Infrared Physics & Technology 75 (2016) 12–17

Contents lists available at ScienceDirect

Infrared Physics & Technology

journal homepage: www.elsevier.com/locate/infrared

Review

Infrared/laser multi-sensor fusion and tracking based on the multi-scale model

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ARTICLE INFO

Article history:
Received 20 June 2015
Available online 20 January 2016

Keywords:
Infrared/laser composite detection system
Data fusion
Multi-scale theory
CMKF

ABSTRACT

The state estimation problem of targets detected by infrared/laser composite detection system with different sampling rates was studied in this paper. An effective state estimation algorithm based on data fusion is presented. Because sampling rate of infrared detection system is much higher than that of the laser detection system, the theory of multi-scale analysis is used to establish multi-scale model in this algorithm. At the fine scale, angle information provided by infrared detection system is used to estimate the target state through the unscented Kalman filter. It makes full use of the high frequency characteristic of infrared detection system to improve target state estimation accuracy. At the coarse scale, due to the sampling ratio of infrared and laser detection systems is an integer multiple, the angle information can be fused directly with the distance information of laser detection system to determine the target location. The fused information is served as observation, while the converted measurement Kalman filter (CMKF) is used to estimate the target state, which greatly reduces the complexity of filtering process and gets the optimal fusion estimation. The simulation results of tracking a target in 3-D space by infrared and laser detection systems demonstrate that the proposed algorithm in this paper is efficient and can obtain better performance than traditional algorithm.

Contents

1. Introduction

Data fusion is a multilevel, multifaceted process dealing with detection, association, correlation, estimation and combination of data or information from multiple sources to achieve refined state estimation, identity recognition and assessments of situation and threat completely and timely. As a typical data fusion system, infrared/laser composite detection system is widely used in military fields and civil applications [1,2], such as target tracking, integrated navigation and fault detection. As passive detection system, infrared detection system has a good concealment and low detectability with higher angular resolution, but it can't get range information of targets. Meanwhile, laser detection system has higher ranging accuracy, and its distance measurement satisfies

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http://dx.doi.org/10.1016/j.infrared.2016.01.001
1350-4495/

the requirement of infrared detection system. The complementary properties of infrared/laser detection system make them be utilized together, which make the detection system more intelligent in target detection, recognition, and improve the system's noise-resistant, survivability and effective working abilities efficiently.

As one of the most effective approach for asynchronous information fusion, multi-scale analysis theory was first introduced in 1995 [3]. It provides a scale recursive way to handle measurements at different scales. Based on this idea, measurements observed by different sensors at different sampling instants could be fused effectively. In recent years, a lot of work on the multi-scale theory has been done and obtained plentiful research results. Bar-Shalom et al. [2,4] presented some effective algorithms for asynchronous multi-sensor fusion. But the data within a scale is usually grouped and batch processed, the computation complexity is heavy. Chenglin Wen et al. [5] presented a fused state estimate algorithm by establishing system model first at a proper scale and then fusing the asynchronous multi-rate multi-sensor data step by step. The algorithm is promising in that it has proper computation complexity and can obtain nearly optimal state estimate, however, it requires the sampling ratio between different sensors equal to the power of two. Yanyan Hu et al. [6] proposed an asynchronous IMM fusion estimation algorithm for stochastic multi-model systems with multiple asynchronous sensors. Sampling rates of the sensors can be arbitrary as well as initial sampling time instant. But the previous-research focused on the optimal estimation of homogeneous sensors, and can't directly apply to the infrared/laser composite detection system due to the complementary information of infrared and laser detection systems [7–9]. On the other side, in tracking applications, target dynamics are usually modeled in Cartesian coordinate, while the measurements of infrared/laser composite detection system are available directly in spherical coordinates. Because the nonlinear transformation of an unbiased spherical measurement to a Cartesian converted measurement creates a bias in the converted measurement error, and results in coupling of the measurement error, Kalman filter is not optimal in this case. The common solution is to use converted measurement Kalman filter (CMKF) algorithm [10]. Motivated by above ideas, this paper proposed a novel state estimation algorithm of targets for infrared/laser detection and tracking system which combined multi-scale analysis theory and CMKF, named multi-scale converted measurement Kalman filter (MCMKF) algorithm.

The outline of the paper is as follows. In Section 2, the problem is formulated. In Section 3, the MCMKF algorithm is described in detail. Section 4 shows the results of simulation. Section 5 contains conclusion and discussion.

2. Problem formulation

A multi-sensor dynamic system will be considered in this paper. This multi-sensor system includes infrared and laser detection systems to observe a target during the same period of time with different sampling rates. The measurements are obtained asynchronously at different scales, including azimuth angle α_m and elevation angle β_m acquired from infrared detection system with higher sampling rate at fine scale which is named scale 1, range r_m acquired from laser detection system with lower sampling rate at coarse scale which is named scale 2. Generally, target dynamics are usually modeled in Cartesian coordinate, while the obtained measurements are available directly in spherical coordinates.

The sampling time of infrared/laser detection system are illustrated in Fig. 1. It's assumed the target is detected by infrared and laser detection systems with sampling period T and t respectively. Meanwhile n is defined as the ratio of t to T. That is to say, the sampling period T of infrared sensor on scale 1 and the sampling period t of laser sensor on scale 2 meet the relationship.

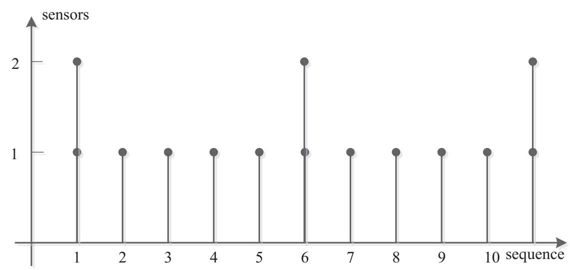

Fig. 1. Infrared/laser sampling illustration.

$$t = nT \tag{1}$$

The discrete-time dynamic system with infrared and laser detection systems can be described by [11,12]

$$x(k+1) = Fx(k) + w(k) \tag{2}$$

$$Z_i(k_i) = h_i(x_i(k_i)) + v_i(k_i) \quad i = 1,2 \tag{3}$$

where $x(k)$ is the state vector at time k at the fine scale 1. F is the system state transition matrix, $w(k)$ is system noise and is assumed to be Gaussian distribution with mean zero and covariance Q. $z_i(k_i)$ represents measurement at time k_i at the scale i, and $h_i(\cdot)$ is nonlinear transformation function at scale i. $x(i,k_i)$ is the state vector at time k_i at the scale i. $v_i(k_i)$ is measurement noise.

When $i = 1$, there are $k_1 = k$ and $x_1(k_1) = x(k)$. If the target moves at a constant velocity, $x(k)$ can be described as: $x(k) = [x, v_x, y, v_y, z, v_z]$. v_x, v_y and v_z are the velocity of x, y and z. The system state transition matrix F is

$$F = \begin{bmatrix} 1 & T & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & T & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & T \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$z_1(k_1)$ is the measurement at the fine scale 1, $z_1(k_1) = [\alpha_m, \beta_m]$. The nonlinear transformation function $h_1(\cdot)$ at scale 1 is as follows.

$$\alpha_m = \arctan\frac{y}{x} \tag{4}$$

$$\beta_m = \arctan\frac{z}{\sqrt{x^2+y^2}} \tag{5}$$

At coarse scale 2, due to the sampling period of laser is the integer times of infrared detection system, the angle information with high precision can be directly fused with the distance information of laser detection system. The combined information is thought as the observation of filter at coarse scale, so that the measurement $z_2(k_2)$ at the coarse scale 2 can be expressed as $z_2(k_2) = [r_m, \alpha_m, \beta_m]$. The nonlinear transformation function $h_2(\cdot)$ at scale 2 is represented as (6) in addition to (4) and (5).

$$r_m = \sqrt{x^2+y^2+z^2} \tag{6}$$

3. MCMKF algorithm for tracking

In this section, the MCMKF algorithm which fuses information from infrared/laser detection system is presented. Because infrared sampling rate is much higher than that of the laser sensor, multi-scale model is established according to the different sampling frequency of sensors. A filtering estimation can be achieved as soon as a measurement is gotten. At fine scale, the unscented Kalman filter