Duality for Convexification of Autonomous Control Problems

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ABSTRACT: Many future engineering applications will require dramatic increases in our existing Autonomous Control capabilities. These include robotic sample return missions to planets, comets, and asteroids, formation flying spacecraft applications, applications utilizing swarms of autonomous agents, unmanned aerial, ground, and underwater vehicles, and autonomous commercial robotic applications. A key control challenge for many autonomous systems is to achieve the performance goals safely with minimal resource use in the presence of mission constraints and uncertainties. In principle these problems can be formulated and solved as optimization problems. The challenge is solving them reliably onboard the autonomous system in real time.

Our research has provided new analytical results that enabled the formulation of many autonomous control problems in a convex optimization framework, i.e., convexification of the control problem. The main mathematical theory used in achieving convexification is the duality theory of optimization. Duality theory manifests itself as Pontryagin’s Maximum Principle in infinite dimensional optimization problems and as KKT conditions in finite dimensional parameter optimization problems. Both theories were instrumental in our developments. Our analytical framework also allowed the computation of the precise bounds of performance for a control system, e.g., the bounds of agility for a vehicle, so that we can make accurate quantification of the capabilities enabled. This proved to be an important step in rigorous V&V of the resulting control decision making algorithms.

This presentation introduces several real-world examples where this approach either produced dramatically improved performance over the heritage technology or enabled a new technology. A particularly important application is the fuel optimal control for planetary soft landing, whose complete solution has been an open problem since the Apollo Moon landings of 1960s. We developed a novel “lossless convexification” method of solution, which will enable the next generation planetary missions, such as Mars robotic sample return and manned missions. Another interesting example is Markov chain synthesis with temporal and spatial safety constraints.