchronization Scheme based on Noise-Induced Synchronization using Environmental Sound,” *Proc. RISP International Workshop on NCSP*, 5PM1-3-2, 2013.

[5] J. Hill and D. Culler, “Mica: A Wireless Platform for Deeply Embedded Networks,” *IEEE Micro*, Vol. 22, pp. 12-24, 2002.