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Lifetime-aware Information Aggregation under Uncertainty for Advanced Driver Assistance Systems

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A B S T R A C T

Advanced Driver Assistance Systems require a huge amount of sensor information. Information sensed by the vehicle's on-board sensors is often not sufficient due to physical limitations, thus, vehicles exchange information with each other to enhance their knowledge. However, both local and remote measurements are only a noisy view on the environment. If a vehicle receives faulty information about its environment, its decision-making may perform wrong actions. In this paper, we focus on the accuracy of information w. r. t. the correctness of the provided information. To increase the accuracy, we use a data representation that depicts every measurement as a probability vector. This representation contains all available information and tracks accuracy while aggregating and fusing information. To incorporate measurements sensed at different times and locations, we model the environmental changes. As information expires after a certain time, we combine a Markov model with an aging model to keep the aggregated information stable even after message expiration. We achieve this by reducing the impact of information with increasing age. Our extensive evaluation shows that our novel approach outperforms state-of-the-art approaches significantly.

1. Introduction

Advanced Driver Assistance Systems (ADASs) increase the convenience and safety of drivers [1]. These systems heavily rely on high-quality information collected by local sensors. Due to physical limitations, vehicles need to exchange information with each other to increase their awareness beyond their local perception. However, sensors only a noisy observation of the environment, which depends on the quality of the available sensors. In the vehicular context, the vehicles are heterogeneous in terms of available sensors and the quality of their measurements.

As wrong measurements can result in wrong or unprecise actions taken by the system, vehicles aggregate information to increase the accuracy of the provided information. The varying quality of the sensor measurements is an important meta-information for the aggregation process. Based on the quality, a measurement's weight in the aggregation process is higher or lower.

The accuracy of a measurement can be increased by aggregating multiple independent sensor measurements. Information aggregation and fusion have been extensively investigated in the field of Wireless Sensor Networks (WSN). According to Durrant-Whyte [2], information fusion can be divided into three categories: *complementary, redundant* and *cooperative* fusion. In this work, we focus on redundant aggregation. The idea of redundant aggregation is to aggregate similar or almost similar messages to reduce network load while increasing accuracy and reliability [3]. The

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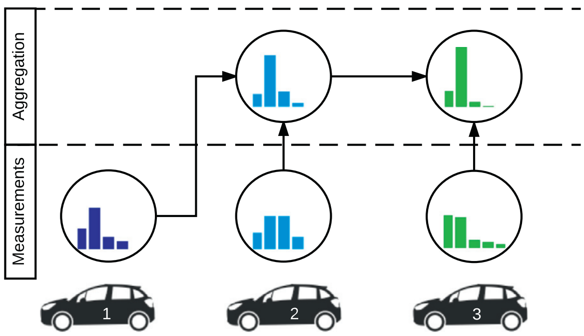

Fig. 1. In-Network aggregation process. The bars in the plots represent the probability of the variable being in a certain state. The states are numbered from 1 on the left to 5 on the right.

processing and aggregation of messages can be performed by intermediate vehicles [4].

Considering the usecase of temperature measurements as an example, calculating the average of the sensed values leads to more reliable results in most cases. However, as vehicles are equipped with sensors of different quality, the sensor accuracy is not the same for all retrieved values. Thus, we can enhance the quality of the aggregate further by taking the sensor accuracy into account. Therefore, each sensor does not only measure the exact value but provides a distribution vector based on the sensor properties like the sensor context and the sensor accuracy. This distribution vector can be produced by performing multiple measurements in a certain time interval or by using knowledge of the sensor accuracy. In the case of temperature sensors, the distribution vector will be based on a Gaussian distribution. Hence, a probability vector per measurement can be created using a Gaussian distribution with the measured value and the sensor deviation. The resulting vector can be aggregated with other measurements to increase accuracy.

Fig. 1 depicts an example scenario of information exchange in the vehicular scenario. In this example, the observed variable has five possible values named states. Vehicle 1 is deployed with a sensor of moderate accuracy. To allow the succeeding vehicles to enhance their view on the variable, vehicle 1 shares its measurement. Using only the measurements of its onboard sensors, vehicle 2 would not be able to decide in which state the observed variable is, as the probabilities for state 2 and 3 are equal. However, using the information provided by vehicle 1, vehicle 2 is able to decide about the state of the observed variable cooperatively. Simultaneously, it increases the accuracy compared to the measurement of vehicle 1. Vehicle 2 shares the measurements it received together with its own measurement with vehicle 3. Vehicle 3 by itself would even have derived the wrong value, as the probability for state 1 is higher than the probability for state 2, but state 1 has been barred from vehicle 1 and 2. As vehicle 3 receives the information from vehicle 2, it can correct its inaccurate measurement.

Our contribution is the modeling of the measurement process including the spatio-temporal influences on measurements. Compared to our approach in previous work[5], we reduce the impact of old information to ensure a resilient aggregation result even at information expiration. To achieve this, we combine our prediction-based aggregation approach with our information-aging approach [6]. For this adaptation, our information-aging approach needs to be adapted to work appropriately for vector-based measurements with multiple states and consider the known spatio-temporal dependency between measurements. The additional knowledge provided with the spatio-temporal information behavior and the exact measurement distribution increases the performance of our information-aging approach by up to 50% in terms of used optimization potential.

The remainder of this paper structures as follows: In Section 2, we provide an overview over the state-of-the-art approaches. After this, we describe our data model in Section 3, the spatio-temporal changes in Section 4 and our extension, the Quality-of-Information (QoI)-aware aggregation approach, in Section 5. After that, we describe our accuracy measure in Section 6. Subsequent, we evaluate our developed approaches in Section 7 and conclude our paper in Section 8.

2. Related work

Data aggregation is a pivotal technique in resource constraint networks to improve their performance [7]. Performance of a distributed system can be measured in energy consumption, produced data traffic, or achieved data quality. For many applications, like the vehicular application, the location of the measurements should not be omited [8]. In vehicular systems, vehicles are equipped with a variety of sensors like Global Navigation Satellite Systems (GNSSs), Light Detection and Rangings (LIDARs), and cameras [9]. Using local processing capabilities, vehicles can derive information based on these measurements. In distributed systems, information is measured by multiple sensors at different locations and different times. While most measurements are considered to be a single value without accuracy information, Boulis et al. [10] introduced an aggregation algorithm based on a probability distribution, which provided a tradeoff between energy efficiency and accuracy. The idea is to keep meta-information of the aggregation to improve future aggregations. That meta-information is shared with neighbor nodes instead of only the final result. By utilizing that meta-information, the neighbors were able to aggregate information in a decentralized manner. However, due to the different measurement times and locations, simple aggregation methods are generally not suitable.

This issue has been investigated extensively in the research of Wireless Sensor Networks (WSNs). For wireless sensor networks, the spatio-temporal correlation between sensor measurements is an important information for efficient communication protocols. This correlation has been modeled and used for aggregation in WSNs to support efficient communication protocols [11,12]. They developed multi models for measuring the spatio-temporal correlation between measurements. If the correlation between two measurements is high, one of them can likely be omited to reduce the energy consumption of the network.