Position and Velocity Estimations of 2D-Moving Object Using Kalman Filter: Literature Review

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***Abstract*—This paper proposes a position and velocity estimation scheme for 2D-moving object using Kalman filter. First of all, the 2D-moving object is represented by a state-space scheme where sensors are used to sense the system states. The main objective of a 2D-moving object is to estimate the position and velocity of moving object. The optimal signal processing algorithm called Kalman filter is proposed to estimate the position and velocity of the target object. A comprehensive literature review has been analyze by advantages and disadvantages about using optimal signal processing algorithms, Kalman filter, and moving object tracking. Extensive simulation results show that the proposed algorithm can properly track the position and velocity of moving object.**

***Index Terms*—Moving object, position estimation, velocity estimation, Kalman Filter.**

I. Introduction

In today's world, 2D-moving object tracking or detection is a widely used in the field of video surveillance, artificial intelligent, and traffic management. Object tracking is the process of sampling the position and location information of targeted elements over time. Motion detection and motion estimation are the two basic building block of 2D-moving object tracking [1], [2]. In this paper, an intelligent signal processing algorithm is proposed for position and velocity estimation of 2D-moving object. The motto of this paper is to investigate whether Kalman filter can accurately estimate position and velocity of 2D-moving object or not. The main contributions of this paper are:

- A comprehensive state-of-the-art target tracking system is presented in a comprehensive way.
- The 2D-moving object is represented by a state-space framework. The sensors are used to track the position and velocity under noisy environment.
- Intelligent signal processing algorithm called Kalman filter is adopted and verified for target tracking systems.
- Extensive simulation results show that the proposed algorithm can properly track the position and velocity of moving object.

Organisation: The rest of this paper is organized as follows. The state-of-the-art literature about target tracking is presented in Section II. The 2D-moving object system is described in Section III. The proposed algorithm is described in Section IV. The simulation results and discussions are given in Section V. Conclusions and future work are presented at the end of the paper.

Notation: Bold face lower and upper case letters are used to represent vectors and matrices, respectively; superscripts $\mathbf{x}'$ denotes the transpose of $\mathbf{x}$.

II. Literature Review

A comprehensive literature review about moving object tracking using Kalman filter (KF) is described in Tables I-II. The literature review consists of advantages and disadvantages of various methods of tracking object. It has been observed that in most of the 2D-moving object tracking or detection, the Kalman filter works effectively. It has a great impact on minimising error covariance and can accurately track down target moving object. This algorithm is therefore very reliable method because it provides very high estimation accuracy than the other tracking methods. For 2D object detection, the process and measurement may be corrupted by noise. Interestingly, the KF can reduce noise rather than corrupting information which could damage visual effects. Moreover, the fuzzy aided KF, feature matching, inertial measurement unit (IMU) based KF, extended KF, least squared, and least mean squared (LMS) are the other algorithms are used for target tracking.

III. 2D-Moving Object State-Space Representation

In generally, 2D-moving object tracking or detection system has two major applications such as motion detection and motion estimation. Object detection is the very first step of the system as it has the straight impact of the background information. The main task of object detection is to find and indentify the object from a video sequence. To remove the spatial and temporal redundancies of video coding, 2D orthogonal transforms and motion compensation techniques can be used. Most of the cases 2D discrete cosine transform is used because of its highest energy compaction. The motion

TABLE I: State-of-the-art literature (first part).

Approach	Advantage	Disadvantage	Ref.
Object tracking using KF	Can accurately track objects, Linear system.	Covariance being assumed, Does not apply for non-linear systems.	[3]
Moving object tracking by KF	Can track down moving object accurately, Errors are minimal	Complex procedure, Very hard to implement	[4]
Multiple moving object detection and tracking using artificial intelligent	Can accurately track object and detect, Efficient.	Multiple classifications, Longer process	[5]
Detection and tracking using different methods	Reliable	Result may differ for environments	[6]
Robust object tracking by dynamic covariance	Robust, Accuracy level is very high	Performance is not so good	[7]
Irregular movement by unscented KF of 2D/3D tracking	Each track has own system, Efficient design.	Not reliable for detection	[8]
Multi view tracking using neural network	Reduce cost, Can do multi view tracking	Has lacking on tracking, Can be improved more	[9]
Video surveillance	Effective method	Requires huge data sets, Increase data storage	[10]
The KF and probability product kernel is used for tracking	Can recognise colour image, Can track all points	Very large data sets, Worse performance	[11]
Moving object tracking with video using KF	Provide better estimation accuracy, Minimum error covariance.	Very expensive, Not suitable for automated surveillance	[12]
Fuzzy aided KF	Very effective approach	This method is more suitable than KF	[13]
Target tracking using KF	More robust, Suitable for indoor and outdoor	Cannot track far region, Inaccurate in lighting	[14]

detection and motion estimation are the two major building blocks for video surveillance [1], [25]. In motion detection, the moving object is identified by extracting the changes in object boundaries whereas, in motion estimation, the vectors are computed to estimate the position of the moving object [26]. Motion estimation is the technique of obtaining motion vectors that can elaborate the transformation mainly from one 2D image to another, usually from same frames in a video sequence. In this paper an optimal algorithm called Kalman filter being introduced to estimate position and velocity of a 2D moving object. The 2D-moving object is represented as follows [20]:

$$\mathbf{x}_{k+1} = \mathbf{A}\mathbf{x}_k + \mathbf{B}\mathbf{u}_k + \mathbf{n}_k. \tag{1}$$

$$\mathbf{z}_k = \mathbf{H}\mathbf{x}_k + \mathbf{w}_k. \tag{2}$$

where $\mathbf{x} = [x \; y \; v_x \; v_y]'$ is the system state variable, x/y is the position, v_x/v_y is the coordinate velocity, and $\mathbf{n}/\mathbf{w}$ is the noise. $\mathbf{n} \backsim N(\mathbf{0}, \mathbf{Q})$ and $\mathbf{w} \backsim N(\mathbf{0}, \mathbf{R})$ are the Gaussian noises.

TABLE II: State-of-the-art literature (remaining part).

Object tracking using KF, KLNN, LSTMs	KF is more reliable than other methods	Complex video surveillance system is used	[15]
Feature matching and KF approaches	Improve position, velocity estimation, Improve algorithmic performance	Performance degradation happens	[16]
Inertial measurement unit and position sensor are for tracking	Can estimate orientation and position correctly, Reduce orientation error.	Quaternion system might not give correct value, Very lengthy process.	[17]
Vision data fusion	Application based approach, Reliable	Complex, Longer process	[18]
Data classification	Do not need manual cleaning, The burden of hand processing is reduced	Not automatic like non data driven method, Sometimes error shows if there is nothing	[19]
Survey on moving object tracking	Can work in dynamic environment. Reduce error.	Cannot conduct multiple videos.	[20]
Tracking video objects	70-80 % noise can reduce, Measurements can be improved by 11.27%	Accuracy is low	[21], [22]
Moving object using Kalman filter	Suitable for indoor and outdoor environment, Algorithm applied successfully	Very large data set	[23]
Multi object tracking using motion context	Multiple object tracking, More robust	Sometimes misdetection happens	[24]

$\mathbf{B}$ is the input matrix, and $\mathbf{u}$ is the control variable. $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{H}$ are given by [20]:

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}. \tag{3}$$

$$\mathbf{B} = \begin{bmatrix} 0.5\Delta t^2 & 0 \\ 0 & 0.5\Delta t^2 \\ \Delta t & 0 \\ 0 & \Delta t \end{bmatrix}. \tag{4}$$

Here, Δt is the step size and $\mathbf{H}$ is the sensor sensing matrix. The proposed algorithm is described in the following section.

IV. Proposed Algorithm

The KF is a set of algorithm that can estimate the system when it cannot be measured directly. It is widely used in

$$\mathbf{H} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}. \quad (5)$$

all aspects of technologies such as motion captures, control systems, signal processing, missile guidance, navigation systems of marine and spacecraft, and trajectory tracking. For a moving object tracking, Kalman filter takes the current states of the system, and make prediction on the basis of a current estimation of measurements and make a prediction for the next state of the system. Then it compares its prediction with the received data and corrects itself upon the error. The KF algorithm can be summarized as prediction and correction parts.

- **Prediction Step:** Produces estimates of the current state variables, along with their uncertainties [27], [28].
- **Correction Step:** Updated the estimate of the current state variables using a weighted average, with more weight being given to estimates with higher certainty [29], [30].

The prediction step is given by [31], [30]:

$$\hat{\mathbf{x}}_{k|k-1} = \mathbf{A}\hat{\mathbf{x}}_{k-1|k-1} + \mathbf{B}\mathbf{u}_k. \quad (6)$$

$$\mathbf{P}_{k|k-1} = \mathbf{A}\mathbf{P}_{k-1|k-1}\mathbf{A}' + \mathbf{Q}. \quad (7)$$

Here, $\hat{\mathbf{x}}_{k|k-1}$ and $\mathbf{P}_{k|k-1}$ are the prediction state and error covariance while $\hat{\mathbf{x}}_{k-1|k-1}$ and $\mathbf{P}_{k-1|k-1}$ are their corresponding initial values.

The correction step for state estimation is given by [32]:

$$\hat{\mathbf{x}}_{k|k} = \hat{\mathbf{x}}_{k|k-1} + \mathbf{K}_k[\mathbf{z}_k - \mathbf{H}\hat{\mathbf{x}}_{k|k-1})]. \quad (8)$$

$$\mathbf{K}_k = \mathbf{P}_{k|k-1}\mathbf{H}'(\mathbf{H}\mathbf{P}_{k|k-1}\mathbf{H}' + \mathbf{R})^{-1}. \quad (9)$$

$$\mathbf{P}_{k|k} = \mathbf{P}_{k|k-1} - \mathbf{K}_k\mathbf{H}\mathbf{P}_{k|k-1}. \quad (10)$$

Here, $\hat{\mathbf{x}}_{k|k}$ and $\mathbf{P}_{k|k}$ are the updated state and error covariance, and $\mathbf{K}_k$ is the estimation gain.

V. Simulation Results and Discussions

The process and noise covariance are assumed to be $0.005\mathbf{I}$ and $0.05\mathbf{I}$. Matlab is used for simulation. After initial some essential parameters such as predicted state and error covariances, the proposed algorithm is run. The simulation results are shown in Figs. 1-2 when step size is 0.01 sec. It is observed that the proposed algorithm can properly track the position and velocity of moving object.

VI. Conclusion and Future Work

This paper presents the optimal signal processing algorithm for moving object detections. The main purpose of this paper was to find out whether it is the most suitable and accurate algorithm for the estimation of position and velocity or not. Extensive simulation results show that the proposed method can properly track the position and velocity of moving object. In future, we will apply signal processing algorithm on motion capture systems with covariance estimation approach.

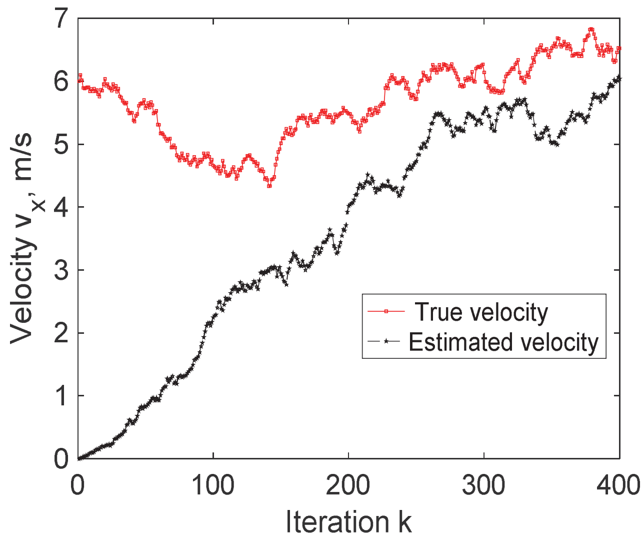

Fig. 1: Velocity v_x estimation of moving object.

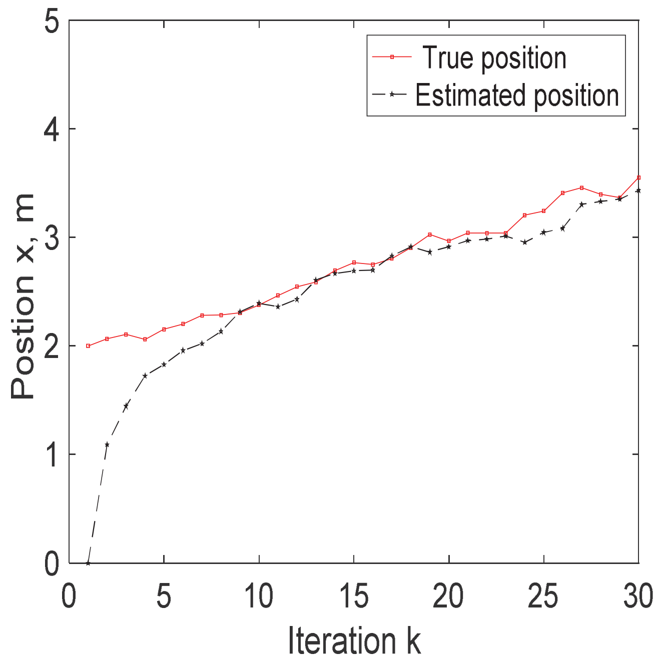

Fig. 2: Position x estimation of moving object.

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