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Quadrocopter Ball Juggling

The Quadrocopter Ball Juggling project was done as an MSc thesis at the Flying Machine Arena, at the Institute for Dynamic Systems and Control, ETH Zurich. During the project algorithms were developed with which a quadrocopter can hit a ball towards a target, permitting one quadrocopter to juggle a ball, return a ball thrown by a human or multiple quadrocopters to “play” ping-pong. This is a novel, visually engaging problem with a very obvious success/failure metric, where any lay observer can judge how well the system works. As such the completed project attracts much attention, and is a very tangible demonstration of various aspects of control systems. A video of the system in action uploaded to Youtube has been viewed over two million times, and the project has also received media attention, most recently on the Galileo television program on the German Pro 7.

During the project, dynamic models were created of quadrocopter and ball flight, and the impact of the ball on the racket. These models had to be abstract enough to be mathematically tractable, but still encode the essence of the problem. Using the model for the ball, an estimation scheme was developed to observe the ball's position, velocity and drag coefficient, allowing for accurate long-term prediction of the ball flight. Because the rackets have a very small “sweet spot”, accurate prediction of the impact point is crucial to system performance.

The quadrocopter model was in turn used to generate input trajectories for the vehicles. These trajectories are generated in real time, to move the quadrocopter from its initial state to the state required at impact, where the desired final state is calculated using a simplified ball/racket impact model, so that the ball will fly towards a target after the impact.

After initial, disappointing results, learning/adaptation algorithms were added, allowing the system to improve its performance over time. The system thus learns the characteristics of the ball, the rackets, and an aiming bias (e.g. “to hit the target, one must aim slightly left and behind it”). This learning implies that the system is continuously adapting, and improving. A major challenge here was the unpredictability and unrepeatability of the system.

In the future, the project will serve as a test bed for control, estimation, learning and trajectory generation strategies. The work done so far serves as proof-of-concept, showing that human/quadrocopter ball playing is possible. Much work can still be done to improve the performance of the system, with improved robustness being an obvious goal.

The Flying Machine Arena as a whole is a large research project, where currently four PhD students do research on miniature unmanned aerial vehicles, specifically with quadrocopters – mechanically simple, extremely robust four-rotor vehicles. The various research focuses on quadrocopter control and estimation, taking into account the complex aerodynamic properties of quadrocopters (e.g. inherent instability, ground effect), tight weight constraints and limited battery life. At its most general, the research has as goal the development of algorithms which generate control inputs minimizing some performance metric, subject to constraints – the metric and constraints being used to encode specific objectives. By applying a rigorous scientific approach to fundamental issues like real-time trajectory generation, learning from sparse observations, and precise trajectory following, we expect this research to advance our theoretical understanding of quadrocopter controls, lead to advances in the control of real-world quadrocopter vehicles. Finally, the scientific results are expected to be applicable to a much wider range of controls problems.

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