Proceedings of the 1st international Symposium on AI and Fluid Mechanics
Abstract No S2 A1

Automatic search for an effective cost function in the suboptimal control of cylinder wake by genetic programming

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Abstract

The flow around a circular cylinder has been considered a typical benchmark problem because of its geometric simplicity while containing essential physics and complexity of a flow around a bluff body[1]. Among various control methodologies, the suboptimal control theory provides a control input that minimizes a user-specified cost function without conducting an adjoint analysis[2], assuming a short time horizon. The methodology has been successfully applied to various flow control problems, including a circular cylinder wake[1], a turbulent channel flow[3], and a backward-step facing flow[4]. Despite its success, the suboptimal control framework has one challenge: its long-term control performance depends critically on how the cost function is defined[1,3,5]. A previous study[1] demonstrates that the cost function quantifying the deviation of the pressure from that under the potential (inviscid) flow condition achieves superior drag reduction compared to the case where the drag is directly set as a cost function. A similar non-intuitive choice of the cost function for better performance can be found in other literature[1–3,6]. Notably, these cost functions were identified on a trial-and-error basis with a limited search space, and there are no general guidelines for setting the cost function for a given objective, such as drag reduction.

Building upon our previous work considering a turbulent channel flow[7], the present study employs genetic programming[8–10]—a machine learning method that optimizes equations—to systematically examine and optimize various cost function formulations (see Figure 1 for the outline of the process). As shown in Figure 2, our preliminary investigation reveals that the present scheme can find a cost function that drastically reduces drag for three-dimensional wake. Our final paper and presentation will focus on the identified cost function through comprehensive genetic programming optimization. Moreover, we will analyze the wake modifications and assess how much the outcomes depend on the Reynolds number.

Keywords: Flow control, suboptimal control, genetic programming

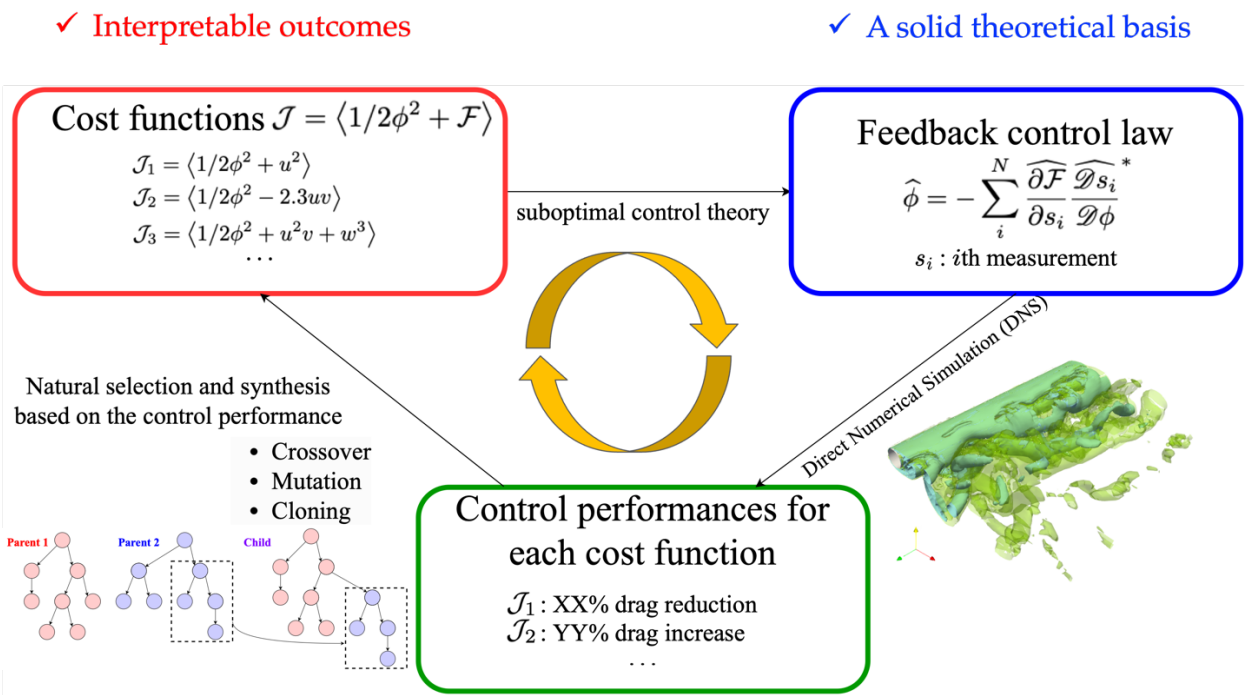

Figure 1 The schematic of the present optimization scheme for the cost functional optimization problem

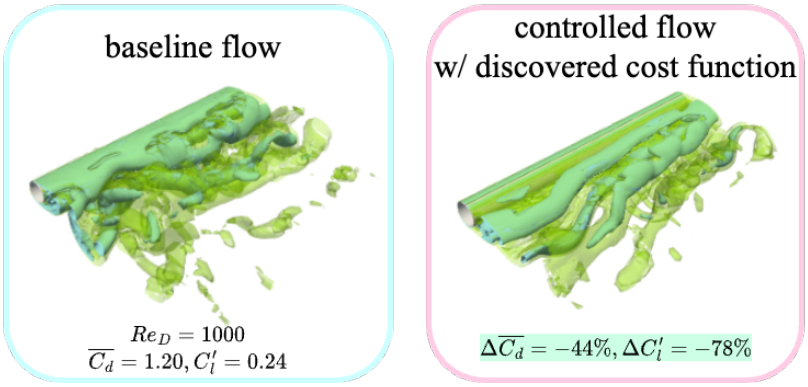

Figure 2 Perspective views of the wake vortices behind the cylinder without and with the present control scheme

1. Min, C. & Choi, H. Suboptimal feedback control of vortex shedding at low Reynolds numbers. *Journal of Fluid Mechanics* **401**, 123–156 (1999).

2. Bewley, T. R., Moin, P. & Temam, R. DNS-based predictive control of turbulence: an optimal benchmark for feedback algorithms. *Journal of Fluid Mechanics* **447**, 179–225 (2001).

3. Lee, C., Kim, J. & Choi, H. Suboptimal control of turbulent channel flow for drag reduction. *Journal of Fluid Mechanics* **358**, 245–258 (1998).
4. Kang, S. & Choi, H. Suboptimal feedback control of turbulent flow over a backward-facing step. *Journal of Fluid Mechanics* **463**, 201–227 (2002).
5. Choi, H., Jeon, W.-P. & Kim, J. Control of Flow Over a Bluff Body. *Annual Review of Fluid Mechanics* **40**, 113–139 (2008).
6. Flinois, T. L. B. & Colonius, T. Optimal control of circular cylinder wakes using long control horizons. *Physics of Fluids* **27**, 087105 (2015).
7. Yugeta, Y. & Hasegawa, Y. AUTOMATIC EXPLORATION OF COST FUNCTION FOR SUBOPTIMAL CONTROL OF TURBULENT FLOW BY MACHINE LEARNING. in *European drag reduction and flow control meeting 2024* (Turin, Italy, 2024).
8. Gautier, N. *et al.* Closed-loop separation control using machine learning. *Journal of Fluid Mechanics* **770**, 442–457 (2015).
9. Zhou, Y., Fan, D., Zhang, B., Li, R. & Noack, B. R. Artificial intelligence control of a turbulent jet. *Journal of Fluid Mechanics* **897**, A27 (2020).
10. Koza, J. R. Genetic programming as a means for programming computers by natural selection. *Stat Comput* **4**, 87–112 (1994).