Silesian University of Technology
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Doctoral dissertation

Model-Based Adaptive Path Planning Algorithm for Unmanned Aerial Vehicles

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Abstract

From military reconnaissance, through conducting measurements in remote locations to package delivery – the growing popularity of Unmanned Aerial Vehicles (UAVs) encourages employing them for various missions. For example, UAVs measure air pollution. A novel approach is to build a High-Altitude Long Endurance UAV able to stay airborne for prolonged amounts of time and use it to measure air pollution over a broad range of altitudes – from hundreds of meters above ground level up to lower stratosphere.

The goal of this doctoral dissertation was to design and verify the model-based adaptive path planning algorithm for pollution sampling with a HALE UAV flying autonomously in a limited environment. Under the course of the thesis Adaptive Path Planner (APP) was developed and positively verified in Model-in-the-Loop (MIL) simulation.

The author proposed and formulated the theoretical foundation of a two-stage model-based APP algorithm consisting of Global Path Planner (GPP) and Local Path Planner (LPP). The output of GPP and LPP can be verified with MIL before deploying it to the UAV. Furthermore, the author presented the concept of an environment map. It consists of a terrain map, a wind map, an airspace map and a measure map. Each of them describes the most prominent components of the scene important for providing the optimal path.

GPP is a global optimization algorithm, which provides an obstacle-free feasible path optimized for minimum energy expenditure while subject to kinematic constraints of the UAV. GPP is meant to be mainly a mission planner that is run on a PC-class workstation in a Ground Control Station (GCS). The algorithm can adaptively recalculate the path.

LPP is a local planning algorithm employed for rapidly computing obstacle-free path in GCS, as well as locally using the UAV onboard computer. LPP is used as a fallback when the communication with GCS is down. Hence, minimal computation time is favored over minimizing energy expenditure. a local path is used, for example, to perform a Return-To-Home (RTH) maneuver or to guide the UAV to an emergency landing spot.

Extensive tests of APP were carried out to compare different flavors of global single-objective optimization algorithms employed by GPP (I-GWO, $ACO_{\mathbb{R}}$, PSO and GA) and planning algorithms used by LPP (RRT, RRT* and BiRRT). The results were analyzed and the optimal algorithms chosen. Then, their crucial parameters were further calibrated.

Finally, GPP and LPP were integrated and the whole APP was verified in MIL simulation on selected use cases inspired by real pollution sampling missions in Poland and in the Arctic. The comparative analysis of generated paths against reference paths supplied by a human expert showed that APP performance successfully allows it to replace the human. Further research positively verified the adaptive re-planning capability of APP.