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A convolutional neural network based method for event classification in event-driven multi-sensor network☆

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ABSTRACT

A multi-sensor network usually produces a large scale of data, some of which represent specific meaningful events. For event-driven multi-sensor networks, event classification is the basis of subsequent high-level decisions and controls. However, the accuracy improvement of classification is always a challenge. Recently the deep learning methods have achieved vast success in many conventional fields, and one of the most popular deep architectures is convolutional neural network (CNN) which sufficiently utilizes partial features of the input images. In this paper, we make some analogy between an image and sensor data, then propose a CNN-based method to improve the event classification accuracy for homogenous multi-sensor networks. An variant of AlexNet has been designed and established for classifying the event by acoustic signals. The results indicate that this CNN-based classifier outperforms than k Nearest Neighbor (kNN) and Support Vector Machine (SVM) methods on our data set with a higher accuracy.

1. Introduction

Sensors are objects designed for measuring some specific physical quantity values in their surroundings, and providing related output signals representing the quantities such as temperature, sound or pressure, which are widely applied in the field of measuring systems [1]. Due to the inherent limits of precision, range, and power for a single sensor [2], multiple sensors are usually organized as a sensor network to obtain information and improve the holistic stability and robustness [3]. Then some multi-sensor information fusion methods can be applied to settle the accompanying challenges (e.g., information redundancy, data imperfection and data conflict) and fuse the original low-level data to a unified picture for high-level decisions. Generally, the original sensor data can be collected from two kinds of multi-sensor network architectures:

1. Homogenous networks [4]: the sensors measure the same physical quantity and output the sampling results in the same format (e.g., a normalized vector).

2. Heterogeneous networks [5]: the sensors measure some different physical quantities (e.g., temperature, humidity, sound intensity) and output different kinds of signals.

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Usually the sensor data is complementary due to the restriction of sensors' sensing area, or correlated if they sample the same object. In this paper we study the large-scale sensor data classification problem in homogenous sensor network for its ease of deployment.

For the purpose of saving energy, the event-driven sensing technologies are widely applied in multi-sensor networks, where the network centers (e.g., the sinks or base stations) transmit the measured data only when the pre-defined events occurs [6,7]. Here the pre-defined events are the ones which may occur and can be sensed by a specific network, thus they can be defined in advance to denote the status of the networks' surroundings. Here comes the requirement that the event classification should have a high accuracy which can strongly support the network center to make a proper decision. However, most sensors only work and detect in a limited range of area, thus the returned values only describe some partial situations. These partial sensor data should be organized and processed uniformly to dig the potential meaningful information denoting a specific event.

Recent years, the accelerating development of varied sensor technologies has pushed the studies and applications of multi-sensor fusion forward to a further and wider range as multi-disciplinary fields. Some algorithms and methods for event classification in multi-sensor network have been proposed to improve the performance. Y. Zhang [8] provides a multiple-metric learning algorithm to learn jointly a set of optimal homogenous/heterogeneous metrics in order to fuse the data and classify the events. A framework for collaborative computing and multi-sensor data fusion in body sensor networks has been constructed to monitor a single individuals' emotion [9]. Moreover, a fire detection system utilizing heterogeneous multi-sensor data has been established contributing to the security of forest resources [10].

In this paper, we mainly address the pre-defined event classification problem in homogenous multi-sensor networks, and we explore a new solution in combination with some powerful deep learning theories. Recently, the deep learning methods have drawn huge attention in the computer vision area, for example, convolutional neural networks (CNNs) [11,12] which learn better than shallow artificial neural networks (ANNs), due to their innovative structures and methods to extract more abstract and higher-level features for training. Many works have demonstrated the impressive performance of CNNs in the fields of image and speech recognition, and some other deep learning architectures are also very promising. For example, a joint guidance image filter to refine the coarse transmission map based on deep neural network has been proposed and proved that it outperforms conventional methods [13]. We notice that the deep learning theories have rarely been used for solutions to the classification problems of multi-sensor networks. Therefore, we do some analogy between an actual image and sensor data, and find out that the homogeneous sensor data can also be seen as a special "image" due to their major similarities, thus firstly in our proposed method we organize the whole sensor data in once sampling to be a composite matrix for deep learning. Then inspired by the highly efficient image classification procedure based on the current state-of-the-art architectures of CNNs, we use a variant of AlexNet [12] to discover the hidden events with a higher classification accuracy. By our simulation experiments, this proposed CNN-based classification method has been proved to be able to improve the accuracy compared with the methods based on k Nearest Neighbor (kNN) [14] and Support Vector Machine (SVM) [15].

The following notations will be used in this paper. Bold upper case letters denote matrices and bold lower case letters are used to denote vectors. A vector $\boldsymbol{a}$ is a column vector, $(\cdot)^T$ represents transpose function of a matrix or a vector. θ denotes all parameters which should be trained (including all weights and biases), $\boldsymbol{D}$ denotes the training data set, and $|\boldsymbol{D}|$ is the number of training instances. $\boldsymbol{x}^{(i)}$ is the ith input instance, and $\boldsymbol{y}^{(i)}$ is its corresponding class label.

The rest of this paper is organized as follows: In Section 2, we briefly introduce a simple homogenous multi-sensor network model, and give an overview of CNNs. In Section 3, the theory basis of the proposed method is presented and a variant CNN based on AlexNet is designed and established for the sensor data. We compare the proposed CNN-based method with several other methods (e.g., SVM and kNN), and give the classification performance in Section 4 to prove the better effectiveness of the proposed. Finally we summarize this paper in Section 5.

2. Preliminaries

2.1. Multi-sensor network model

The main part of a typical multi-sensor network consists of some distributed sensor nodes sampling a target object, and a sink node collecting the sensor data. Due to the transmission constraint of sensor nodes, there is a base station to deliver the sensor data to a computing center through the Internet. In multi-sensor fusion this base station usually acts as a primary data fusion center as well. We present a simple homogenous multi-sensor network model as Fig. 1.

For a event-driven network, the target object is supervised to detect some pre-defined events. Once a pre-defined event occurs, the base station should fuse the sensor data, generate a complete description of the target and transmit the message to computing center for high-level decisions. The problem we concentrate on in this paper is the accuracy improvement of pre-defined events classification. Our goal is to develop a new method to solve this classification challenge with higher accuracy.