Overhead the albatross hangs motionless upon the air (Dynamic Soaring)

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Topics covered:

- Trajectory optimization
- Lyapunov theory
- Trajectory stabilization through local linearization/LQR
- Stability under uncertainty

Albatrosses can travel a thousand kilometres daily over the oceans. They utilise the horizontal wind gradients a few metres above the ocean using a flight strategy called dynamic soaring. Dynamic soaring can be described as a sequence of upward and downward climbs through the wind shear layers. This motion is obtained by means of intricate and dynamic flight manoeuvres. In this project we aim to simulate these minimum cost trajectories under different wind conditions.

Using albatross dynamics from [Bousquet et. al.], we will use direct collocation on the nonlinear dynamics to optimize a trajectory which minimizes energy expenditure during the albatross flight. For the cost function, we will minimize the elevation loss during flight as a proxy for energy lost. In contrast to the paper, which finds the minimum wind required for energy conservation, we propose to choose a wind value below that which allows energy conservation and find the flight under these suboptimal conditions.

When executing the optimized albatross trajectory, realistically the albatross will experience deviations from the planned trajectory. We plan to incorporate trajectory stabilization, using finite-horizon LQR to attract the albatross to its nominal trajectory. We also plan to compute the invariant “funnels” around the trajectory using Lyapunov analysis. We will perform simulations to demonstrate that our invariant regions are accurate under the modeling assumptions made.

If time allows, we would like to investigate how each phase of the problem (the optimal trajectory, and the shape of the invariant “funnels” around the trajectory) is impacted by varying the assumed wind speed. This will give us a sense of the stability of the albatross’s flight in the presence of uncertainty.

Deliverables:

For the first project update, we will model albatross flight using equations of motion developed in [Bousquet et. al.], [Denny et al.]. We will have begun to develop the direct collocation scheme for trajectory optimization. This will include formally forming the cost function and the constraints for the optimization.

For the second project update, we will have completed the trajectory optimization and will be implementing the trajectory stabilization. This will involve linearizing the dynamics about the optimal trajectory, and implementing an LQR controller to drive the system back to the optimal trajectory. We will use the method discussed in class of having a time-varying coordinate system, and driving the bird to the origin of that time-varying coordinate system. We will also show progress on computing the Lyapunov “funnels” though do not expect to have that completed.

For the final submission, we will have simulation results showing the execution of our optimized trajectories, including stabilization and reachability analysis, in the presence of disturbances.