Object Tracking in Surveillance System using Particle Filter and ACF Detection

Hanandiya Putra
School of Computing
Telkom University
Bandung, Indonesia
hanandiyaputra@student.telkomuniversity.ac.id

Hilal H. Nuha
School of Computing
Telkom University
Bandung, Indonesia
hilalnuha@ieee.org

Muhamad Irsan
School of Computing
Telkom University
Bandung, Indonesia
irsanfaiz@telkomuniversity.ac.id

Aji Gautama Putrada
School of Computing
Telkom University
Bandung, Indonesia
ajigps@telkomuniversity.ac.id

Syifak Binti Izhar Hisham
School of Computer Science
Univeristi Malaysia Pahang
Pahang, Malaysia
syifakizhar@umpsa.edu.my

***Abstract*— This paper presents a study on object tracking in surveillance systems using Particle Filter and Aggregate Channel Features (ACF) detection to address the challenges of accurately tracking multiple objects in dynamic environments. Object tracking is a crucial component in computer vision, with applications spanning from surveillance and security to autonomous navigation and robotics. In this work, we leverage Particle Filter, a robust Bayesian-based filtering algorithm known for its effectiveness in non-linear and non-Gaussian conditions, to track objects consistently over time. The ACF detection method is employed for its high precision in identifying objects across various frames, thereby enhancing initial detection accuracy. Performance testing is conducted across four datasets, using key metrics such as precision, Multiple Object Tracking Precision (MOTP), and Multiple Object Tracking Accuracy (MOTA) to evaluate effectiveness. The results show that while Particle Filter combined with ACF detection achieves consistently high precision (95-99%) and stable MOTP rates (69-79%), challenges arise in maintaining uninterrupted tracking accuracy, as evidenced by lower MOTA scores (3.1-7.2%) and a significant rate of false negatives, especially in complex scenarios with occlusions. These findings suggest that although Particle Filter and ACF detection are effective for initial detection and data handling, enhancements or hybrid methods may be required for applications demanding high accuracy in continuous multi-object tracking.**

Keywords—computer vision, multiple-object tracking, particle filter, clear mot, acf detection

I. INTRODUCTION

Computer vision has developed into a dynamic element of artificial intelligence focusing on enabling machines to comprehend and interpret visual inputs from their surroundings. Computer software and hardware are used to analyze and process visual information and data. It includes the process of acquiring, transmitting, processing, screening, storing and understanding visual information [1]. Object tracking is one of the important tasks in computer vision that tries to detect and track objects in image sequences. In object tracking, the target specifies in the first frame and must be detected and tracked in the next frames of the video [2].

Several studies have revealed how object tracking is an important field in computer vision. A study explains that real-time object tracking represents a pivotal and complex task within the field of computer vision [3]. Object tracking has been an active research area in the vision community in recent years. It has many potential applications in the fields of intelligent robots, monitoring and surveillance, human computer interfaces, smart rooms, vehicle tracking, biomedical image analysis, and video compression [4]. These fields are highly regarded for their transformative potential across various applications and industries.

Furthermore, other studies have defined Particle Filter. Awal *et al.* [5] explains that particle filter is a Monte Carlo and recursive Bayesian estimation-based filtering algorithm. Particle Filter performs superior compared to conventional methods such as the Kalman Filter when applied to non-linear or non-Gaussian conditions. Akca and Efe [6] also explain that in Particle Filter, continuous distributions are represented through an approximation, with posterior probabilities updated via random sampling particles. Unlike methods requiring functional approximation or linearization, the particle filter operates without these constraints. However, this advantage comes at the cost of increased computational demand.

In the context of Multi-Object Tracking, Multi-Object Tracking (MOT) is the task of detecting the presence of multiple objects in video and associating these detections over time according to object identities [7]. Yoon *et* al. [8] explains that MOT is important for many computer vision tasks with applications such as surveillance, traffic safety, automotive driver assistance systems, and robotics. Multi-Object Tracking also aims to estimate trajectories of multiple objects in the same category in videos [9].

Other papers have shown that Bayesian Filter is one of the most effective algorithms in the realm of object tracking. Ong *et al.* [10] performed a 3D Position Estimation using the Classical Bayesian Filter as a formulation and yields a high percentage of Multi-Object Tracking Accuracy (MOTA) and Multi-Object Tracking Precision (MOTP). One of the applications of Bayesian Filter is Particle Filter (PF). However, the implementation of Particle Filter for object tracking still has room for improvement. Sulistyaningrum *et al.* [11] shows that using Particle Filter for tracking, the accuracy of tracking and people counting has a rate of 89.33% and 77.33% respectively with no

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occlusion handling. There is a research potential to increase the rate of precision, with the addition of implementing a Multi-Object Tracking onto it.

Particle Filter is a state space method for applying Bayesian filters. The main idea is to approximate the posterior probability distribution by the particles. Each particle represents a state of the object hypothesis, with a discrete sampling corresponding to probability (weight). The particles are usually done resampling to relieve particle degeneration. The efficiency and accuracy of particle filters for tracking depends on the distribution and effective model of observation for particle weighting [11]. Cho *et* al. [4] explains that Particle Filter provides a robust tracking of moving objects in a cluttered environment. They are used in the case of non-linear and non-Gaussian problems where the interest lies in the detection and tracking of moving objects.

This paper proposes using Particle Filter to apply Multi-Object Tracking (MOT) for online and real-time tracking. First, we use a dataset of a pedestrian video from MATLAB website. Then, we designed a program that is capable of tracking objects using Particle Filter and applying MOT. After that, the video is going to be loaded into the program. After it's finished running, the program is going to output the results using ACF detection. This is going to output the performance analysis of MOT using Particle Filter, highlighting the percentage of many metrics such as MOTA, MOTP, precision, and recall.

In this section, we breakdown the systematic for the remainder of this paper. Section II compares related works and this research. Section III explains the methodology in this research. Section IV shows the performance of our research. Section V presents the conclusions to our research.

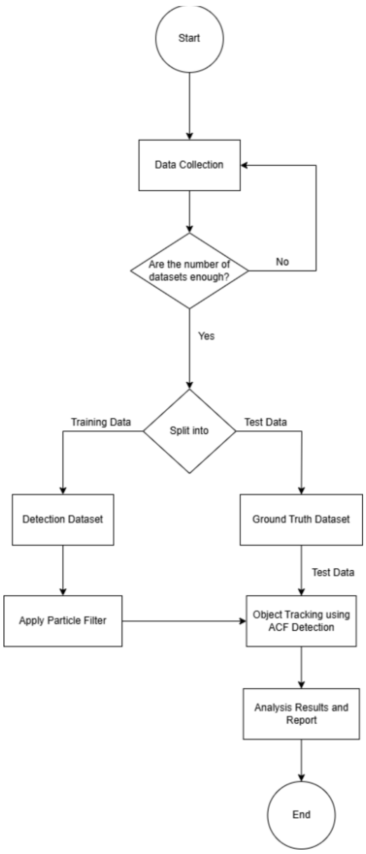

Fig. 1. Particle Filter-Based Object Detection System Research Workflow

II. Related Works

Research on object tracking generally uses two types of motion: linear and non-linear. However, linear motion usually not practical in high dimensions, because of the computing time, continuous update overtime, and large covariance matrices [12]. Also, Adžemović *et* al [13] explains that although Kalman Filter is a very strong baseline for linear motion, it fell short when it comes to non-linear motion.

Many studies have used MOT for object tracking. Sulistyaningrum *et* al[11] applied MOT to the object tracking system using particle filter. The study's results obtained an accuracy of 89.33% for object tracking and 77.33% for object counting. According to Ong *et* al [10], MOT algorithms can operate in two ways to produce current estimates. First, as soon as the data arrives, and second is in batch, which delays the estimation until more data is available.

Aggregate Channel Features (ACF) is one of the method that is used in object detection. Several studies have shown the excellence of ACF detection, like the study conducted by Hua *et* al [14], explains that compared with other statistical feature-based and deep learning-based algorithms, ACF algorithm exhibits better real-time performance with a lower hardware requirement despite lower detection performance.

TABLE I. Research that is state-of-the-art in Object Tracking System

Cite	Non-Linear Motion	Multi-Object Tracking	ACF Detection
[12]	✓	×	×
[13]	✓	×	×
[11]	✓	✓	×
[10]	×	✓	×
[14]	×	×	✓
Proposed Method	✓	✓	✓

III. Methodology

We designed a research flow for particle filter-based system for object tracking. First, we use a dataset of a series of images from MOT challenge. Then, we combine all the frames into a single video. After that, we designed a system that is capable of tracking objects using Particle Filter and applying MOT. After that, the video is going to be loaded into the program. ACF detection is going to be used for object tracking. This is going to output the performance analysis of CLEAR MOT metrics. Fig. 1 visualizes the research flow.

A. Multi-Object Tracking

Multi-Object Tracking (MOT) is a method to track multiple objects over a sequence of images or frames. Tracking is usually performed on higher-level applications that require the location and object in every frame. One of the methods for object tracking is estimation-based. Estimation-based methods formulate the tracking problem to an estimation problem in which an object is represented by a state vector. The state vector describes the dynamic behavior of a system, such as the position and velocity of an