Multi-sensor Fusion through Adaptive Bayesian Networks

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Abstract. Common sensory devices for measuring environmental data are typically heterogeneous, and present strict energy constraints; moreover, they are likely affected by noise, and their behavior may vary across time. Bayesian Networks constitute a suitable tool for pre-processing such data before performing more refined artificial reasoning; the approach proposed here aims at obtaining the best trade-off between performance and cost, by adapting the operating mode of the underlying sensory devices. Moreover, self-configuration of the nodes providing the evidence to the Bayesian network is carried out by means of an on-line multi-objective optimization.

Keywords: Ambient Intelligence, Bayesian Networks, Multi-objective optimization.

1 Motivations and Related Work

Artificial reasoning in many real world scenarios relies on measurements collected from diverse sensory sources; commonly available devices are typically affected by noise, and characterized by heterogeneity as regards their energy requirements; moreover their behavior may vary across time.

One of the application scenarios of artificial intelligence where multi-sensor data fusion is particularly relevant is Ambient Intelligence (AmI). The AmI paradigm relies on the capability of sensing the environment, through the deployment of a pervasive and ubiquitous sensory infrastructure, surrounding the user, for monitoring relevant ambient features. Among these, a high attention is devoted to context information, such as the users’ presence in monitored areas or current users’ activities [9,6,2].

In our work, we present a sample scenario of an AmI system devoted to detect users’ presence through a wide set of simple and low-cost devices, possibly affected by a non negligible degree of uncertainty, as well as devices capable of measuring environmental features only partially related to the human presence, and finally a limited set of more precise, though more expensive sensors. In particular, we suppose that the sensory infrastructure is embodied into a Wireless Sensor Network (WSN) [1], whose nodes, pervasively deployed in the environment, are capable of on-board computing functionalities and are characterized by limited, non-renewable, energy resources.
In order to estimate the environmental features of interest, while keeping the sensor nodes operating costs low, we propose a system that fully exploits the intrinsic statistical dependencies in the available sensory readings and copes with their inherent uncertainty by performing a multi-sensor data fusion.

Few works in literature propose a real multi-sensor data fusion framework for Ambient Intelligence. Remarkable exceptions are works presented in [5] and [7]. The authors of [5] propose a multi-sensor fusion system for integrating heterogeneous sensory information in order to perform user activity monitoring. The authors present a comparison between two probabilistic approaches (Hidden Markov Models, and Conditional Random Fields), and point out the effectiveness of a probabilistic system for activity detection in terms of dealing with uncertainty. The authors of [7] present an activity recognition approach reinforced by information about users’ location. The proposed framework uses a variety of multimodal and unobtrusive wireless sensors integrated into everyday objects; this sensory infrastructure provides data to an enhanced Bayesian Network fusion engine able to select the most informative features.

Unlike other works reported in literature, the work presented here focuses on the dynamic management of the devices providing information to the inference system, thus allowing to deal with such conflicting goals as energy saving and accuracy of the outcome. In particular, the proposed system comprises two levels of reasoning; at the low level a Bayesian network for reasoning on the relevant environmental feature (such as users’ presence), merges the available sensory data, while the upper level performs a meta-reasoning on system performance and cost. This meta-level is able to trade the reliability of the Bayesian network outcome for the relative cost in terms of consumed energy, in order to steer a decision about which sensory devices are to be activated or de-activated.

The remainder of the paper is organized as follows. Section 2 presents the general architecture of the proposed system, while Section 3 details its self-configuration capability. The self-configuration process is illustrated through a running example in Section 4 and finally Section 5 reports our conclusions.

2 The Proposed System

One of the requirements characterizing AmI is the availability of a pervasive sensory infrastructure characterized by a low cost and general as much as possible. For this reason, often, reasonings about context are not be performed via specialized sensors, so that the sensed signals will only be partially correlated to the features of interest.

In order to correctly infer the presence of users from the available sensory information a Bayesian inference system for multi-sensor data fusion has been developed. Probabilistic reasoning accounts for the partial correlation between sensory signals and states, and allows to cope with noisy data. The possibility of integrating data coming from multiple sensors exploits the redundancy of such devices deployed throughout the environment.