Closed-loop turbulence control using machine learning[0]

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Active turbulence control is a rapidly evolving, interdisciplinary field of research. In particular, closed-loop control with sensor information can offer distinct benefits over blind open-loop forcing. The range of current and future engineering applications of closed-loop turbulence control has truly epic proportions, including cars, trains, airplanes, jet noise, air conditioning, medical applications, wind turbines, combustors, and energy systems. This includes, for instance, many configurations presented at this workshop.

A key feature, opportunity and technical challenge of closed-loop turbulence control is the inherent nonlinearity of the actuation response. For instance, excitation at a given frequency will affect also other frequencies. Such frequency cross-talk is not accessible in any linear control framework. In this presentation, we present a feedback control strategy which identifies and exploits the best nonlinear actuation opportunities in an unsupervised manner. This strategy, called *machine learning control (MLC)* in the sequel, optimizes a cost functional by a model-free exploration of control laws. MLC has several competitive key features: (1) The resulting feedback law may result in in-time, adaptive or open-loop actuation, depending on which is optimal for the cost functional. (2) The optimization uses an evolutionary machine learning method, which, by construction, is unlikely to be trapped in local minima. (3) No dynamical model of the plant is required for control design.[12] (4) No working open-loop control is required in contrast to extremum-seeking approaches.

The approach is illustrated for a strongly nonlinear dynamical system which is not accessible to linear control design. MLC's capabilities are demonstrated for closed-loop control in four different experimental shear flows setups: (1) the TUCOROM mixing layer tunnel, (2) the Görtler PMMH water tunnel with a backward facing step, (3) the LML Boundary-Layer wind tunnel with a separating turbulent boundary layer, and (4) the Malavard wind tunnel with the SepaCoDe ramp. In all cases, MLC finds a control which yields a significantly better performance with respect to the given cost functional as compared to the best previously tested open-loop actuation.

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[0]Or: stop thinking and let the computer and your experiment do the hard work!

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[12]For some people, this spells a big relief.

BIO: Bernd NOACK develops closed-loop flow control solutions for cars, airplanes and transport systems — in an interdisciplinary effort with dedicated colleagues, PostDocs and PhD students at Institute PPRIME (Poitiers, France) and with the groups of Profs. M. W. Abel, J.-L. Aider, S. Brunton, S. Krajnović, A. Kourta, R. Martinuzzi, M. Morzyński, R. K. Niven, C. O. Paschereit, B. Protas, R. Radespiel, R. Semaan, M. Schlegel and industry. He is Director of Research CNRS at Institute PPRIME, Co-Chair of 'Flow Modelling & Control' at TU Braunschweig, and Senior Researcher at the Collaborative Research Center 'Fundamentals of high lift for future transport aircraft' (SFB 880, TU Braunschweig). He has co-authored about 180 publications, 2 patents and 1 book on ROM and flow control. His work has been honored by numerous awards, e.g. a Fellowship of the American Physical Society, an ANR Chair of Excellence (senior category), and a Scientific Excellence Award of CNRS.

Subset of the turbulence control team at the TUCOROM wind-tunnel. From top left to bottom right: S. Brunton, V. Parezanovic, J.-C. Laurentie, M. Segond, T. Duriez and B.R. Noack.