Object Tracking in Surveillance System Using Extended Kalman Filter and ACF Detection

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***Abstract*— This study explores an advanced approach to multi-object tracking in surveillance systems by employing the Extended Kalman Filter (EKF) and Aggregate Channel Features (ACF) detection. Our research addresses challenges inherent in real-time object tracking, such as occlusions and complex trajectories, with an EKF-based solution that offers enhanced tracking precision and continuity. By integrating ACF detection, we improve initial object detection speed and accuracy, thereby facilitating more reliable tracking initialization. We tested this approach on diverse datasets—each representing varied environmental conditions—to assess performance across metrics including Multiple Object Tracking Accuracy (MOTA), Multiple Object Tracking Precision (MOTP), precision, and recall. The results demonstrate that while the EKF-ACF framework achieves high spatial accuracy and precision, it also encounters limitations in minimizing missed detections in crowded scenes. This study underscores the utility of the EKF-ACF approach in surveillance applications, especially in scenarios demanding real-time, high-precision tracking of dynamic objects.**

Keywords—Extended Kalman Filter (EKF), Object Tracking, Multi-Object Tracking, ACF Detection, Pedestrian.

I. INTRODUCTION

Object tracking is one of the most critical areas of research due to changes in the motion of objects[1]. Recent advancements in tracking algorithms have significantly improved the handling of challenges such as occlusion, varying lighting, and multiple moving objects. By utilizing attributes like shape, color, and motion, techniques like Kalman filters, particle filters, and silhouette tracking enhance tracking accuracy. These methods are widely applied in areas such as traffic monitoring, security systems, and human-computer interaction. Luo et al. [2] proposed a similar optimization technique using Gaussian filtering for Bluetooth-based indoor positioning, reducing noise and improving accuracy under complex environmental conditions, further underscoring the importance of such filtering methods in real-time tracking scenarios.

Several studies emphasize Bayesian methods for handling uncertainties in video tracking. Dore *et al*. [3] demonstrated that Bayesian state estimation combines object dynamics with noisy data for accurate motion prediction. Applied probabilistic graphical models to model dependencies, improving tracking in real-time. Notably, the Kalman Filter emerges as a specific application within the Bayesian framework, operating under linear and Gaussian assumptions as a specialized "child" of Bayesian filtering methods.

Numerous studies highlight the significance of object tracking in computer vision, as described by Mangawati *et al*. [1]. Object tracking monitors an object's movement over time by determining its position in each video frame, relying on attributes such as shape, color, motion, and texture. Bukey *et al*. [4] further emphasize that the core of object tracking is establishing the relevance of the targeted object and its components across successive frames. Building consistent relationships between target objects and their parts across video frames is considered a foundational step in tracking, as it allows each algorithm to capture varying levels of detail depending on the requirements of the application.

Furthermore, other studies have explored the Extended Kalman Filter. Omeragic et al. [5] explain that the Extended Kalman Filter (EKF) is a robust approach for object tracking in dynamic, non-linear environments. By employing first-order linearization through the Jacobian matrix, EKF adapts effectively to non-linear trajectories, offering greater flexibility than the Standard Kalman Filter (SKF). Integrated with the Constant Turn Rate and Velocity (CTRV) model, EKF enhances tracking precision by accurately handling curvilinear motion and reducing errors. This approach enables more accurate state prediction and updates in complex conditions by calculating the Jacobian at each step to manage non-linearities.

In the paper by Qiankun Liu, Bin Liu, Yue Wu, Weihai Li, and Nenghai Yu[6], Multi-Object Tracking (MOT) is defined as the task of estimating the trajectories of multiple objects in dynamic scenes while maintaining their identities across frames. This approach is particularly valuable in real-time applications like autonomous driving, where continuously detecting and associating objects is essential. MOT often involves distinguishing keyframes for object detection and utilizing motion cues in non-key frames to propagate object positions without repeated detection. This strategy efficiently addresses challenges such as occlusions and re-identification, ensuring object continuity and improving tracking accuracy throughout sequences.

Gunjal et al. [7] presented a method for tracking moving objects using the Kalman filter, particularly effective in surveillance and real-time tracking applications. Their approach involved breaking down video input into frames and identifying moving objects through color recognition. The Kalman filter was crucial for estimating object positions by minimizing the error between actual and predicted locations, effectively tracking even when the object is momentarily out of sight. Unlike traditional methods like particle filtering, which require extensive computation, the Kalman filter provided a faster, less resource-intensive solution, proving advantageous in dynamic surveillance environments.

Yang et al. [8] developed an Extended Kalman Filter (EKF) to track extended objects, specifically tackling the complex task of estimating the shapes of objects, such as ellipses. This approach employs a nonlinear measurement equation that integrates both shape and kinematic parameters, capturing the spatial distribution of measurements through a multiplicative noise model. By forgoing the Hessian calculations required in the Second Order EKF, this EKF approach significantly reduces computational demands while preserving accuracy in tracking variations in both object orientation and size. Simulation results illustrate the EKF's strong performance, especially under conditions where the orientation of the object changes, marking it as an efficient solution for complex tracking scenarios.

The Extended Kalman Filter (EKF) is a crucial method in the field of object tracking, providing the ability to predict and update the estimated position, speed, and trajectory of moving objects in real-time applications. Omeragic *et al[5]*. EKF-based tracking systems can utilize various data sources, including sensors like cameras or radar, which allow for continuous monitoring of objects in complex, dynamic environments such as autonomous driving or video surveillance systems. The EKF functions by linearizing nonlinear motion and measurement models around the current state estimate, which enables it to better handle unpredictable object behaviour, including changes in direction and speed. However, one challenge of applying EKF lies in managing the computational demands needed to process data in real-time while maintaining accuracy under varying conditions.

This paper proposes using the Extended Kalman Filter (EKF) to apply Multi-Object Tracking (MOT) for online and real-time tracking. To achieve this goal, we follow several steps. First, we use a dataset of a pedestrian video from the MATLAB website. Then, the video is loaded into a program that utilizes the Extended Kalman Filter. After that, the program outputs two types of detections, namely Aggregated Channel Features (ACF) and You Only Look Once version 4 (YOLOv4). The final output provides a performance analysis of the Extended Kalman Filter, highlighting the percentage of various metrics such as Multiple Object Tracking Accuracy (MOTA), Multiple Object Tracking Precision (MOTP), precision, and recall.

In this section, we provide an overview of the paper's organization. Section II outlines the methodology used in this research. Section III presents the performance results. Finally, Section IV offers the conclusions of the study.

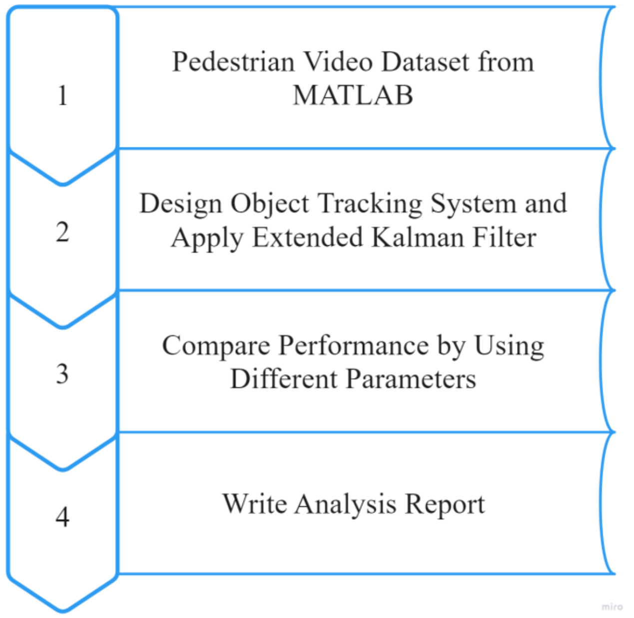

Fig. 1. Research Workflow for Object Tracking Using Extended Kalman Filter