Abstract – Implementation of Particle Filter in place of Extended Kalman Filter

State estimation is a critical component in modern aircraft navigation and control systems, ensuring accurate and reliable information about the aircraft's position, velocity, and attitude. Traditional methods for state estimation, such as the Extended Kalman Filter (EKF), are widely used due to their simplicity and computational efficiency. However, the EKF is inherently limited in its ability to handle highly nonlinear systems and complex, non-Gaussian noise. The EKF operates by linearizing the system dynamics and measurement models at each time step, which can lead to significant errors in state estimation when dealing with systems exhibiting strong nonlinearities or when sensor data is corrupted by non-Gaussian noise.

In this paper, we explore the use of the Particle Filter (PF) as a more robust alternative to the EKF for aircraft state estimation. The Particle Filter is a non-parametric, sequential Monte Carlo method that approximates the posterior distribution of the system's state by using a set of particles. Unlike the EKF, the PF does not rely on linearization, making it well-suited for highly nonlinear systems. It is also capable of handling non-Gaussian noise in sensor measurements, which is particularly useful in real-world applications where noise often deviates from the ideal Gaussian assumption.

The expected results from implementing the Particle Filter for aircraft state estimation are anticipated to show significant improvements in both accuracy and robustness compared to the EKF. Specifically, we expect that the PF will provide more accurate estimates of the aircraft's state in scenarios where the system exhibits strong nonlinearities or where measurement noise is non-Gaussian. For example, in an aircraft experiencing rapid changes in attitude or velocity, the EKF may fail to capture the true state due to its linearization process, resulting in a degradation of performance. In contrast, the Particle Filter, by maintaining a particle-based representation of the state distribution, can more effectively track the aircraft’s state under such dynamic conditions.

Furthermore, when dealing with real-world sensor data, especially from nonlinear systems like aircraft, the noise in measurements is often not Gaussian, and sensor errors may not be independent or identically distributed. This is particularly true for high-speed aircraft operating in turbulent conditions or environments with significant wind disturbances. The Particle Filter, with its ability to handle arbitrary noise distributions, is expected to outperform the EKF by providing more reliable state estimates under these challenging conditions. The ability to model non-Gaussian noise more effectively is one of the key advantages of the PF, as it can better approximate the true distribution of the state and reduce the influence of outliers or noisy measurements.

In addition to better handling of nonlinearities and non-Gaussian noise, another key benefit of implementing the Particle Filter is its improved robustness in scenarios where the EKF may become unstable. EKF-based methods can experience divergence when the linearization of the system’s dynamics is poor or when the state estimate significantly deviates from the true state. This is particularly problematic in aircraft navigation, where small errors in state estimation can lead to large deviations over time. The Particle Filter, on the other hand, is less prone to divergence because it uses a large number of particles to represent the state distribution. Even in the presence of large initial errors or poor sensor measurements, the PF can still provide a more stable and reliable estimate of the true state by updating the particles iteratively and resampling based on the likelihood of the measurements.

The expected output of this research will include a comparative analysis of the Particle Filter and the Extended Kalman Filter in terms of state estimation accuracy, robustness to noise, and computational efficiency. We anticipate that the Particle Filter will show superior performance in these scenarios, providing more accurate state estimates, reducing estimation errors, and being more resilient to sensor imperfections. The expected results will demonstrate that the PF significantly outperforms the EKF in highly dynamic environments, especially those with nonlinear system behavior and complex measurement noise.

The improved performance of the Particle Filter is expected to be particularly beneficial for real-time applications in autonomous aircraft, where precise state estimation is crucial for control and navigation. With more accurate and reliable state estimates, the PF will enable better decision-making for control systems, allowing for safer and more efficient flight operations. For example, in autonomous flight, accurate attitude and position estimates are essential for collision avoidance, path planning, and trajectory optimization. By providing better state estimation, the Particle Filter can enhance the performance of these systems, making them more reliable and capable of handling dynamic and uncertain environments.

In conclusion, this research will demonstrate the advantages of using the Particle Filter over the Extended Kalman Filter for aircraft state estimation, particularly in the presence of nonlinear system dynamics and non-Gaussian noise. The expected results will show that the PF offers more accurate, robust, and reliable state estimates, making it a promising approach for real-time navigation and control applications in aerospace systems. By addressing the limitations of the EKF, the Particle Filter can improve the performance of state estimation and contribute to the development of more autonomous and reliable aircraft and aerospace systems.