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Experimental Study on Noise-induced Synchronization using Environmental Noise

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Abstract– We have proposed a natural synchronization scheme using environmental noise. The proposed scheme is based on noise-induced synchronization phenomenon; the phases of uncoupled nonlinear limit cycle oscillators synchronize with each other by adding common noise to each of them. The proposed scheme does not require signal exchange between the devices to synchronize. The oscillators running on the devices can synchronize with each other because the environmental fluctuations are similar in neighboring area. In our previous research, we have shown feasibility of the synchronization by using temperature, humidity, environmental sounds, and electromagnetic wave. In this paper, we investigate synchronization performances of the proposed scheme using various environmental noises. We have confirmed that noise-induced synchronization could be achieved by temperature, humidity, environmental sound, electromagnetic wave and acceleration.

1. Introduction

Noise-induced synchronization is a phenomenon that uncoupled nonlinear limit-cycle oscillators synchronize with each other by adding common noise, such as the Gaussian white noise [1,2,3], Poisson noise [4,5], colored noise [6] and so on. The oscillators also synchronize by inputting cross-correlated noise to the oscillators [6,7].

We have proposed a natural synchronization scheme based on the noise-induced synchronization [7]. We use natural environmental fluctuations as inputting noise to oscillators. Noise induced synchronization can be achieved by using natural environmental fluctuations because natural environmental fluctuations are similar in neighboring area. In our proposed scheme, the devices can be synchronized with each other by performing actions according to the phase of each oscillator running on devices. In the conventional synchronization systems, such as GPS and radio clock, wireless signal exchanges are required. In these synchronization systems, communication modules are required and the power consumption to exchange synchronization signals is necessary. On the other hand, in our proposed scheme, any signal exchange is not required to synchronize. It needs only obtaining environmental noise such as temperature, humidity and so on. The devices can be synchronized in outage of the GPS and power efficient synchronization is achieved.

In this paper, we investigate the performance of the proposed scheme using various types of the environmental noise. We introduce temperature, humidity, environmental sound, electromagnetic wave, sunlight and acceleration. We evaluate the synchronization accuracy and time to synchronize for all examples of the environmental noises and summarize the synchronization performances, which will be applied to real systems.

2. Noise-Induced Synchronization using Natural Environmental noise

In the proposed scheme, the devices achieve synchronization by only obtaining the environmental noise [7]. As shown in Fig.1, each device input the environmental noise to the nonlinear limit-cycle oscillators running on itself. By noise-induced synchronization phenomenon, the oscillators running on each device will be synchronized with any interactions among the devices. In proposed system, wireless devices equipped with sensors obtaining environmental noise are used.

In this paper, we experiment noise induced synchronization using various environmental noise, such as humidity, environmental sound, electromagnetic wave, sunlight and acceleration. We show the synchronization accuracy of each scheme.

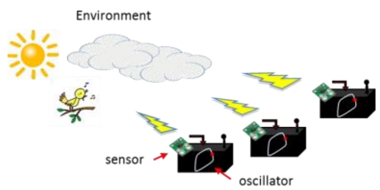


Fig.1 Proposed system based on noise-induced synchronization using environmental noise

In our system, the noise data are sampled every t seconds. We normalized the obtained data to prevent the stranger values obtained by the sensor from being input to the oscillator. For example, the obtained data is taken the time average value of l seconds. We calculate the moving average; the average of last m seconds ($m > l$). We calculate the moving average every n seconds. The sequences are divided by the standard deviation. By these normalization, the average of the normalized data is 0 and the standard deviation is 1. We input the normalized data to the oscillator every $t \cdot n$ seconds.

Here, we show the one example of noise-induced synchronization. We use FitzHugh-Nagumo oscillators defined by the following equation,

$$\frac{du}{dt} = \varepsilon(v + c - d \cdot u), \quad (1)$$

$$\frac{dv}{dt} = v - \frac{v^3}{3} - u + I. \quad (2)$$

Where, we fix the parameters at ε=0.08, c=0.7, d=0.8 and I=0.8. The state of FitzHugh-Nagumo oscillators are calculated by Runge-Kutta method. The histogram of the phase difference between the oscillators when the Gaussian white noise is input to each oscillator every 12 steps of Runge-Kutta steps is shown in Fig.2. From Fig.2, we can find that synchronization of oscillators can achieve even when the noise is input in several steps constant interval.

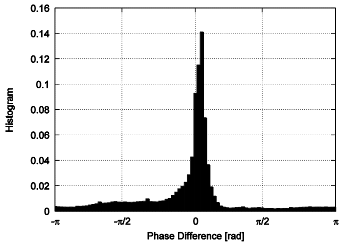


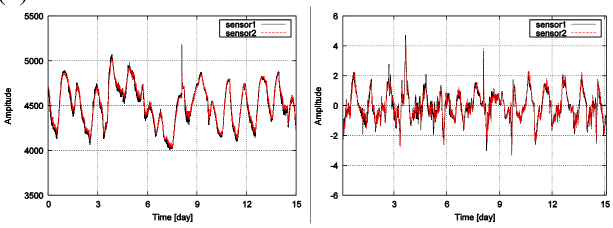
Fig.2 Histogram of the phase difference (White Gaussian noise)

3. Experiment of Noise-Induced Synchronization using Environmental Noise

In this section, we examine 6 kinds of environmental noises. We evaluate the synchronization performances for each of them and summarize them from the viewpoint of the application systems.

3.1. Experiment using Temperature

In this experiment, temperature obtained by wireless sensor devices are used as input noise to the nonlinear oscillators. Sampling rate is about 8 seconds. We have normalized the obtained data to prevent the stranger values from the measurement. We calculate the time average value of the 150 seconds. And, we also calculate the moving average of last 7500 seconds, in 150 seconds interval. The sequences of the moving average are divided by the standard deviation of the 7500 seconds data used for calculation of moving average. The raw data of temperature is shown in Fig.3 (a) and normalized data is shown in Fig.3 (b).



(a) Raw data. (b) Normalized data.

Fig.3 Temperature data.

The normalized data of temperature is input to each oscillator every 11 steps of Runge-Kutta step. The period of the oscillator is about 83.2 minutes. We evaluate the phase difference between two FitzHugh-Nagumo oscillators. The histogram of phase difference is shown in Fig.4. From Fig.4, we can find that there is the highest point near 0 of the phase difference.

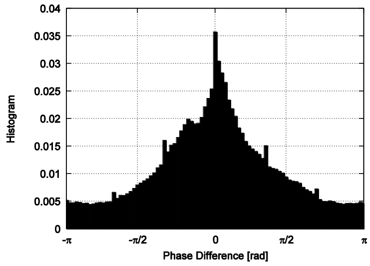
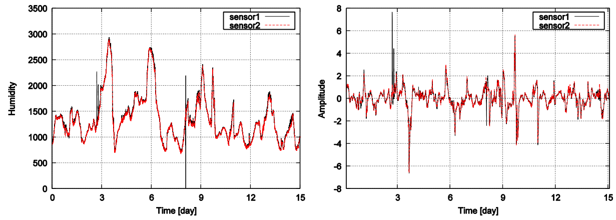


Fig.4 Histogram of the phase difference (Temperature data)

3.2. Experiment using Humidity

In this experiment, humidity obtained by wireless sensor devices are used as input noise to the nonlinear oscillators. Sampling rate is about 8 seconds. We normalized the fluctuations by same process as temperature. The raw data of humidity is shown in Fig.5 (a) and normalized data is shown in Fig.5 (b).



(a) Raw data. (b) Normalized data.

Fig.5 Humidity data.

The normalized data of humidity is input to each oscillator every 11 steps of Runge-Kutta step. The period of the oscillator is about 83.2 minutes. We evaluate the phase difference between two FitzHugh-Nagumo oscillators. The histogram of phase difference is shown in Fig.6. From Fig.6, we can find that there is the highest point near 0 of the phase difference.

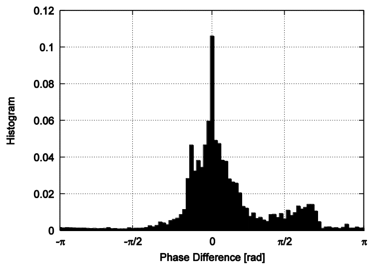
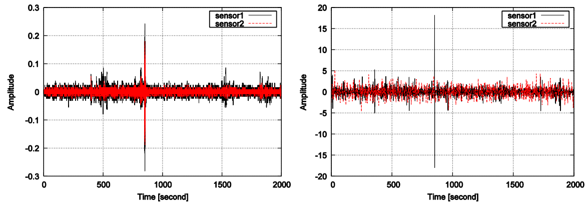


Fig.6 Histogram of the phase difference of oscillators. (Humidity data)

3.3. Experiment using Environmental Sound

In this experiment, environmental sound is obtained in verandah in a house in Kanagawa prefecture. Sampling frequency is 22.05 kHz. In order to extract main frequency which is correlated between time series of the data, we count the crossing of the 0 value in a constant time. The raw data of environmental sounds is shown in Fig.7 (a) and normalized data is shown in Fig.7 (b).



(a) Raw data. (b) Normalized data.

Fig.7 Environmental sound data.

The normalized data of environmental sound is input to each oscillator every 30 steps of Runge-Kutta step. The period of the oscillator is about 6.1 seconds. We evaluate the phase difference between two oscillators. The histogram of phase difference is shown in Fig.8. From Fig.8, we can find that there is the highest point near 0 of the phase difference.

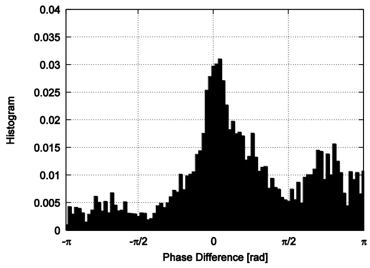
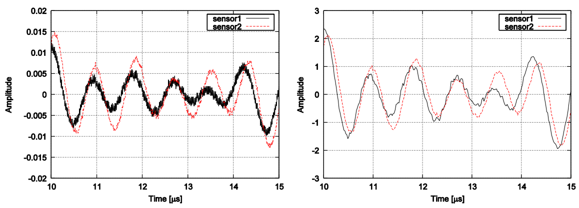


Fig.8 Histogram of the phase difference of oscillators. (Environmental sound data)

3.4. Experiment using Electromagnetic wave

In this experiment, electromagnetic waves are obtained by two independent antennas in building outside in Tokyo University of Science. We calculate the time average value of 5 points. We use normalized fluctuations as input noise to the oscillators. The raw data of electromagnetic wave is shown in Fig.9 (a) and normalized data is shown in Fig.9 (b).



(a) Raw data. (b) Normalized data.

Fig.9 Electromagnetic wave data.

The normalized data of electromagnetic wave is input to each oscillator every 120 steps of Runge-Kutta step. The period of the oscillator is about 59.6 nanoseconds. We evaluate the phase difference between two oscillators. The histogram of phase difference is shown in Fig.10. From Fig.10, we can find that there is the highest point near 0 of the phase difference. We can also find that there are cluster states.

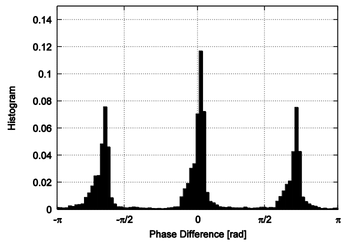
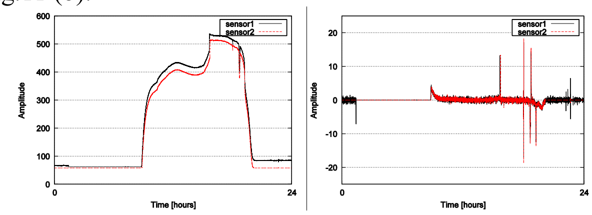


Fig.10 Histogram of the phase difference of oscillators. (Electromagnetic wave data)

3.5. Experiment using sunlight

In this experiment, sunlight is obtained by two sensors in verandah in our laboratory. Sampling rate is about 15 milliseconds. We calculate the time average value of 300 milliseconds. We take the difference between the last and the new data of the average value. The raw data of sunlight is shown in Fig.11 (a) and normalized data is shown in Fig.11 (b).



(a) Raw data. (b) Normalized data.

Fig.11 Environmental sunlight data.

The normalized data of sunlight is input to each oscillator every 11 steps of Runge-Kutta step. The period of the oscillator is about 10.0 seconds. We evaluate the phase difference between two oscillators. The histogram of phase difference is shown in Fig.12. From Fig.12, we can find that the oscillators does not synchronize.

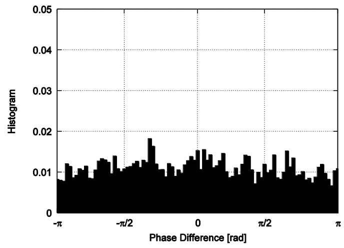
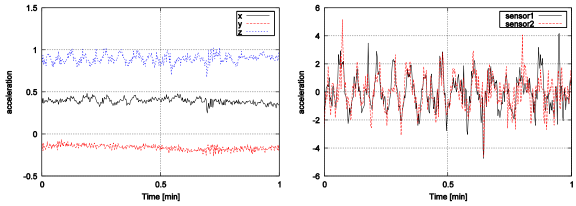


Fig.12 Histogram of the phase difference of oscillators. (Sunlight data)

3.6. Experiment using Accelerations

In this experiment, acceleration is obtained by 3-axis acceleration sensors in a car. 3–axis acceleration sensors are attached right and left side of the dashboard. We measured (X,Y,Z) component. X -axis of the acceleration sensor is perpendicular to the direction of movement. Y -axis of the acceleration sensor is parallel to the direction of movement. Z -axis of the sensors is perpendicular to the ground. Sampling rate is about 15 milliseconds. Measured (X,Y,Z) component is taken the inner product. We take the difference between the front and new data. The raw data of acceleration is shown in Fig.13 (a) and normalized data is shown in Fig.13 (b).



(a) Raw data. (b) Normalized data.

Fig.13 Acceleration data.

The normalized data of acceleration is input to each oscillator every 20 steps of Runge-Kutta step. The period of the oscillator is about 274.5 milliseconds. We evaluate the phase difference between two oscillators. The histogram of phase difference is shown in Fig.14. From Fig.14, we can find that there is the highest point near 0 of the phase difference.

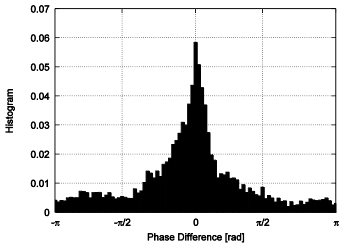


Fig.14 Histogram of the phase difference of oscillators. (Acceleration data)

3.7. Synchronization accuracy and Time to Synchronize

We evaluate the time accuracy and the time to synchronize of each environmental noise. We define the synchronization as 1/40 of 1 period of oscillators. Table 1 show the synchronization accuracy and time to synchronize of each environmental noise. From Table 1, we can find that the accuracy and the time to synchronize are changed by the environmental noise and the period of oscillators. If our proposed scheme is applied to some synchronization system, the period of oscillators is set to appropriate value according to system requirement. Therefore, environmental noise should be selected depending on the application system.

Table 1 Synchronization accuracy of each environmental noise

Environmental noise	1 Period	Accuracy	Time to synchronize
Temperature	83.2 min.	2.08min.	12.3 days (213.6 cycle)
Humidity	83.2 min.	2.08min.	8.7 days (151.4 cycle)
Sound	6.1 sec.	0.15 sec.	20.2 min. (198.3 cycle)
Electro-magnetic wave	59.6 nanosec.	1.49 nanosec.	7.0 μsec. (116.8 cycle)
Acceleration	274.5 millisec.	6.85 millisec.	107.6 sec. (392 cycle)

4. Conclusion

In this paper, we have investigated the performance of the proposed scheme using various types of the environmental noise. We have introduced temperature, humidity, environmental sound, electromagnetic wave, sunlight and acceleration. We have obtained environmental noise and normalized the data to input to the oscillators. We have shown that the oscillators synchronize by the normalized temperature, humidity, environmental sound, electromagnetic wave and acceleration. We have also evaluated the synchronization accuracy and time to synchronize of each environmental noise. We have shown that the accuracy and the time to synchronize are changed by the environmental noise and the period of oscillators.

In future work, we consider how to improve the synchronization accuracy, and most effective noise for some application system.

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