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Extracting semantic event information from distributed sensing devices using fuzzy sets

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Abstract

Event detection is a central task for distributed sensor systems and detecting forthcoming events in a timely manner is the main way of minimizing their possibly damaging effects. The state-of-the-art methods for event description and detection always rely on using crisp raw sensory data, which requires huge data transmission as well as is time-consuming. However, even a centralized processing manner cannot ensure accurate event decision due to the imprecision and uncertainty of raw sensor readings. In many cases, users do not care about the raw sensory data or the data format used for in-network processing, but instead they are concerned with the semantic event information, such as "how serious is it?" and "where will it occur?" In addition, the main technique employed by the existing solution for detecting problems is collaboration with neighbors, which requires massive data exchange between neighbors that is highly intensive in terms of wireless communication. In this paper, we introduce an energy-efficient, reliable semantic event information extraction framework using fuzzy sets. Linguistic event variables instead of raw sensor data are used for event information transmission and fusion, and fuzzy method-based semantic event information filtering and fusion algorithms are proposed. Extensive evaluations based on both real-life and synthetic data sets demonstrated that our framework only incurs a small communication cost and it returns interpretable event information with guaranteed accuracy.

Keywords: Accuracy; Energy efficient; Event detection; Fuzzy set; Sensor system

1. Introduction

Sensor network systems typically comprise many small devices, which are deployed over a geographical area for monitoring physical phenomena such as temperature, humidity, vibrations, and seismic events. These tiny devices have limited computing power, memory, and energy resources, where the energy supply is typically highly constrained and it is often difficult to replace or recharge. Thus, handling massive amounts of raw sensory data (relatively big data) is a very expensive task for these limited-resource sensor nodes. Therefore, designing reliable, energy-efficient data processing algorithms to extract information of interest from distributed sensor devices is a significant challenge. Since

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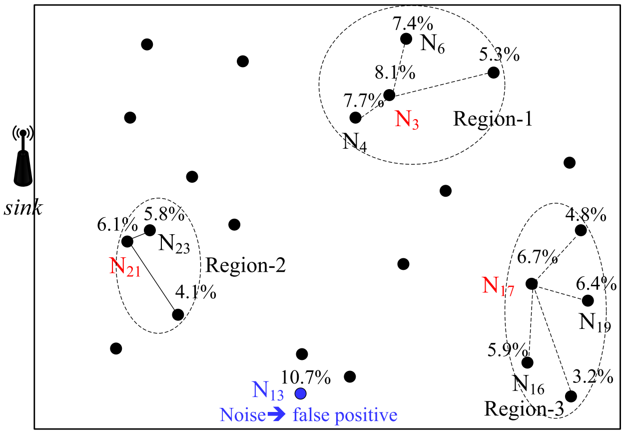

Fig. 1. Gas concentration monitoring in a coal mine.

the data transmission accounts for the main communication cost, an effective way is to reduce the data transmission while guarantee the user-specified accuracy. In addition, small amount of data transmission also contributes to short response time and less signal interference in wireless communication.

Event (region) detection is a common required service in sensor systems such as environmental monitoring [1–4] and object tracking [5–7], and it has attracted increasing attention from researchers. Various state-of-the-art event description and detection approaches have been reported [8–25], which can be roughly divided into two main categories: node-level event detection [14,21,22] using model-based techniques (e.g., Gaussian processes [11], regression [12], and dynamic-probabilistic models [13]) and collaboration-based complex event detection [23] using both modeling and voting techniques [15,17,19,20].

Node-level event detection. Different application scenarios use various event description approaches, e.g., a single node can detect local events when sensor nodes are deployed sparsely (rare redundant nodes). In this case, the communication and time overheads are small, but the reliability of detection decisions is difficult to guarantee. In particular, this approach does not work when users want to find the top-k event regions. For example, the sensor nodes are used for monitoring gas concentrations in a coal mine safety monitoring system, as shown in Fig. 1. The nodes labeled with gas concentration (%) data are key node-level events. The results for the top-3 events are N_3, N_4, and N_6, which are in the same region (region 1). However the user's desired top-3 events may be region 1, region 2, and region 3, where the representative nodes are N_3, N_{21}, and N_{17}, respectively. In addition, false positives might occur in the node-level event detection approach due to a lack of spatial correlation analysis. For example, node-level event N_{13} might be a false positive in Fig. 1.

Collaboration-based event detection. In many sensor network applications, the sensor nodes are densely deployed. Therefore, collaboration between neighboring sensor nodes can be used to improve the reliability of event analysis, where the representative approaches are weight-based "voting techniques" [15,17,19,20]. Collaboration-based event detection can reduce the false event regions (false negatives) and false node-level events (false positives), thereby improving the reliability of the detection decisions. For example, the top-3 collaboration-based event detection results are region 1, region 2, and region 3, where the representative nodes are N_3, N_{21}, and N_{17}, respectively. However, collaboration-based event detection methods require massive data exchange, which is expensive in terms of energy and time consumption.

In addition, the existing solutions for event description and detection always use the raw sensing data, which results in massive data transmission as well as is time-consuming. However, even centralized processing cannot ensure accurate detection results due to the imprecise raw sensor data. In many cases, users do not care about these raw sensory data or the data format during in-network fusion, but instead they are concerned with the semantic event information, such as "how serious is it?" and "where will it occur?" Fuzzy methods are useful for analyzing and processing the imprecise and uncertain data obtained from sensor systems in a robust and understandable manner.

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