REINFORCEMENT LEARNING FOR SEMI-ACTIVE STRUCTURAL CONTROL AND DECENTRALIZED MITIGATION OF VIBRATIONS: DEVELOPMENT OF NEW CONTROL ALGORITHMS AND ASSESSMENT OF THEIR EFFICIENCY

The idea that we learn by interacting with our environment
is probably the first to occur to us when we think about the nature of learning
/Sutton & Barto, 2020/

Project goal

We intend to develop and verify a *fundamentally new and unexplored approach* to structural control by:

- Customizing, developing and applying the machine learning techniques of reinforcement learning (RL) for the purpose of structural control.
- Investigating and optimizing their performance and robustness in semi-active global and decentralized mitigation of structural vibrations.
- Verification of the developed methods in numerical and experimental setups.

Motivation

Active structural control can be summarized as *working against the structure* by applying external control forces. This is potentially dangerous. In contrast, recently surging semi-active control is based on a fundamentally different, nature-inspired paradigm of *dynamic self-adaptation*: it relies on low-cost adaptation of local structural characteristics. The techniques currently employed to design structural control systems are overwhelmingly classical and analytical. They are time-proven and efficient in applications to active control of linear systems. However, their effective application is much more difficult in case of semi-active control. This is due to the nature of the semi-active actuators, which are energy-efficient and often fail-safe but hard to be effectively processed using classical formulations. There is thus a clear need for new, effective and robust techniques applicable in semi-active control of structures, and this is the main motivation behind this project.

Reinforcement learning (RL), a field of machine learning, is founded on the idea of learning from interaction with the environment. RL approaches achieved recently exceptional successes in a variety of hard problems, ranging from the superhuman level of proficiency in the games of chess and Go, through thermal soaring of gliders and swimming by body undulation, to autonomous car driving. The algorithmic framework of RL provides two features (*trial-and-error search* and the ability of *handling delayed rewards*) that make it perfectly suited for tackling hard problems of structural control. Astonishingly, RL seems to be largely ignored in structural control. We are aware of only a handful of attempts which, although pioneering, are limited and involve active control, simple structures or simple RL approaches. This project aims at bridging this gap.

Planned research

Instead of designing control algorithms ourselves, we will design a framework that learns them by itself in repeated trial-and-error interactions with simulated virtual environments. We will start with simple structures and simple control aims to form basic algorithmic building blocks for the subsequent tasks. Then, we will consider decentralized control of modular structures and aim to generalize the control algorithms to be effective in various geometric configurations of modules and to rely on the signals from their local neighborhood only. This should lead to plug-and-play type of controlled modules. Finally, we will promote robustness, that is ensure the control is enough error-tolerant to cope with real-world structures. To achieve these aims, we will adapt, propose and utilize various concepts: ensemble learning, collective control, actor-critic architecture, etc. The performance will be assessed numerically and experimentally, and compared to classical control.

Substantial results expected

Structural vibration is a ubiquitous engineering problem. The project will contribute to the advancement of cost-effective, lightweight and safe structures by development of new RL-based frameworks for robust semi-active structural control. In particular, we expect the project to result in

- RL framework for learning general robust control algorithms applicable at the global and local levels of complex structures, including modular structures.
- A number of specific semi-active control algorithms.
- Two specific RL techniques that promote generalized, versatile and error-tolerant control algorithms: model ensemble learning and ensemble (collective) control.

We expect the project to generate <u>original high-quality results</u> publishable in world leading scientific journals in the fields of structural mechanics, smart structures and structural control.