Adaptive Kalman Filter for UAV Dynamic Flight Maneuvers

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Abstract:

In this paper, we introduce an Adaptive Kalman Filter (AKF) specifically designed to optimize the performance of Unmanned Aerial Vehicles (UAVs) under dynamic flight conditions. Conventional Kalman Filters, while effective under stable conditions, often fall short in scenarios involving high-intensity maneuvers due to their reliance on static process models, resulting in suboptimal performance. The proposed AKF overcomes this limitation by dynamically adjusting the process noise covariance, informed by ongoing maneuver detection.

The core innovation of the AKF lies in its ability to adapt to changing flight dynamics. Traditional Kalman Filters assume a constant level of process noise, which is inadequate for the variable conditions experienced during aggressive UAV maneuvers. Our AKF leverages a maneuver detection algorithm that utilizes data from residuals, acceleration and gyroscope measurements to identify changes in flight conditions. By dynamically adjusting the process noise covariance matrix based on this real-time information, the AKF maintains high estimation accuracy even during rapid and unpredictable movements.

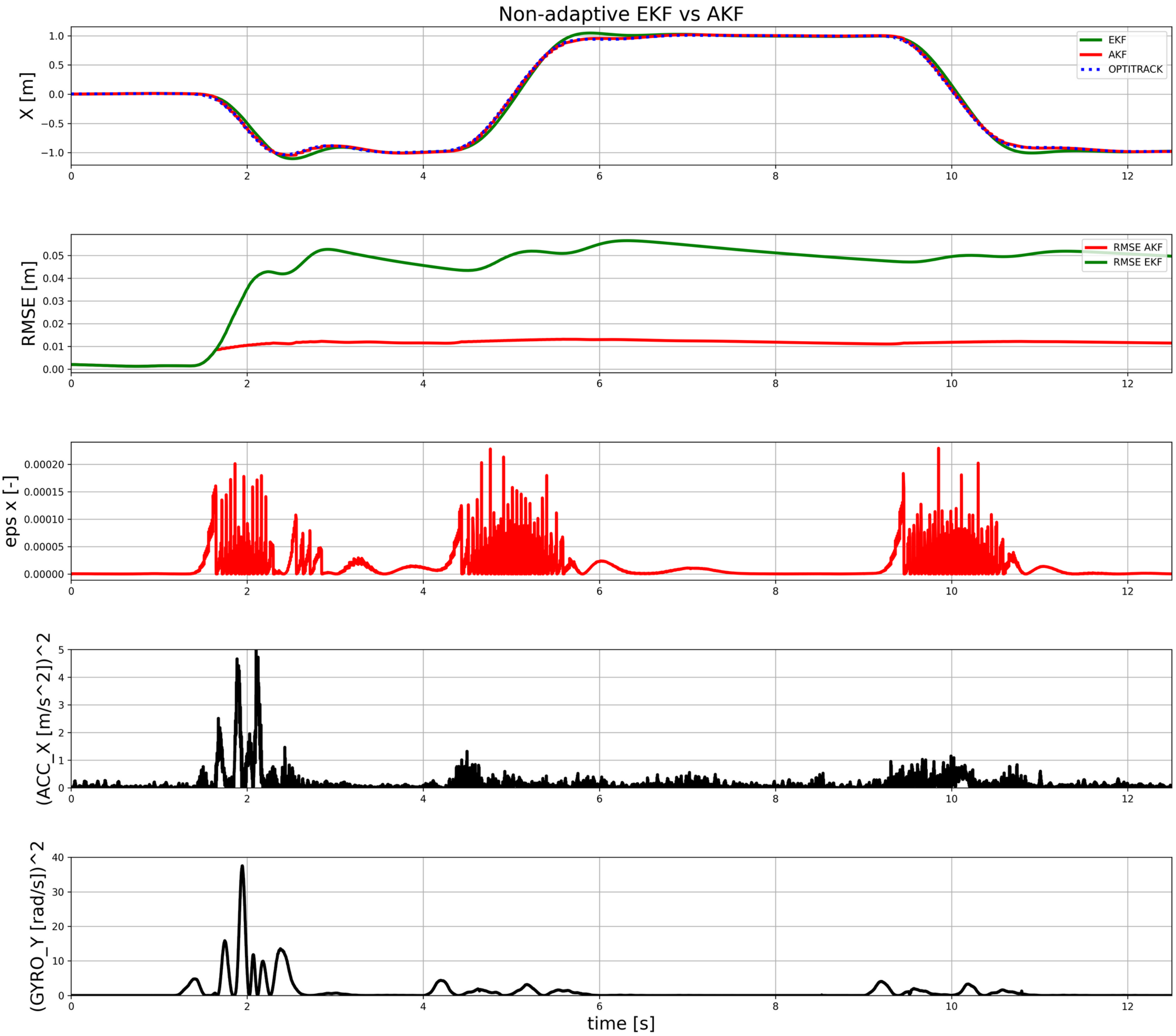
To validate the effectiveness of the AKF, we conducted extensive simulations and real-world tests using the OptiTrack motion capture system, which provided precise measurements of UAV movement. The OptiTrack system, is renowned for its high accuracy and reliability, making it an ideal choice for capturing the complex maneuvers performed during our tests. This system tracked the UAV's position and orientation in real-time, supplying the necessary data to evaluate the AKF's performance.

Our simulation results demonstrate that the AKF significantly improves state estimation accuracy compared to traditional Kalman Filters. Specifically, the AKF showed marked improvements in position estimation, with root mean square errors (RMSE) reduced by up to 80% during aggressive maneuvers. The AKF maintaines robust performance, effectively handles sudden changes in flight dynamics and consistently provides accurate state estimates.

The AKF's enhanced responsiveness is particularly beneficial for advanced UAV applications requiring high agility and precision. For instance, in autonomous drone operations, where quick and accurate state estimation is crucial for obstacle avoidance and navigation, the AKF offers a substantial performance boost. Similarly, in aerial robotics, where precise control is necessary for tasks such as inspection, mapping, and delivery, the AKF's ability to adapt to dynamic conditions ensures superior operational efficiency.

This paper details the development, implementation, and evaluation of the AKF, providing insights into its potential for elevating UAV performance standards in increasingly demanding operational

contexts. Our findings indicate that this adaptive approach holds substantial promise for a wide range of applications, paving the way for more resilient and capable UAV systems in the future.



This figure shows preliminary results of the Adaptive Kalman Filter (AKF) in improving state estimation accuracy during high-intensity UAV maneuvers. The first graph shows the changes in the X position for the standard Kalman Filter, the AKF, and the measurements directly taken from the OptiTrack system. The second graph illustrates the variation in RMSE over time.