Synchronization features of spiral and target wave structures

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Abstract. The interaction of two lattices of nonlocally coupled oscillators is considered. The synchronization effects of spiral waves including spiral wave chimeras are studied in lattices of Nekorkin maps, and the synchronization features of target waves and target wave chimeras are explored in lattices of van der Pol oscillators. No-flux boundary conditions and random initial conditions are used in both cases. We explore the features of mutual synchronization of spiral wave structures and target wave structures for dissipative and inertial inter-layer coupling between the lattices and for local and nonlocal intra-layer coupling between the lattice oscillators. It is established that the mechanisms of their synchronization are different. It is shown that spiral wave chimera states are not completely synchronized even with large values of the inter-layer coupling strength. In contrast, target wave chimera states can be synchronized including synchronization of incoherent cores.

Introduction

Recently, much attention has been paid to the study of synchronization of various complex spatio-temporal structures (see refs 46–53 in [1]). It seems important and interesting to explore the features of synchronization of both spiral and target wave structures. The obtained results can have both scientific and practical significance. It has been established that target and spiral wave modes characterize the regimes of heart muscle functioning. The heart rate driver is the source of excitation of target waves in the heart muscle, and these waves characterize the normal heart function. In cases of heart diseases associated with the heart muscle fibrillation and tachycardia, spiral waves modes are generated when the front of a target wave is destroyed. Spiral waves are one of the reasons for the disruption of the normal functioning of the heart, and from this point of view, their occurrence is undesirable [2-3]. The aim of the work is to show similarities and differences in the synchronization effect for both spiral and target wave spatio-temporal structures.

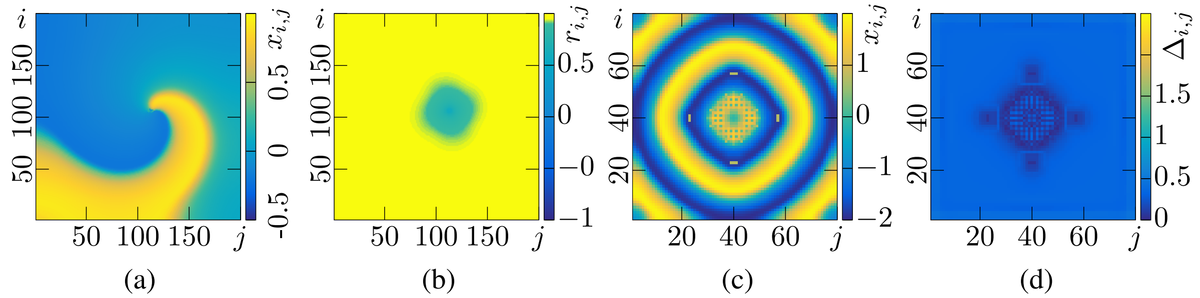

Figure 1: Snapshot of synchronized structure (a) and corresponding correlations map (b) for spiral wave chimeras in the lattices of Nekorkin maps; snapshot of synchronized structures (c) and root-mean-square deviations map (d) for target wave chimeras in the lattices of van der Pol oscillators.

Results and discussion

As numerical modeling shows, the effects of synchronization for spiral and target wave chimeras differ significantly. Incoherent cores of spiral wave chimera states decrease in the synchronization mode and do not realize a complete synchronization effect, but synchronize only partially even if the value of the inter-lattice coupling strength of the interacting 2D ensembles is sufficiently large. Besides, it is shown that there is a cluster of desynchronized oscillators not only when obvious incoherent cores are observed in the spiral wave chimera, but also when the regular spiral wave is realized. (Fig. 1(a,b)). The two-layer network of coupled van der Pol oscillators can demonstrate complete synchronization of target wave chimera states, when both coherence regions and incoherent cores of the chimera structure are synchronized. This finding differs from the corresponding result obtained for spiral wave chimera regimes. The incoherent cores of the target wave structures are synchronized and this effect is achieved at lower values of the inter-layer coupling strength as compared with those ones for synchronization of the coherence regions. In other words, the clusters of oscillators with incoherent dynamics are synchronized earlier with increasing the inter-layer coupling strength. Complete synchronization of the whole wave structures, including the coherence regions, can be achieved only when the inter-layer coupling becomes rather strong.

References

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