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Design of Kalman filter for Airborne Applications

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ABSTRACT
Today multiple multi-sensor airborne surveillance systems are available which comprises of primary radar and secondary surveillance radar as the active sensor on board. The electronics and communication support measure system (ECSMS) will aid in identification, detection and classification of targets. These systems will detect, identify, classify the different threats present in the surveillance area and supports defense operation. These systems contain multiple functional operations as detection of air borne and surface target, tracking, and Multi-sensor data fusion. This paper presents the multi-sensor data fusion technique and how to detect and track moving target in the surveillance area.
Keyword- Detection, Tracking, Multi-sensor Data fusion.

I. INTRODUCTION

In the Airborne surveillance system one of the most important application is Multi-sensor data fusion. Different types of sensors are often fused to acquire information about the system which cannot be acquired by a single sensor alone. Sensors play an important role, because we have a need to gather information and process it for some tasks. Working with several types of sensors in practical application involves several uncertainties that can be overcome using sensor fusion techniques. Smart devices require reliable and different types of sensory data, fusing them to obtain better information regarding their objectives. Different types of sensors are often fused to acquire information which cannot be acquired by a single sensor alone. Sensor fusion is particularly applicable in defense systems for object detection and navigation.

In defense systems different applications based on identification, classification and tracking of objects in the target area. WSNs are used in several fields such as industrial control, precision agriculture, analysis of vital parameters in medicine, and dataset generation for modeling of ecosystems and prediction in environmental monitoring applications. One of the most important applications is moving object detection and tracking and another one is Multi-sensor data Fusion. Target tracking are often used in many applications including object detection and tracking and another one is Multi-sensor data Fusion. Target tracking are often used in many applications including air defense, ground target tracking, and missile defense. In tracking systems two problems must be considered: prediction and correction. Predict the location of an object being tracked in the next frame, that is identify a region in which the probability of finding object is high and identify the object in the next frame within designated region. A well-known solution for prediction is Kalman filter, a recursive estimator of state of a dynamic system. Kalman filter have been adopted in video tracking. The success or failure of any tracking algorithm depends a lot on the degree that the tracked object can be distinguished from its surroundings. In particular, the set of features used by the tracking algorithm to represent the objects being tracked plays a major role in tracking performance. Here we propose moving object detection and tracking and a Data fusion technique in which central limit theorem is used as fusion algorithm, which is implemented using MATLAB. The hardware implementation has been done on FPGA Spartan 6 board. The proposed technique is less costly than previous techniques both in terms of economic feasibility and in terms of computation.

II. DESCRIPTION OF KALMAN FILTER

The Kalman filter addresses the general problem of trying to estimate the state x of a discrete-time controlled process that is governed by the linear stochastic difference equations,

$$x_k = Ax_{k-1} + Bu_k + W_{k-1} \quad \ldots. \quad (1)$$

with a measurement Z that is,

$$z_k = Hx_k + V_k \quad \ldots \quad (2)$$

The random variables W_k and V_k represent the process and measurement noise respectively,
Where,

$$\hat{x}_k = \hat{x}_k^- + k(z_k - H\hat{x}_k^-) \quad .. . \quad (3)$$

The difference in above equation is called the measurement innovation, or the residual. The residual reflects the discrepancy between the predicted measurement and the actual measurement. A residual of zero means that the two are in complete agreement.

The kalman gain is given as,

$$k_k = p_k^- H^T (H p_k^- H^T + R)^{-1} \qquad k_k = \frac{p_k^- H^T}{H p_k^- H^T + R} \quad \dots \quad (4)$$

Looking at equation we see that as the measurement error covariance approaches zero, the gain K weights the residual more heavily. The Kalman filter estimates a process by using a form of feedback control: the filter estimates the process state at some time and then obtains feedback in the form of (noisy) measurements.

A. Kalman filter time update equations:

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_k$$
$$p_k^- = Ap_{k-1}A^T + Q \quad \dots. \quad (5)$$

Again notice how the time update equations in table 2.1 project the state and covariance estimates forward from time step k-1 to step k .

B. Kalman filter measurement update equations:

$$k_k = p_k^- H^T (H p_k^- H^T + R)^{-1}$$
$$\hat{x}_k = \hat{x}_k^- + k_k (z_k - H\hat{x}_k^-)$$
$$p_k = (I - k_k H) p_k^- \quad ..(6)$$

The first task during the measurement update is to compute the Kalman gain. The next step is to actually measure the process to obtain , and then to generate an a posteriori state estimate by incorporating the measurement as in equation. The final step is to obtain an a posteriori error covariance estimate via equation. After each time and measurement update pair, the process is repeated with the previous a posteriori estimates used to project or predict the new a priori estimates.

III. MOVING OBJECT DETECTION AND TRACKING

A. Background Detection

The background detection process means to detect the background image from a sequence of more sample images. The background detection also needs to ensure the actualization of background image according to new changes of the background. We will represent the background image as B(x,y).
Average Value Algorithm

This algorithm computes value of the background image pixel at position x, y as an average value of values at the same position using L sample images. Mathematically it is,

$$B(x,y) = \frac{I(x,y,0) + I(x,y,1) + \dots\dots + I(x,y,L-1)}{L} \quad \dots \quad (7)$$

The background image that is acquired using this algorithm is usually blurred. It means that pixels of acquired background image do not show the real value, they are only edged towards the real value. The big change for a little period of time has a big influence on background image detection.

B. Object Detection and Object Tracking

The most used approach to detect objects in a video sequence is background subtraction. Here we perform the pixel subtraction between the current image and the background image. If the subtraction value is greater than some define threshold value then that is belong to foreground object pixel otherwise that is a background object pixel.

[Current pixel –Background pixel]:
> T Foreground object pixel
< T Background object pixel

We use both region based and feature based algorithms for tracking. First for region based we use the Kalman filter for find the region of vehicle in the next frame. We find the center of object and then use Kalman filter for predicts the position of it in the next frame.

IV. MULTI-SENSOR DATA FUSION

Multi-sensor data fusion (MSDF) is defined as the process of combining information from multiple sources to produce the most precise and complete unified data about an entity, activity or event. MSDF is the combination and application of many conventional disciplines and new areas of engineering. The measurement value taken from a single sensor is not accurate and not reliable. It consumes more time. The spatial coverage of a single sensor is also low. Compared to the single sensor measurement, the MSDF gives more accurate, reliable and timely data. It covers a larger geometrical area and the results obtained are fault tolerant. In this paper state vector fusion algorithms is considered and employed in a tracking system. Thus we have adopted the state-vector fusion technique for fusing multiple sensors track data to provide complete and precise trajectory information about the system.

A. State vector fusion algorithm:

State Vector Fusion (SVF) is a Kalman Filter (KF) based data fusion. The KF is given for each set of observations, i.e., the algorithm is applied independently for each sensor (data) and generates state estimates. As shown in Fig.1

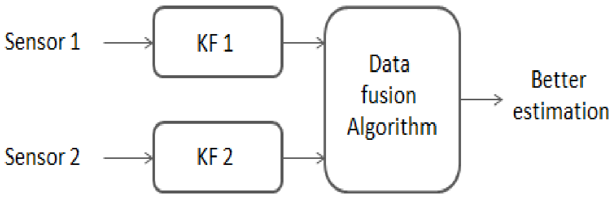

Fig.1 State vector fusion

In this method, individual sensor data is filtered using Kalman filter using measurement noise characteristics of the respective Temperatures sensors. The state and state error-covariance estimates of Kalman filter for each of the sensors are then used to obtain the fused state according to the following equations :

Fused State:

$$\hat{x}_{Fi,i} = \hat{x}_1 + \hat{p}_1(p_E)^{-1}[\hat{x}_2 - \hat{x}_1] \quad \ldots (8)$$

covariance of Fused state:

$$\hat{p}_F = \hat{p}_1 - \hat{p}_1(p_E)^{-1}\hat{p}_1^T \quad p_E = \hat{p}_1 + \hat{p}_2^T \quad \ldots (9)$$

Where,

$\hat{x}_{Fi,i}$ - State estimation of fused state

P_F – Error covariance of fused state

$\hat{x}_1$ - State estimation of first sensor data

$\hat{x}_2$ - State estimation of second sensor data

$\hat{p}_1$ - Error covariance of first sensor

$\hat{p}_2$ - Error covariance of second sensor

V. SIMULATION RESULTS

i. Kalman filter is applied to the sample video. Moving object is detected and tracked by using the Kalman filter:

Fig.2 Sample video

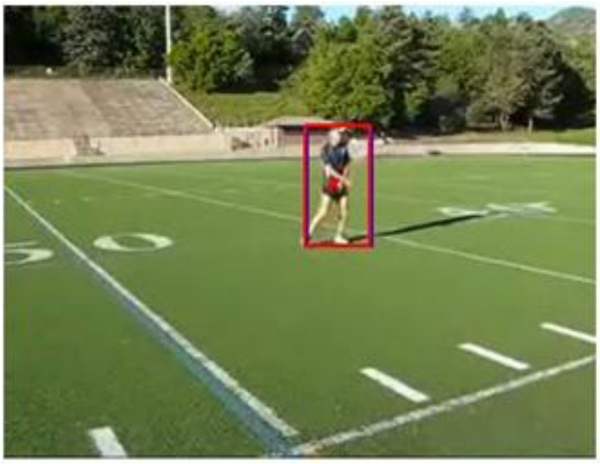

Fig.3 Detection of Moving object

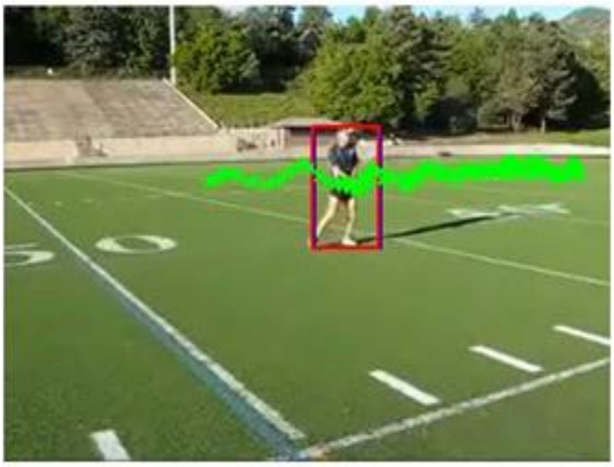

Fig.4 Tracked path of moving object in the video

Kalman filter is applied to temperature sensor 1 and temperature sensor 2 to obtain the multi-sensor data fusion result:

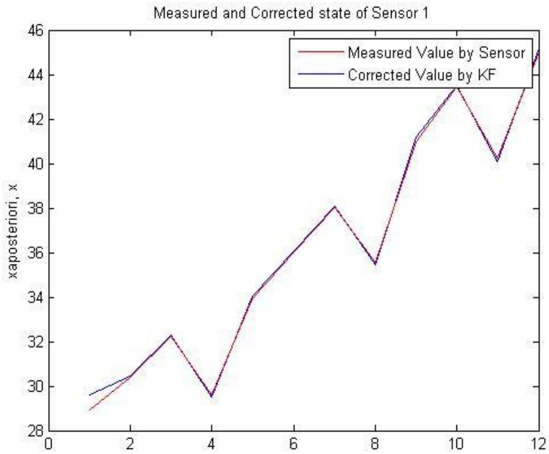

Fig.5 KF apply to temperature sensor 1

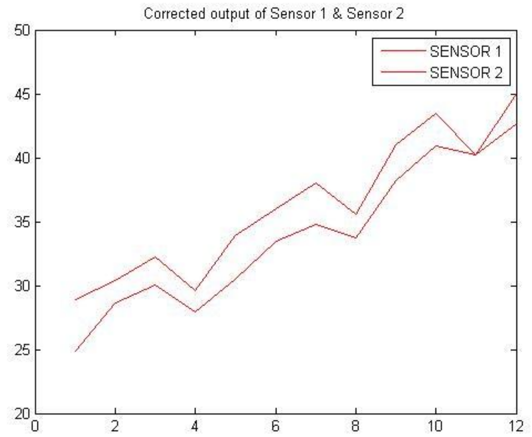

Fig.6 KF apply to temperature sensor 2 State vector data fusion algorithm apply to emperature sensors as:

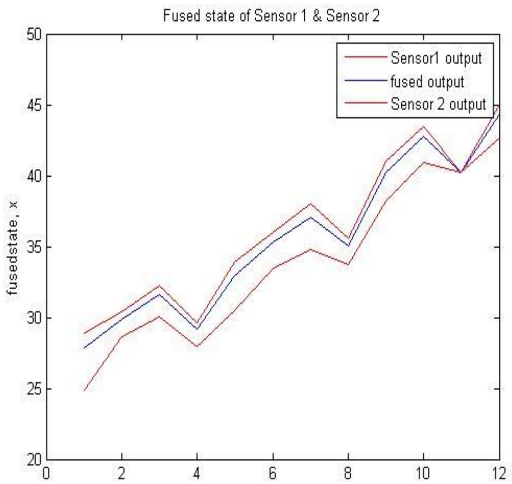

Fig.7 Result of state vector data fusion algorithm

TABLE 1. ERROR BEFORE FUSUSION

Error before Fusion	Error after Fusion
4.7600	1.7590
1.7780	0.5331
2.2826	0.6853
1.5681	0.3734
3.5350	1.0970
2.6151	0.7851
3.2720	0.9653
1.7721	0.4354
2.9406	0.9586

VI. CONCLUSION AND FUTURE WORK

In this work, Kalman Filter based State Vector Fusion (SVF) algorithms have been implemented in a tracking system. From the performance measure it is observed that the Kalman Filter based State Vector Fusion algorithm performs well comparatively, for the system taken. This work can be further extended by implementing sensors with nonlinear characteristics in more systems and different fusion algorithms can be developed and implemented in many other systems. FPGA-based design exhibits similar accuracy to computer-based implementation but is much faster. FPGA implementation is then not only viable but superior to micro-controller based design.

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