Using Direct Methods for Solving Optimal Missile Control Problems

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Abstract:

Optimization is very important part of the flight vehicles' design process. It is used to tailor the performance of the object and to maximize its efficiency during flight. It is broadly used in every branch of the design process including aerodynamics, propulsion, structural design and GNC topics. The latter is particularly important dealing with all kinds of missiles. The optimized guidance and control algorithms allow for fulfilling the mission objectives with high precision and accuracy. One example are the air defense systems, which need to neutralize foreign vehicles with high precision, the other one are the surface to surface missiles that should pinpoint the distant ground-based targets. Lowering the impact point dispersion of such missiles is a key aspect that requires optimal control algorithms development.

Various types of control and guidance methods and algorithms are used. The most widely utilized is proportional navigation with many of its variants. This method tries to keep the line-of sight vector, which connects missile and target, fixed relative to some reference system. In recent times various optimal control method gained more interest due to the increase in computational power, because with the exception of simple problems they need to be solved numerically. Generally methods for solving optimal control problems can be divided into direct and indirect. The former use a general nonlinear programming solvers to obtain a solution and the latter use the calculus of variations to determine the optimality conditions, like Pontryagin's Maximum Principle, formulate Hamiltonian and solve the Two Point Boundary Value Problem as a result.

In this article the use of direct methods for solving an optimal control problem for a surface to surface missile will be presented. The missile examined in the paper, for simplification purposes, is controlled by two thrusters that can apply a force in both direction in two perpendicular planes of the missile. The value of the thrust of both thrusters as a function of time is the optimization parameter. The missile model was developed in MATLAB/Simulink environment and was validated using the flight data and then converted to C++ to increase the computation speed. The article will compare the results of optimization regarding accuracy and time of a generally available online solver IPOPT and solver developed by the author. Also the influence of the use of automatic differentiation compared to finite difference method for the gradient calculations will be examined. The results showing the missile accuracy with the optimal control will be presented.