Information Fusion 27 (2016) 41–53

Contents lists available at ScienceDirect

Information Fusion

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

Target tracking using Interactive Multiple Model for Wireless Sensor Network

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ARTICLE INFO

Article history:
Received 26 June 2014
Received in revised form 23 March 2015
Accepted 16 May 2015
Available online 23 May 2015

Keywords:
Wireless Sensor Network (WSN)
Person detection
Tracking
Kalman Filter (KF)
Interacting Multiple Model (IMM)

ABSTRACT

Target tracking in a Wireless Sensor Network (WSN) environment is a challenging research problem. Interactive Multiple Model (IMM) is a popular scheme for accurate target tracking. The existing target tracking scheme used in WSN employs Kalman Filter (KF) which fails to track the target accurately due to non availability of target data at regular intervals and missing of packets. Though existing KF based tracking in WSN scheme detects the target, it fails to identify the target. To overcome these problems, this paper proposes a IMM based Target Tracking in WSN named ITTWSN that uses multiple models (velocity and acceleration) to handle both maneuvering and non maneuvering targets and multiple sensors to detect and identify the targets. The performance of the proposed ITTWSN is compared with the KF scheme and it is found that the accuracy of the proposed ITTWSN is better than the existing KF based approach.

1. Introduction

Location detection and tracking of moving targets using Wireless Sensor Networks (WSNs) comprise a popular area of research. Tracking could be defined as establishing coherent relations of targets between successive events that indicate the movement of the target. WSNs have been used in many applications such as industrial process monitoring and control, health monitoring, environment and habitat monitoring, healthcare applications, home automation, traffic control and surveillance systems, object detection and tracking, disaster management and security surveillance. Many intelligent environments and security systems deploy WSN to detect, identify the location and track the moving targets.

Several solutions for target detection and tracking have been proposed in literature [1,2]. The proposed solutions in the literature use acoustic sensor, image sensor and Passive Infra Red (PIR) sensor for target detection. Tracking is achieved using techniques such as Particle Filter [3], mobile agents [1] and Kalman Filter (KF) [4,5]. Although PIR sensor senses the presence of an object, it fails to classify the object. Hence, in addition to PIR sensor, another sensor is required to identify the object for tracking applications, when multiple targets are present.

In a randomly deployed WSN, the object detection events occur randomly and hence the packets (samples) may not arrive at regular time intervals. Also, a target may be detected by more than one sensor or may not be sensed even by a single sensor at time. Hence, there is a need to predict the future position of a target, based on the target dynamics even if its events are missed.

Though IMM is used for target tracking in RADAR applications, it is not applied for target tracking in WSN as per the literature survey. This paper proposes IMM based tracking scheme for Wireless Sensor Network (ITTWSN) using multiple sensors. IMM uses a velocity model and an acceleration model to describe the motion of the target. These models interact with each other probabilistically and adjust their parameters to provide optimum results. The basic equations of IMM are obtained from Mazor et al. [6] and the measurements are obtained from heterogeneous sensors.

The proposed ITTWSN scheme overcomes the limitations in the existing schemes due to localization errors, missing events phenomenon caused by failure of nodes and random deployment of sensors. The proposed scheme is validated in real time and applied for detecting intruders.

The paper is organized as follows. Section 2 describes the related work. The proposed ITTWSN based target tracking method for WSN (ITTWSN) is explained in section 3. Section 4 gives the real time implementation details of the proposed method for detecting the intruder. Section 5 provides simulation results and discussion. Section 6 presents the conclusion and future work.

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http://dx.doi.org/10.1016/j.inffus.2015.05.004
1566-2535/

2. Related work

To make WSN cost effective, the individual nodes have to be low-end and inexpensive. Umesh Babu et al. [5] proposed a KF based method for tracking the target in a sensor network. Their approach used acoustic signal and Time Difference of Arrival (TDoA) for target detection and localization. But their scheme failed to identify the target. An active badge system [7] presented a scheme for identifying the targets. The drawback of their system is limited scalability. A method for object tracking in an indoor environment is proposed by Kim et al. [8]. Radio Frequency Identifier (RFID) system has been used to increase the accuracy and resolution of location estimation. RFIDs provide superior performance in industries and office buildings with many corridors and rooms where real-time tracking is mandatory. RFIDs are cheaper, thus making the deployment cost effective. But this method tracks only the authorized person who wears the RFID tag.

Brooks et al. [9] suggested a tracking scheme, in which the sensor network is sub divided into smaller units called spatial cells with three different states: Alerted cell, Active cell and Sleeping cell. An alerted cell is a cell that has not yet detected the target and the active cell is a cell that has detected the target. The sleeping cell is neither alerted nor active, but ready to accept the target state packets. The tracking approach may be centralized or localized [10]. In centralized processing, all nodes sensing the target, report their readings to the sink node which combines them to obtain the desired estimates. In the localized processing, a manager node collects the local sensor readings and estimates the target position. It hands over the whole targets' state to the nodes close to the track. When two targets are similar, it is difficult to track the target in the crossover scenario [11].

Vaidehi et al. [12] proposed an energy efficient cluster based tracking using Extended Kalman Filter for predicting the object movement. The paper also proposes a novel routing algorithm called Delay-less Optimal Shortest Path Routing Algorithm (DOSPRA), which reduces the routing delays in the cluster.

Bar-Shalom and Birmiwal [13] presented KF based target tracking scheme to provide an estimate of the states of the target. The velocity model KF gives poor performance for a maneuvering target and the acceleration model KF gives inferior performance when the target moves with linear velocity. A single KF is no longer acceptable and will lead to filter divergence, when the target starts maneuvering because its acceleration appears as extensive process noise in the target model and it cannot be covered by original process noise variance. Hence Multiple Model (MM) filter is needed for efficient tracking of maneuvering and non maneuvering targets.

To precisely estimate the state of the target, the exact model of a maneuvering target needs to be selected [14]. Interacting Multiple Model (IMM) is one of the several approaches to handle the maneuvering problem. In Interacting Multiple Model (IMM) estimator, multiple models are used to describe the motion of the target. The IMM makes use of a bank of Kalman Filters to accommodate various possible target trajectory patterns and conditions [15,16]. The final estimate is obtained by the weighted sum of estimates from sub-filters of the different models [17] and switching between models is obtained as per Markov transition probability matrix. The IMM estimator with KF as a sub filter uses a set of models to describe the target model [18,19].

3. Proposed IMM based target tracking method for WSN (ITTWSN)

This section describes the proposed IMM based tracking scheme for WSN named ITTWSN. The use of the IMM estimator yields considerable noise reduction during uniform motion, while maintaining the accuracy of the state estimates during maneuver.

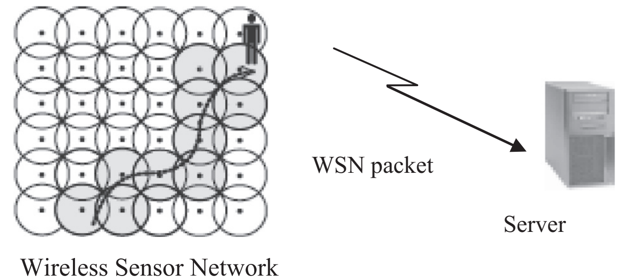

Fig. 1. WSN system overview.

Fig. 1 shows the general WSN system overview. The grid deployment of sensors (dots), sensing range of each sensor (circles), a target path (solid line) and corresponding sensors (shaded circle) along the target path are shown. A target moving in the WSN deployment area detected by the sensor node produces an event in WSN. Upon detection of the target, WSN packets are generated in the detected nodes and routed to the server.

A node present in WSN detects the presence and identity of the target using PIR and RFID sensors respectively. The location of the sensor which detects the target is considered as the position of the target. WSN nodes generate packets consisting of node id., RFID value, location (Latitude, Longitude, Altitude – LLA), time and date as pay load. This packet is sent to a sink node which separates the payload and gets the position of the target, the target's identity through RFID and the event time. The consecutive position information obtained from the packets for a specific target is used to derive the velocity of the target. The position and velocity values thus obtained are used to initialize the filters in IMM. Using successive velocity values, acceleration of the target is derived. The KF of each (velocity and acceleration model) is thus initialized using the first three measurements obtained from the specific target. When the tracks of the multiple objects overlap, the proposed scheme ITTWSN tracks the object accurately as it uses RFID sensors for identifying the target. Hence the efficiency of the proposed system is not reduced in crossover scenarios.

In any realistic multi target tracking scenario, the targets being tracked undergo occasional maneuvers. Consequently, the motion of such targets cannot be modeled accurately with a single set of state equations. Hence, multiple model filters are used to represent the target motion both in linear and maneuvering condition. The KF is the elementary filter for these models. The proposed block diagram of ITTWSN based tracking is shown in the Fig. 2.

The IMM estimator is designed with two models namely the velocity and the acceleration to represent the linear and maneuver motion respectively. These filters probabilistically interact with each other and adjust their parameters to provide optimum results. A maneuvering target is modeled by the following system and measurement models.

The state and measurement equations of KF are given below.

3.1. System model

The system model provides the present state of the system at any time step and is given by,

$$x_k = Fx_{k-1} + Gp_{k-1} \tag{1}$$

where x_k – state vector at time k, F – state transition matrix, G – control input matrix, p_k – process noise with covariance Q_k, where, $Q_k = E[p_k p_k^T]$ and T represents transpose.