Applications:

Hereby is some of the applications in which Kalman filter is majorly used.

1. Aerospace:

The Kalman filter is used in spacecraft navigation, satellite control, and guidance systems to estimate the spacecraft's position and velocity, track and predict orbits, and control thrusters. It is used because it can handle noise and uncertainty in measurements and can provide accurate estimates of the state of the spacecraft. An example of its use is the Apollo Lunar Module descent guidance system, which used a Kalman filter to estimate the spacecraft's state and guide it to a safe landing on the moon.

1. Robotics:

The Kalman filter is used in robot navigation and localization, simultaneous localization and mapping (SLAM), and control of robot arms to estimate the robot's pose, map the environment, and improve control performance. It is used because it can handle sensor noise and uncertainties and can provide accurate estimates of the robot's state. An example of its use is the Mars Exploration Rovers, which used Kalman filters to estimate their position and orientation and navigate on the surface of Mars.

1. Control systems:

The Kalman filter is used in control systems such as optimal control, adaptive control, and model predictive control to estimate the system's state and provide feedback to adjust control inputs in real-time. It is used because it can provide accurate estimates of the system's state even in the presence of noise and uncertainties. An example of its use is the flight control system of the F-14 Tomcat aircraft, which used a Kalman filter to estimate the aircraft's state and provide feedback for control inputs.

1. Signal processing:

The Kalman filter is used in signal processing applications such as speech and image processing to reduce noise and improve signal quality. It is used because it can handle noise and uncertainties in measurements and can provide accurate estimates of the signal. An example of its use is in speech recognition systems, which use Kalman filters to estimate the speech signal and remove noise.

1. Finance and economics:

The Kalman filter is used in finance and economics to model and forecast time series data, such as stock prices and economic indicators. It is used because it can handle noisy data and provide accurate estimates of the underlying trends and patterns. An example of its use is in predicting stock prices, where Kalman filters are used to estimate the underlying trends and predict future prices.

1. Medical applications:

The Kalman filter is used in medical applications such as tracking of medical instruments, estimating patient physiological parameters, and fusing data from multiple sensors. It is used because it can handle noise and uncertainties in measurements and provide accurate estimates of the patient's state. An example of its use is in cardiac monitoring, where Kalman filters are used to estimate the patient's heart rate and detect arrhythmias.

1. Automotive:

The Kalman filter is used in automotive applications such as navigation, driver assistance systems, and control of autonomous vehicles. It is used because it can handle sensor noise and uncertainties and provide accurate estimates of the vehicle's state. An example of its use is in GPS navigation systems, which use Kalman filters to estimate the vehicle's position and improve accuracy.

1. Geophysics:

The Kalman filter is used in geophysical applications such as seismic data processing, gravity field modeling, and atmospheric modeling. It is used because it can handle noisy data and provide accurate estimates of the underlying patterns and trends. An example of its use is in earthquake detection, where Kalman filters are used to estimate the location and magnitude of earthquakes from seismic data.

Here is some of the reference links for detailed version of applications of Kalman filter which provides the information about how it has been used and what is the process.

1. Aerospace
   1. Navigation: [Link](https://www.researchgate.net/publication/224138621_Applications_of_Kalman_Filtering_in_Aerospace_1960_to_the_Present_Historical_Perspectives#:~:text=In%20the%201960s%2C%20the%20Kalman,before%20it%20could%20be%20used.)
   2. Satellite tracking: [Link](https://www.researchgate.net/publication/332902163_Satellite_Orbit_Estimation_Using_Kalman_Filters)
   3. Attitude: [Link](https://www.researchgate.net/publication/296658639_Kalman_filtering_for_spacecraft_attitude_estimation)
2. Robotics
   1. Odometry: [Link](https://www.researchgate.net/publication/221645970_Localization_of_a_Mobile_Robot_based_in_Odometry_and_Natural_Landmarks_using_Extended_Kalman_Filter)
   2. Robot vision: [Link](https://www.researchgate.net/publication/254061349_Kalman_Filter_for_Robot_Vision_A_Survey)
   3. SLAM: [Link](https://www.researchgate.net/publication/281067001_Extended_Kalman_Filter_EKF_-based_Local_SLAM_in_Dynamic_Environments)
3. BIOMEDICAL ENGINEERING
   1. Image Processing : <https://inis.iaea.org/collection/NCLCollectionStore/_Public/43/052/43052892.pdf>
   2. BioSignal Processing <https://www.researchgate.net/publication/221787837_The_Use_of_Kalman_Filter_in_Biomedical_Signal_Processing>
   3. Physiological Monitoring

R. Vullings, B. de Vries and J. W. M. Bergmans, "An Adaptive Kalman Filter for ECG Signal Enhancement," in IEEE Transactions on Biomedical Engineering, vol. 58, no. 4, pp. 1094-1103, April 2011, doi: 10.1109/TBME.2010.2099229.

<https://ieeexplore.ieee.org/document/5667049>

1. FINANCE
   1. Volatility Estimation

<https://www.researchgate.net/profile/Mohamed_Mourad_Lafifi/post/Is_there_an_optimal_sampling_period_for_a_Kalman_filter/attachment/5a72f2b94cde266d5887f1f8/AS%3A589179222253568%401517482681074/download/Noise+Reduced+Realized+Volatility+A+Kalman+Filter+Approach+Doug+Steigerwald.pdf>

* 1. Value at risk

<https://www.adrian.idv.hk/2019-08-18-kalman/>

DRAWBACKS ➖

The Kalman filter makes the assumption that the system being modelled is linear, which may not necessarily be the case in actual use. The Kalman filter might not be able to estimate the system state under such circumstances.

Sensitivity to early conditions: How well the Kalman filter performs can be significantly influenced by the initial system state estimations. This might lead to subpar performance in communication systems when the beginning conditions can be very unpredictable.

High-dimensional systems are challenging to handle because of the Kalman filter's computational complexity, which increases as the dimensionality of the system being estimated increases. This could restrict the filter's usefulness in high-dimensional systems.

Lack of explicit handling of constraints: Neither the state inputs nor the control inputs are expressly handled by the Kalman filter. This could be an issue if the system is subject to physical limitations, such as restrictions on acceleration or velocity. Such circumstances can be handled by optimization-based filters or constrained Kalman filters.

ALTENATIVES ➖

1. Particle Filter: A non-parametric Bayesian filter capable of handling nonlinear, non-Gaussian systems, the particle filter. Without making any assumptions about linearity or gaussianity, it can be used to estimate the system's state and probability distribution. Although they can be computationally expensive, particle filters occasionally offer estimates that are more precise than Kalman filters.

2. Extended Kalman filter: this nonlinear variant of the Kalman filter uses first-order Taylor expansion to linearize the system dynamics and observation model. It can deal with non-linear systems, but if the non-linearities are too great, it could perform poorly.

3. Unscented Kalman Filter (UKF): This Kalman filter modification may handle nonlinear systems by approximating the probability distribution of the system state using a set of sigma points. Compared to the EKF, it can offer estimates that are more accurate while keeping a lower computing cost.

4. Constrained Kalman Filter (optional): This version of the Kalman filter explicitly handles limitations on the state or control inputs. It can be helpful in applications where the system must satisfy physical limits.

The choice of which algorithm to use depends on the specific requirements and characteristics of the system being estimated. There is no one-size-fits-all solution, and each algorithm has its strengths and weaknesses.

The Kalman filter is a well-established and widely used algorithm for state estimation, particularly for linear, Gaussian systems. It is computationally efficient and provides optimal estimates under the given assumptions.

However, if the system is nonlinear or the noise is non-Gaussian, other algorithms may provide better estimates. For example, particle filters and unscented Kalman filters can handle nonlinear systems and non-Gaussian noise. Iterative Kalman filters and robust Kalman filters can improve the accuracy of the estimate and handle outliers or non-Gaussian noise. Constrained Kalman filters can handle physical constraints on the system.