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Ensemble based traffic light control for city zones using a reduced number of sensors

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ABSTRACT

Rapid advances in computing, sensing and telecommunication technology offer unprecedented opportunities for artificial intelligence concepts to expand their applications in the field of traffic management and control. Our methodology gravitates around a powerful decision-making method: ensemble-based systems. This technique is used to accurately classify the near future traffic conditions and to make efficient decisions for adapting the traffic lights sequences within an urban area to optimize the traffic flows. The proposed approach requires only measurements provided by traffic sensors located along the principal roads entering the zone. This reduced number of sensors are considered to be enough relevant for classifying the near future state of the traffic and moreover, their measurements can be validated through analytical/hardware redundancy. Our methodology is meant to be implemented within the framework of a wireless sensor and actuator network and is confirmed by computer simulation, including normal or abnormal traffic conditions, for the central part of the city of Timisoara-Romania.

1. Introduction

Urban traffic represents a highly complex phenomenon that becomes more and more a major concern for our everyday life. The escalating demand for people and goods mobility in urban areas (with limited road infrastructure) has caused frequent traffic congestion, with various undesirable consequences: delays, energy waste, noise, pollution or road accidents. Over the years a diverse range of solutions had been applied to reduce the level of traffic congestion and to minimize the consequences. Due to the intricate set of interactions between road infrastructure, diverse types of vehicles, weather conditions and multitude of technologies involved, a general approach has yet to be found.

With the continuous advancements in computing, communication and sensing technology, a series of artificial intelligence concepts had been employed in traffic management and optimization: expert systems (Findler and Stapp, 1992), prediction-based optimization (Tavladakis and Voulgaris, 1999; Liu et al., 2002), fuzzy logic (Tan et al., 1995; Lee et al., 1995), neural networks (Srinivasan et al., 2006; Vlahogianni et al., 2005), evolutionary algorithms (Taale et al., 1998), reinforcement learning (Thorpe and Andersson, 1996; Sutton, 1996), etc. Their direct outcome resides in an overall improvement of traffic flows in both normal and abnormal traffic circumstances.

This paper proposes a new perspective upon adaptive traffic light control in urban areas employing not a single expert system but a mixture of experts (ensemble based system), in order to boost the traffic decision accuracy. Our approach is based on the following premises: *(i) only a small number of roads entering a city zone coagulate the majority of traffic* – the

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situation is similar to the one known from internet network traffic where large "elephant flows" have a much higher effect on the traffic than small "mice flows" (Erman et al., 2007); *(ii) sensors are the traffic devices most prone to malfunctioning* – considering a plethora of sensors to measure the traffic parameters on every unimportant road will complicate the decisional architecture with no relevant results in terms of accuracy; *(iii) for an optimal traffic light control we need a precise evaluator of the near future state of the traffic* – the concept we identified to fit this task is an ensemble-based decisional system (mixture of experts).

As a consequence, we propose an integrated methodology for adaptive traffic light control within a city zone based on an ensemble of classifiers that intelligently process the input data measured by a reduced number of sensors placed only on principal roads entering that zone. This approach can be naturally implemented in the framework of Wireless Sensor/Actuator Network (WSAN) that extends the capabilities of the well-known wireless sensor network to cope with complex control situations.

The rest of the paper is organized as follows. Section 2 presents the kernel of our methodology – the ensemble based system. In Section 3 we present the overall methodology for adaptive traffic light control, accompanied by the system architecture described in Section 4. In Section 5 a relevant simulation case study for traffic light optimization in the central part of Timisoara-Romania is presented, while the last section outlines the conclusions and final remarks.

2. Ensemble of classifiers

Having its roots in the human nature to request two, three or even more qualified opinions every time a complex decision has to be made, the artificial intelligence concept of ensemble of classifiers has rapidly expanded in the automated decision-making research field (Polikar, 2006; Curiac and Volosencu, 2012). The strategy pursued by these ensemble-based systems is to create a group of diverse classifiers and to combine their outputs in a form that significantly improves the generalization feature when compared with single classifiers (Chandra and Yao, 2006). Thus, when carefully designed, these committees of classifiers outperform any individual classifier in the majority of complex applications (Llorca et al., 2012; Geisler et al., 2012), including traffic control.

The general structure for an ensemble of classifiers is presented in Fig. 1.

All of the Q classifiers C_q are formulating their own individual hypothesis h_q, which are later aggregated in an overall decision h:

$$h = f(h_1, w_1, \ldots, h_q, w_q, \ldots, h_Q, w_Q), \tag{1}$$

where w_q are the weights corresponding to each individual hypothesis h_q.

One of the important characteristics that are inherently associated with an accurate mixture of classifiers is the diversity between classifiers (Kuncheva and Whitaker, 2003). Even if individual classifiers are accurately covering different parts of the classification space, their combination must work precisely in the entire space. Between different sorts of ensemble forming and training techniques, two approaches are considered to be the most influential (Ahmed and Abdel-Aty, 2013):

- *Bootstrap aggregating (bagging)* is a model averaging technique that uses randomly extracted subsets of a given training set – obtained through a resampling and replacement procedure – to train different models (Breiman, 1996). The classifiers are trained independently and their outputs are combined by simply averaging or voting to generate the overall ensemble output.
- *Boosting* is a technique that builds the ensemble sequentially by adding new weak learners and train them individually using predominantly the subsets of training data that were previously misclassified by other models (Schapire, 1990; Freund and Schapire, 1997). In order to obtain the ensemble's output, the individual classifiers' outputs are weighted according to their accuracy.

The methodology presented in this paper gravitates around the preciseness of classification offered by a carefully constructed ensemble based system (EBS). At every precise moment in time t, EBS receives the measurements $M_i(t)$ from each

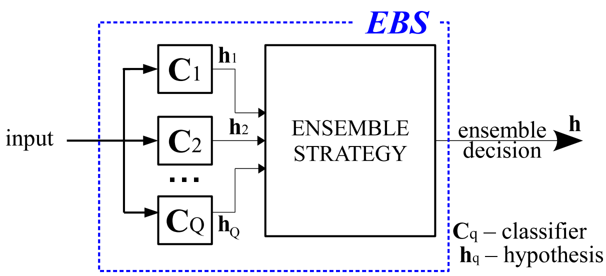

Fig. 1. General structure for an ensemble of classifiers.