Blackbox Optimization for Helicopter Noise Reduction

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1 Introduction

The problem considered in this study belongs to the class of trajectory optimization in the Air Traffic Management (ATM) context. The *optimal* trajectories to be designed are for a specific type of aircraft: rotary-wing aircraft, also called *rotorcraft*. The goal of the optimization is to minimize the noise footprint of this kind of trajectory. This problem has gained interest recently with the emergence of Urban Air Mobility since more and more rotorcraft operations above cities are expected in a near future. However, the noise footprint that would be generated by such operations could be considered as an impediment to their development. In this study, a focus is made on helicopter trajectories. Even though, out of the pandemic context, the number of helicopter operations is negligible compared to commercial airplane traffic, they may contribute to noise annoyance in certain geographical areas such as Issy-les-Moulineaux in France [2]. This motivates the growing interest in the design of optimal helicopter trajectories.

In this study, an helicopter trajectory is modeled as a succession of *waypoints*. A flyable trajectory is computed afterwards from the waypoints thanks to some interpolation method. A *waypoint* is described by four variables: the first three, x, y and z, represent the helicopter position in the 3D space, the fourth one represents its velocity v. The decisions variables of our problem are the variables (x_i, y_i, z_i, v_i) for all $i \in W$, where W is the set of waypoints. The number of waypoints $|W|$ is fixed at the beginning of the optimization. It depends on the problem instance, since the waypoints are located accordingly to obstacle positions. For operational reasons, x and y are continuous variables whereas z and v are integer variables. Therefore, the problem is a mixed-integer optimization problem. It is a constrained problem: all variables are bounded, and additionally there are some flyability constraints (e.g. rate of descent, rate of turn...) and environment constraints, such as obstacle avoidance, to be taken into account. The objective, to be minimized, is a measure of the noise annoyance generated by an helicopter trajectory. For the problem at hand, the objective function evaluations are obtained by numerical simulations through an industrial software. Thus, the optimization problem in our study belongs to the class of *blackbox optimization*.

2 Solution approach and contribution

Computational approaches to solve blackbox optimization problems are based on methods that do not need any gradient information. In this study, where there is no information about the derivatives of the objective function, the MADS (Mesh-Adaptive Direct Search) algorithm [1] is applied through its NOMAD [3] implementation. MADS is a local direct search method for which each iteration is divided in two steps: the *search* and the *poll*. The *search* step is a global search to determine the best current incumbent on a prescribed mesh and the *poll* step consists in a local search around that best incumbent using a set of predefined directions. A guarantee of local convergence, based on the *poll* step, can be provided.

MADS needs to be provided with an initial solution (i.e., an initial trajectory in this study). As it is a local optimization method, the final optimal solution closely depends on the choice of that initial solution. In this work, the initial trajectory is chosen through a greedy constructive algorithm minimizing a weighted criterion of distance travelled and population overflown.

Additionally, surrogate functions can be used within a MADS algorithm to replace computationally expensive simulation. In this work, different types of surrogates of the blackbox function, which are cheaper to evaluate, are investigated. Some of these surrogates are based on physics approximations of the blackbox objective function, while others are based on simplifications in the numerical simulation used to get the value of the objective. Thus, we do not resort to a specific method to build surrogates, such as RBF-based surrogates [4] Each of the proposed surrogates is embedded in an algorithmic scheme, where, first, the surrogate is used for the evaluation of the current incumbent, then, the algorithm switches to the real simulation to reach the optimal solution.

3 Conclusion

In this study, we assessed the benefits of using different types of surrogate to improve the performance of the MADS algorithm, for a real-world application arising in helicopter trajectory optimization. Numerical results on a bench of test cases validate the proposed approach.

References

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