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MASTER

Gaussian Process Enhanced State Estimation for Multirotors

Narla, S.

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Gaussian Process Enhanced State Estimation for Multirotors

Shashank Narla[1] - Msc. Thesis[*†]

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Summary

Kalman filtering is based on a probabilistic Bayesian framework and it allows for efficient recursive state estimation. While Kalman filters are widely adopted in quadrotor applications, the prediction and observation model considered in these approaches are often first-principles based simplistic models that fail to completely capture the true dynamical system. Unmodelled phenomena like aerodynamic forces, thrust variation, and sensor nonlinearities can introduce large tracking errors that affect flight control. This necessitates the development of a methodology that can successfully augment and personalise the simplistic models used in these observers and can also be efficiently blended into the Kalman filter. In this project, Gaussian process (GP) regression is used as a data-driven modelling procedure to augment existing observation and prediction models. First, the prediction model is augmented by a Gaussian process to learn the model error between an approximate nominal model and the observed dynamics. Second, the observation model is blended with the resulting Gaussian process to predict state-dependent uncertainties and measurement likelihood of the sensor. Lastly, these models are integrated into the Kalman filter to form a Gaussian process extended Kalman filter (GP-EKF). The effectiveness of GP-EKF applied to the position subsystem of the quadrotor is studied both in simulation and in a real experiment.

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[1] Control Systems Group, Department of Electrical Engineering, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands
`s.narla@student.tue.nl`

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Abstract

Kalman filtering is based on a probabilistic Bayesian framework and it allows for efficient recursive state estimation. While Kalman filters are widely adopted in quadrotor applications, the prediction and observation model considered in these approaches are often first-principles based simplistic models that fail to completely capture the true dynamical system. Unmodelled phenomena like aerodynamic forces, thrust variation, and sensor nonlinearities can introduce large tracking errors that affect flight control. This necessitates the development of a methodology that can successfully augment and personalise the simplistic models used in these observers and can also be efficiently blended into the Kalman filter. In this project, Gaussian process (GP) regression is used as a data-driven modelling procedure to augment existing observation and prediction models. First, the prediction model is augmented by a Gaussian process to learn the model error between an approximate nominal model and the observed dynamics. Second, the observation model is blended with the resulting Gaussian process to predict state-dependent uncertainties and measurement likelihood of the sensor. Lastly, these models are integrated into the Kalman filter to form a Gaussian process extended Kalman filter (GP-EKF). The effectiveness of GP-EKF applied to the position subsystem of the quadrotor is studied both in simulation and in a real experiment.

1 Introduction

Over the last decade, there has been significant progress in the field of robotics owing to algorithmic advances, prevalence of affordable sensors and computational platforms. Several application domains such as automotive, precision agriculture, inspection, manufacturing, and healthcare have adopted robotics as a solution to their respective challenges. Developing autonomous robots is an interdisciplinary effort involving collaboration between Mechanical Design, Electrical Design, Electronics Assembly, Robotic Software Design and Development, and User Interface (UI)/ Front-End software development (If necessary). The majority of discussions involved in this thesis concerns Robotic Software Design, specifically state estimation, that forms a fundamental pillar towards autonomy.

Figure 1: An autonomous quadrotor inside a greenhouse used to monitor plant health and growth.

Quadrotors are a subdivision of robotics that are becoming increasingly ubiquitous owing to its mechanical simplicity and flexibility. These agile platforms are used in mining, agriculture, photography and numerous other indoor and outdoor applications (Figure 1). The platform handles multiple subsystems such as flight controls, path planning, and sensor fusion simultaneously. This highly nonlinear system has various uncertainties acting due to inertial properties, aerodynamics, wind effects, and flying near objects. Like any robotic platform, precisely estimating system states such as *position, velocity*, *orientation*, and *angular velocity* are essential to accurately control the system through unstructured environments. State estimation supports both low-level robot control and high-level decision making through well-defined observer architectures. State estimation for quadrotors poses an interesting set of challenges, that range from modelling complicated system dynamics to handling sensors with lower Signal-to-Noise ratio (SNR). Another dimension to this problem is tackling hardware limitations to solve the estimation problem onboard with low-latency. Uncertainties in quadrotor arise from sources that can be broadly categorized as:

- Environment: Quadrotors fly in heavily unstructured environments which are unpredictable, where aspects such as wind speed, aerodynamics, and drag affect the predicted state estimates.
- Sensors: Measurements from sensors are subjected to physical limitations such as range and resolution. Secondly, sensors are also prone to noise and failure that limits its dependency.
- Models : Models are abstractions of the physical world and are major causes for inaccuracy. Using inaccurate system models in state estimation with crude approximations can lead to inaccurate prediction of state variable.
- Computation: Robotics are classified as real-time systems with limited onboard computation. This forces a trade-off between accuracy and speed that restrict the choice of algorithms.