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Synchronization of Chaotic Oscillators Using Natural Environmental Noises

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Abstract

In our research, we propose a novel synchronization scheme based on noise-induced synchronization. We introduce natural environmental noise as an additive input noise to uncoupled nonlinear oscillators. The natural environmental noises in neighboring areas are cross-correlated, and we have already shown that limit-cycle oscillators can be synchronized by such cross-correlated noise. In this paper, we investigate the feasibility of the proposed natural synchronization scheme for the Rössler system, one of the chaotic oscillators. We first evaluate the synchronization performance by adding cross-correlated Gaussian noise, and we show the possibility of synchronizing the chaotic oscillators using the cross-correlated noise. We also introduce a real environmental noise, environmental sound data obtained at neighboring microphone devices, and we show that Rössler oscillators can be synchronized by such cross-correlated environmental noise. Our proposed synchronization method can be applied to intermittent communication. Accordingly, we evaluate the collision probability for the proposed synchronization method in intermittent communication. We introduce some cyclic interference sources and measure the probability of collision.

1. Introduction

Noise-induced phase synchronization [1]-[3] is a phenomenon by which uncoupled nonlinear oscillators can be synchronized with each other by adding a common identical noise to each of the oscillators. This synchronization phenomenon does not require any signal exchanges or interactions between the oscillators for synchronization. The theory of this phenomenon has already been clarified for limit-cycle oscillators [2], [3]. Chaotic oscillators can also be synchronized by adding common noises [1].

It has also been shown that the limit-cycle oscillators can be synchronized even when the input noises are not identical but have high cross-correlation [4], [5]. On the basis of this noise-induced synchronization phenomenon with cross-correlated noise, we previously proposed a natural synchronization scheme for uncoupled wireless devices [5], where we use natural environmental noises, such as the temperature and humidity of the air, environmental sounds, and so forth [5]-[7]. Those environmental natural noises obtained at the neighboring devices have high similarity. By adding such similar noises to nonlinear oscillators operating in the neighboring devices, our proposed scheme realizes the natural synchronization of these devices without any interactions or exchanges of the signals. We have already shown the feasibility of the proposed synchronization for limit-cycle oscillators by using real natural environmental noises, such as the humidity and temperature of the air, sound, electromagnetic waves, and so forth [5]-[7].

In this paper, we introduce chaotic oscillators and investigate the feasibility of the proposed natural synchronization for chaotic systems. By synchronizing chaotic oscillators, unconnected devices with chaotic temporal behavior can be synchronized, which will be useful for various new applications. However, the performance of chaotic oscillators under our method has not been considered. First, we evaluate the synchronization rate of chaotic oscillators with additive correlated Gaussian noises. Second, we introduce pairs of real natural environmental data obtained in neighboring areas, and analyze the feasibility of the proposed scheme for chaotic oscillators using real environmental noise.

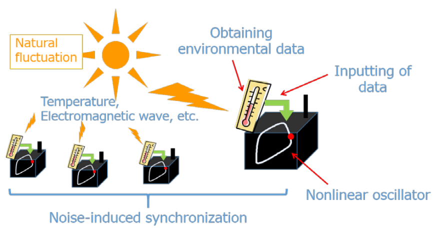
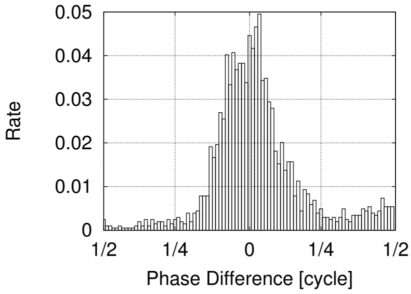


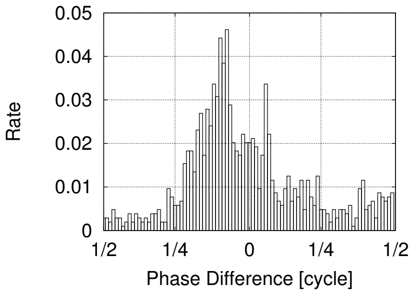
Figure 1: Proposed synchronization system using natural environmental fluctuations

2. Synchronization Induced Using Environmental Noise

Our proposed synchronization scheme is based on a noise-induced synchronization phenomenon by which uncoupled oscillators can be synchronized by adding common noise to



(a) Histogram of time difference when using common noise (cross-correlation coefficient: 1.0)



(b) Histogram of time difference when using cross-correlated noise (cross-correlation coefficient: 0.8)

Figure 2: Histograms of time difference between two Rössler oscillators when adding common noise and cross-correlated noise: (a) histogram with added common noise, (b) histogram with added cross-correlated noise

them. We have applied this phenomenon to synchronization among unconnected devices.

Figure 1 shows a schematic image of our proposed system. We assume that the devices are placed in neighboring areas and that these devices have sensors on them to obtain natural environmental noises. These environmental noises obtained in neighboring devices have high cross-correlation [5]. The devices also have their own nonlinear oscillator operating independently. The obtained environmental noise is added to each oscillator. The oscillators of these devices in neighboring areas are synchronized by noise-induced synchronization. Therefore, the unconnected devices operating the oscillators can be synchronized by adding the obtained environmental noise to each device [5].

We have already shown that limit-cycle oscillators can be synchronized by using real natural noises, such as temperature, humidity, environmental sound and electro-magnetic waves [5]-[7]. We have implemented this proposed scheme in wireless sensor network devices and shown the feasibility of the proposed method for real unconnected devices [7]. We have also implemented the proposed synchronization scheme using several personal computers (PCs) equipped with microphones. Each PC in a neighboring area obtains the environmental sound independently and inputs the sound to a its operating nonlinear oscillator. The oscillators on the PC were synchronized without any interactions between them [6].

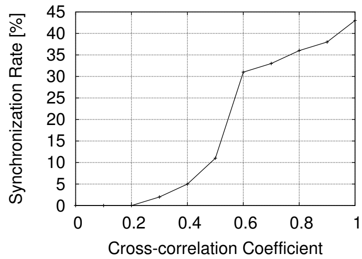


Figure 3: Relationship between synchronization rate and cross-correlation of input noises

3. Performance of Noise-Induced Synchronization of Chaotic Oscillator Using Cross-Correlated Input Sequences

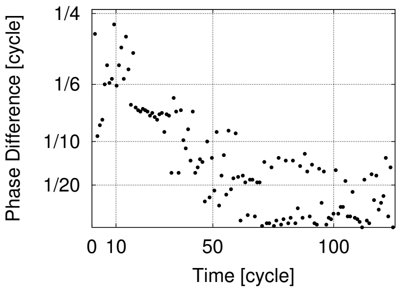
3.1 Synchronization of chaotic oscillators using cross-correlated noises

In this paper, we introduce the synchronization of chaotic oscillators using environmental noise with our proposed scheme. Chaotic oscillators can also be synchronized with each other by adding an identical noise to each oscillator [1]. There may be various applications of our proposed scheme to synchronize unconnected chaotic oscillators using natural environmental noises. For example, using chaotic oscillators synchronized by our proposed natural synchronization scheme, it may be possible to realize chaotic intermittent communication.

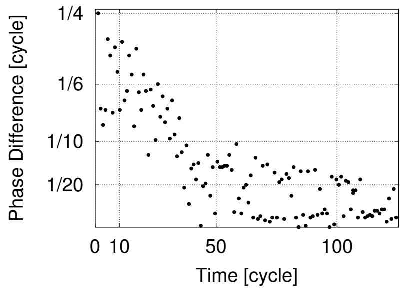
In the previous research on the noise-induced synchronization of chaotic oscillators, identical white Gaussian noises were used for the additive input noise [1]. In our proposed method, we use cross-correlated noises obtained from the environment. Therefore, we first investigate the synchronization rate of chaotic oscillators with added cross-correlated noise.

In this paper, we use the Rössler system as the chaotic oscillators. We assume that there are two chaotic oscillators $\mathbf{X}_1$ and $\mathbf{X}_2$ with additive input noises ξ_1 and ξ_2, respectively. In order to evaluate the temporal differences between the oscillators, we define the Poincaŕe section on $\{x > 0, y = 0\}$. The temporal differences are calculated at the times when the oscillators pass through the Poincaŕe section.

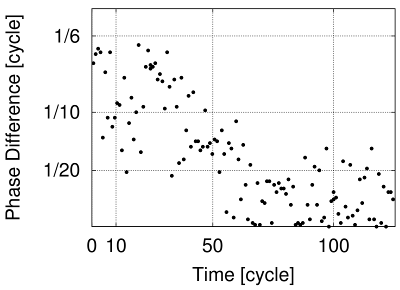
Figures 2(a) and 2(b) show histograms of the phase differences between two unconnected Rössler oscillators with additive common noise and cross-correlated noise, respectively. From these figures, it is found that the frequency of a phase



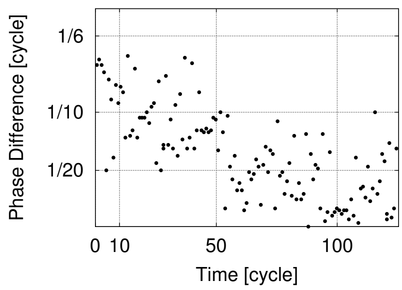
(a)



(b)



(c)



(d)

Figure 4: Time series of phase differences between the Rössler oscillators with added natural environmental sound: The pairs (a) (b) and (c) (d) have the same initial phase difference between the oscillators. Different sequences of environmental sound are used for each pair

difference of around 0 is higher than that of other differences. That means that Rössler oscillators can be synchronized even using cross-correlated noise.

Figure 3 shows the relationship between the synchronization rate and the cross-correlation of input noises. In this case, we set the noise intensity ϵ at 0.3. From this figure, it is found that the synchronization rate is over 40% when we use identical noise (cross-correlation coefficient of 1), but the rate decreases as the cross-correlation is reduced.

3.2 Synchronization of chaotic oscillators using natural environmental fluctuations

We use natural environmental fluctuations as the input noise. In this paper, we use environmental sound as the input noise for chaotic noise-induced synchronization. The noises used in this paper a have high cross-correlation coefficient [6]. We normalize the obtained sound time series to a mean of 0 and a standard deviation of 1.0. We input the sound noise to the chaotic oscillator, and the amplitude of the noise is adjusted by the amplitude ϵ. We use the Rössler oscillators as the chaotic oscillators.

Figures 4(a)-4(d) show time series of the phase differences between two unconnected Rössler oscillators with natural environmental sounds added to each oscillator. Different pairs of environmental sound data collected in neighboring areas are used for each result. These results show that each pair of environmental sound data collected in the neighboring areas synchronizes the unconnected chaotic oscillators.

4. Evaluation of Collision Probability for Proposed Synchronization Method

Our proposed method can reduce collision with a cyclic interference source. We evaluated the collision probability for our proposed method.

Figures 5 and 6 show periods of Rössler and Lorenz oscillators, respectively. From Figs.5 and 6, we find that the cycle of the chaotic oscillator fluctuates widely. The average periods of a cycle in Figs.5 and 6 are 251.08 and 250.53 and the standard deviations are 8.73 and 36.89, respectively.

We evaluated the collision probability for the chaotic synchronization system with a cyclic interference source. The period of the cyclic interference source was set to the same values as those in the Rössler and Lorenz oscillators. We assume that these communication models have a duty ratio in the communication period. In the period of non-communication, the function of communication is dormant. In this investigation, we assume that the cyclic interference source and our proposed system are started at the same time. Figure 7 shows the relationship between the collision probability and the duty ratio of communication period in one cycle

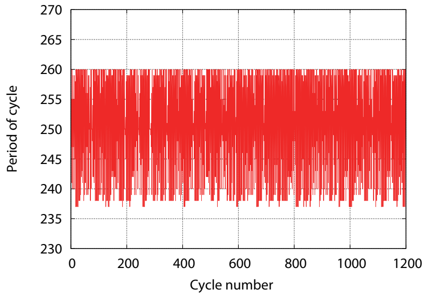


Figure 5: Periods of Rössler oscillator

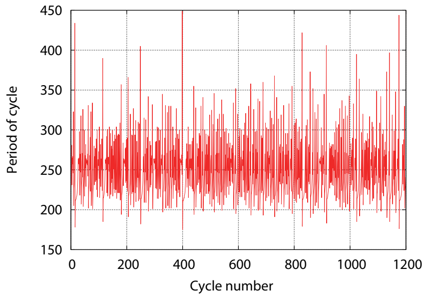


Figure 6: Periods of Lorenz oscillator

of chaotic oscillators. If the cycles of communication systems are fixed, the collision probability should be 100%. From Fig.7, we find that our proposed synchronization system can reduce collision with the cyclic interference source. We also find that the Rössler oscillator has fewer collisions than the Lorenz oscillator.

5. Conclusion

In this paper, we have investigated the noise-induced synchronization between the Rössler oscillators using natural environmental fluctuations obtained in neighboring areas. The natural environmental fluctuations are cross-correlated in neighboring areas. We evaluated the synchronization of chaotic oscillators by adding cross-correlated white Gaussian noises. Our experimental results clarified that the chaotic oscillators can be synchronized even using such cross-correlated noises. Furthermore, we also used natural environmental fluctuations, natural sound time series, as the input noise.

Our results have shown that chaotic oscillators operating on unconnected devices can be synchronized by applying natural signals such as a natural sound time series. We also evaluated the collision probability for the proposed system with a cyclic interference source. When the duty ratio of the communication period was set to 5%, the collision probabilities for Rössler and Lorenz oscillators was 6.67% and 10.00%, respectively. We have shown that using our proposed method with chaotic oscillators can reduce collision with a cyclic interference source.

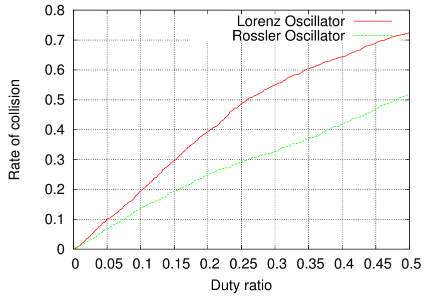


Figure 7: Relationship between duty ratio and collision rate of Rössler oscillator and Lorenz oscillator

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