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PATH PLANNING ON RIEMANNIAN MANIFOLDS WITH APPLICATIONS TO QUADROTOR LOAD TRANSPORTATION

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Abstract

In recent years, path planning has become extremely prevalent in robotic and control engineering applications. In many cases, this amounts to finding trajectories that interpolate a set of knot points while minimizing some quantity of interest, such as the energy consumption, and while completing certain tasks, such as the evasion of prescribed obstacles or inter-agent collisions in the case of multi-agent systems. Often times, such a problem can be recast as a particular variational problem on a Riemannian manifold, where the avoidance tasks are framed in terms of some scalar field on the manifold called the artificial potential.

In this thesis, I study such a variational problem from the ground up. I begin by deriving a set of necessary and sufficient conditions for optimality using the tools of geometric mechanics, prove the existence of global minimizers, classify certain types of local minimizers. Conditions on the artificial potential are found which can be used to guarantee the successful completion of the avoidance tasks, and particular families of potentials are constructed which can be used in a number of applications. The necessary and sufficient conditions for optimality are then reduced by symmetry in the special cases that the underlying Riemannian manifold is a Lie group equipped with a left-invariant metric, or is a Riemannian homogeneous space of such a Lie group. This allows for computationally-feasible trajectories in a number of important robotic applications. Finally, this formalism is applied to the application of teams of quadrotor UAVs transporting a cargo via elastic cables. A control scheme is developed and analyzed which guarantees the exponential convergence of the state variables to arbitrary desired trajectories provided sufficiently small initial errors, and it is subsequently shown that the energy-optimal trajectories in such a control system correspond to the variationally defined curves that were previously studied.

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