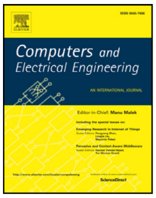
Computers and Electrical Engineering 000 (2016) 1–11

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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



Representing arbitrary sensor observations for target tracking in wireless sensor networks[☆]

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ARTICLE INFO

Article history:
Received 1 May 2016
Revised 25 November 2016
Accepted 25 November 2016
Available online xxx

Keywords:
Wireless sensor network
Target tracking
Heterogeneous sensors
Adaptive state space
Nonparametric representation
Occupancy grid

ABSTRACT

Conventional object tracking in wireless sensor networks requires the use of predefined sensor types, which presents challenges when faced with adaptability and scalability constraints. This paper considers heterogeneous sensors and proposes a sensor-independent tracking framework. The Adaptive Grid Representation of belief Distribution (Adaptive GRiD) provides a common data format to allow heterogeneous sensors to be treated homogeneously. The proposed framework has been evaluated by simulation, and the results demonstrate that the Adaptive GRiD technique yields improved location estimation over a conventional occupancy grid approach.

1. Introduction

This article seeks a solution to the heterogeneous sensor data fusion problem for distributed target tracking, generalising it to *a priori* unknown sensor types of arbitrary number and combination – with a focus on disparate sensors, which produce information in incommensurate information spaces.

The conventional approach to Wireless Sensor Network (WSN) tracking is to choose one [1] or two [2] relevant sensor types and design an algorithm around those specific sensors. The outcome is usually an effective tracking system; however, the algorithm only works for those predefined sensors. As such, it lacks the following qualities required for use with heterogeneous sensors:

Adaptability – The designer of the tracking algorithm may not necessarily have control or knowledge of which sensors will be present in the network. This is true if sensors are retro-fitted after deployment, where certain sensors are mandated for other purposes, or in the case of allied controlled sensors (e.g. on a battlefield). As such, the chosen sensors may not always be available.

Scalability – In a network with heterogeneous sensors, each sensor type provides a different type of information. Each sensor needs to be handled differently by the tracking algorithm, requiring specific algorithms for combining each pair of data types (such as distances and angles). This quickly becomes unwieldy as the number of sensor type combinations rises.

[☆] Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. T. Qiu.

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http://dx.doi.org/10.1016/j.compeleceng.2016.11.033
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Please cite this article as: S.R. Sleep et al., Representing arbitrary sensor observations for target tracking in wireless sensor networks, Computers and Electrical Engineering (2016), http://dx.doi.org/10.1016/j.compeleceng.2016.11.033

Hence, a system is desired which supports any two or more, arbitrary sensors. It follows that without knowing the sensor model *a priori* the fusion algorithm must be able to treat every sensor homogeneously, which necessitates a sensor-independent system. The one concession to uniformity which can be made is to assume that all participating sensors have information useful to target tracking – that is, pertaining to the target's location. We further assume that a model exists for describing and extracting the useful content. Therefore, all participating sensors can provide relevant information (if they have any) so long as the fusion algorithm has an interface to accept it. To clarify, we do not propose a system which can deduce a location estimate from raw sensor data alone. Sensor models must be present to provide context to the sensors' outputs.

In this work we focus on the dynamic state estimation mechanism within the larger target tracking problem. In order to simplify the problem, the following assumptions are made. The sensors' locations are determined a priori by some other mechanism. Sensor observations are already aligned with a global spatial and temporal origin. Models for interpreting sensors' observations are known. The method and extent of information extracted from a sensor and provided to the fusion algorithm is left to the WSN developer. Multi-target tracking in WSNs can be considered for the most part as multiple separate tracking problems, until targets become too close to distinguish between them.

The remainder of this article is laid out as follows. First, related works are analysed in Section 2. Then, a framework for distributed, sensor-independent target tracking algorithms is proposed in Section 3, followed by an associated data format suitable for disparate sensors in Section 4. Section 5 details the proof of concept experimentation undertaken to verify the proposed framework and format, the results of which are presented in Section 6. Finally, our findings and conclusions are presented in Sections 7 and 8 respectively.

2. Related literature

For applying heterogeneous sensors in surveillance and monitoring applications [3,4], sensor diversity has been shown to increase the accuracy [5] and robustness [6] of WSN target tracking. Many WSN tracking algorithms exist that use heterogeneous sensors [7–12], however this concept has rarely been generalised to create an extensible WSN tracker which accommodates various configurations of sensor types [13,14].

The universal WSN aggregation service in [15] aims to reduce network traffic, and hence energy consumption, by either concatenating delayed packets or fusing the information contained within. A custom aggregation function might allow a tracking system to be implemented for specific data, but aggregation is not itself a generalised fusion and state estimation solution. A flexible tracker is proposed by Munz, Dietmayer and Mählisch [13,16] that uses a standardised interface via which sensors provide their observational information to the fusion module. However, that interface is limited to Gaussian distributions, which is not suitable to represent multi-modal or complex multivariate distributions. Kritzler and Krüger [17] identify that a standardised format for communicating and storing the spatiotemporal information is required for fusing disparate sensors; however they don't go as far as recommending generalised methods for fusing the collected information (e.g. filtering). A system designed specifically for WSNs, Envirotrack [18] is a popular tracking 'middleware', in which members of a cluster periodically send sensor measurements, as well as the sensors' locations, to a cluster leader that produces a scalar output using some aggregating function [19,20]. Though it does support heterogeneous sensors, it does not lend itself to fusing *a priori* unknown arbitrary sensors, since targets are defined by some predetermined set of sensor types which detect them. Hong, Rushing, Graves and Criswell [14] used points and lines to represent sensor observations from three specific sensors: binary, bearing, and position sensors. Chu, Haussecker and Zhao [21] treat the state estimate as an arbitrary distribution describing the relative likelihood of all states, which is apt for a sensor-independent approach as it easily represents non-Gaussian observations. They attest that the data format which represents this distribution should be compact, incrementally updatable and, importantly, approximated by a mixture of parametric distributions or some other nonparametric probability mass function. Interestingly, they suggest that the history of all raw sensor measurements is an accurate and data-efficient nonparametric representation, until the belief can be determined to be unimodal, whereupon a Gaussian can be used. The drawback of this in a sensor-independent system is that nodes other than the originating sensor must be able to interpret all raw sensor data.

Many of the works mentioned above identify that some standardised interface is desirable for sensor-independent operation. However, a common format can promote the isolation of sensors which would otherwise work closely with one another. In a custom-built solution, two sensors may have been used together because the unique information they each observe could be combined to create a location estimate. The use of a common format discourages direct collaboration between sensors. The solution, and major challenge, is to allow those sensors to include their unique information in the common format in such a way that the fusion algorithm can combine them to produce an estimate without treating the information differently to any other.

3. Sensor-independent tracking framework

Desirable elements from related, existing methods were examined to prescribe characteristics of a data format that facilitate sensor-independent fusion for a distributed target tracker. These elements include (1) Use a common format for all sensors, (2) Use a common format for sensors and fusion results, (3) The data format should also be a state estimate, (4) Represent information in location space, (5) The format must facilitate incremental updating of the state estimate, (6)

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