Synchronization Conditions For Nonlinear Oscillator Networks

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Abstract

The synchronization of nonlinear oscillators is a fundamental phenomenon with applications across various domains, including neuroscience, power grids, and communication networks. Understanding the conditions that ensure synchronization in networks of coupled oscillators is crucial for the design and control of such complex systems. This thesis addresses the synchronization of nonlinear oscillators under different coupling configurations, establishing theoretical conditions and validating them through simulations and experiments. Using the Lyapunov-Floquet theory and the Master Stability Function (MSF) approach, this study derives necessary and sufficient conditions for synchronization. The analysis is performed for different coupling scenarios, including identical coupling, where a positive coupling constant guarantees synchronization in a network of identical nonlinear oscillators coupled linearly in a full-state fashion; partial-state coupling, where stability is determined through the time evolution of the determinant of the state transition matrix and the behavior of Floquet multipliers; non-identical coupling over an undirected graph for identical nonlinear oscillators, where synchronization conditions are derived based on the spectral properties of the coupling matrix; and non-identical coupling, where synchronization conditions for coupled nonlinear oscillators with non-identical coupling gains over directed graphs are investigated.

The contributions of this work include a comprehensive theoretical framework for synchronization in networks of coupled nonlinear oscillators, proof that positive coupling strength stabilizes eigenmodes in both full-state and partial-state coupling scenarios, validation of theoretical findings through numerical simulations, circuit simulations, and experimental implementations using electronic circuits, and insights into remotely synchronized identical nonlinear oscillators, emphasizing the critical role of coupling strength in maintaining synchronization. The findings in this thesis significantly enhance the understanding of nonlinear oscillator synchronization and provide practical methodologies for designing stable networked systems.