Controlling Synchronization in Complex Networks

N. A. M. Araújo1*, V. H. P. Louzada1, J. S. Andrade Jr.2, and H. J. Herrmann1,2

1Computational Physics for Engineering Materials, IFB, ETH Zurich, Wolfgang-Pauli-Strasse 27, CH-8093 Zurich, Switzerland
2Departamento de Física, Universidade Federal do Ceará, 60451-970 Fortaleza, Ceará, Brazil
*E-mail: nuno@ethz.ch

Abstract
Examples of synchronization can be found in a wide range of phenomena. While in several situations the formation of a coherent state is positive as, for example, in the blinking of fireflies to attract partners and the synchronized motion of bearings, in many others it is unpleasant and should be mitigated. Examples are the epileptic seizures, traffic congestion in communication networks, and the collapse of constructions. Here, we first describe how the concept of synchronization can be applied to study the motion of bearings and to find strategies of improving their synchronizability. Then, we discuss the use of contrarians to suppress undesired synchronization.

Keywords: control, synchronization, bearings, contrarians

1. Introduction
A coherent synchronized motion can naturally emerge in a network of oscillators when the coupling intensity exceeds the synchronization threshold [1, 2, 3]. Synchronization is the mechanism responsible for numerous phenomena such as, e.g., the vital contraction of cells producing the heartbeats, the harmony in an orchestra, and the coherence of an audience clapping after a performance [4]. However, undesired synchronization might also be responsible for neural diseases and collapse of technical infrastructures and networks [5, 6]. Therefore, understanding how synchronization can be enhanced or mitigated is a question of paramount importance.

2. Bearings: enhancing synchronization
Motter et al. [7, 8] showed that synchronization can be enhanced on scale-free topologies by asymmetric weighted couplings, in contrast to random graphs, where the most efficient configuration corresponds to a uniform coupling strength. By expressing the interaction strength $s_i$ of site $i$ in terms of its degree $k_i$ as $s_i \equiv k_i^{-\beta}$, where $\beta$ is a tunable parameter, they observed that the properties of the coupling Laplacian matrix lead to optimal synchronization at $\beta = 1$. Under this condition of maximum synchronizability, the coupling strength just counterbalances the number of connections, thus minimizing the total cost associated with the network of couplings.

Bearings are mechanical dissipative systems that, when perturbed, relax toward a synchronized (bearing) state. They can be perceived as a physical realization
of complex networks of oscillators with asymmetrically weighted couplings. Accordingly, these networks can exhibit optimal synchronization properties through fine-tuning of the local interaction strength as a function of node degree. Araújo et al. [9] showed that, the synchronization of bearings can be maximized by counterbalancing the number of contacts and the inertia of their constituting rotor disks through the mass-radius relation, \( m \sim r^\alpha \), with an optimal exponent \( \alpha = \alpha_x \) which converges to unity for a large number of rotors. Under this condition, the average participation per disk is maximized and the energy dissipation rate is homogeneously distributed among elementary rotors.

3. Contrarians: hindering synchronization

Louzada et al. [10] proposed the use of contrarians to suppress undesired synchronization. The idea is to introduce a second population of contrarian oscillators coupled to the network of normal oscillators but following a different dynamics. They extended the Kuramoto model to include such contrarians and studied different strategies. They showed that the most efficient one solely requires local information. Additionally, by analyzing the model on different network topologies they concluded that even when the distribution of neighboring interactions is narrow, significant improvement is observed when contrarians sit at the highly connected elements.

Acknowledgements

We acknowledge financial support from the European Research Council (ERC) Advanced Grant 319968-FlowCCS, the Brazilian Agencies CNPq, CAPES, FUNCAP and FINEP, the FUNCAP/ CNPq Pronex grant, and the National Institute of Science and Technology for Complex Systems in Brazil.

References