ABSTRACT

Creating autonomous Micro Aerial Vehicles for executing complex missions poses various challenges, including safe navigation in the presence of external wind disturbances. Most current navigation methods handle external wind disturbances through real-time estimation and rejection algorithms in the control stage, but lack safety guarantees in strong winds. Recent robust methods provide safety guarantees but can be overly conservative. With the availability of more powerful computing devices, data-driven control algorithms are becoming increasingly feasible. Combining Gaussian Process models with Model Predictive Control has shown to enhance safety and performance in various control applications. Moreover, Model Predictive Control has been extended to solve more complex optimization algorithms that combine trajectory generation and tracking, preventing reference trajectories that are risky and challenging to control in the presence of disturbances.

This research aims to improve quadrotor navigation in windy environments by using Gaussian Processes to model wind disturbances. The Gaussian Process model is integrated with a Model Predictive Contouring Control formulation that combines trajectory generation and control into one optimization problem. A nominal model of the quadrotor is derived and the Gaussian Process disturbance model is trained with the quadrotor position as input and wind disturbance as output. The wind disturbance map, along with the nominal model, is implemented in the Model Predictive Contouring Controller to consider both the mean and uncertainty of the resulting probabilistic model.

This study validates the use of Gaussian Processes to model complex wind disturbances in quadrotor navigation. The wind disturbance map is trained from available state information, with data collected using an optimal exploration design to minimize uncertainty and reduce exploration times. The hyperparameters involved in training the Gaussian Process model are discussed and the implementation of sparse Gaussian Processes is outlined to make it real-time feasible for the Model Predictive Contouring Control formulation. Including the prediction model by incorporating chance constraints results in improved tracking and increased robustness in cluttered environments compared to the nominal Model Predictive Contouring Control formulation. The proposed algorithm is shown to outperform state-of-the-art methods for safe quadrotor navigation in windy and cluttered environments, being able to handle more complex wind fields than existing methods while also being less conservative.