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Simultaneous Prediction of Wind Speed and Direction by Evolutionary Fuzzy Rule Forest

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Abstract

An accurate estimate of wind speed and direction is important for many application domains including weather prediction, smart grids, and e.g. traffic management. These two environmental variables depend on a number of factors and are linked together. Evolutionary fuzzy rules, based on fuzzy information retrieval and genetic programming, have been used to solve a variety of real–world regression and classification tasks. They were, however, limited by the ability to estimate only one variable by a single model. In this work, we introduce an extended version of this predictor that facilitates an artificial evolution of forests of fuzzy rules. In this way, multiple variables can be predicted by a single model that is able to comprehend complex relations between input and output variables. The usefulness of the proposed concept is demonstrated by the evolution of forests of fuzzy rules for simultaneous wind speed and direction prediction.

Keywords: machine learning, fuzzy rules, compound classifier, forecasting, wind speed and direction

1 Introduction

Prediction of wind speed and direction in specific locations is an important part of operational weather forecasting [1] and has many applications in different domains including energy, traffic, logistics and planning, and e.g. emergency response [2].

Numerical weather prediction is based on computational simulations of atmospheric processes. The simulations rely on approximate solutions of systems of nonlinear partial differential equations that, in a simplified way, describe the evolution of the atmosphere [1]. However, atmospheric numerical prediction models are not always suitable for practical applications and operational weather forecasting. Instead, sophisticated numerical prediction suites that combine multiple data pre and post–processing strategies with several computational models of various aspects of operational weather forecasts are created. Accurate local adaptation of numerical weather forecasts [1] is increasingly demanded by applications such as smart grids and autonomous (environmentally–powered) wireless sensor and actuator networks. The traditional

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statistical adaptation methods are nowadays complemented by machine learning approaches that utilize historical data observations to create accurate location–specific forecasting models [3, 4].

In the field of energy, knowledge of wind speed and direction is very important for wind energy generation, integration, and management. Predicting the amount of generated wind energy is crucial for the safe and effective operation of stochastic renewable energy sources such as wind turbines and wind farms. The estimation of wind energy potential is essential for growth of renewable energy applications that gain on importance in both developed and developing regions [5,6]. Wind speed and direction can be forecasted with different time horizons. Long and mid–term forecasts are needed for energy sources operations management (e.g. maintenance). Short–term forecasts are essential for energy generation control [7]. The requirements of resource and cost constrained devices such as wireless sensor nodes and active RFID tags emphasize the need for well–localized but computationally inexpensive wind parameter forecasting models.

Fuzzy sets and fuzzy logic provide methods and tools for accurate and sensitive data analysis and processing [8]. Fuzzy decision trees [9], if–then rules [10], rule–based systems [11], and hybrid models [12, 13] are examples of efficient, transparent, and easily interpretable classifiers and value estimators. Besides their modelling capabilities and accuracy, fuzzy models are popular due to their linguistic character that allows their comprehension. They are also suitable for use with resource constrained devices such as embedded systems because they can be expressed in a computationally lightweight form (e.g. lookup table, series of instructions). The creation of accurate, coherent, and well–interpretable fuzzy systems is, however, a non-trivial process [14–16].

In this work, evolutionary fuzzy rules [13] are employed to establish a new compound model for joint wind speed and direction prediction. In order to accomplish this goal, the method is extended from a single–output estimator, implemented as a single fuzzy data processing tree, to a more general model that can estimate multiple output values at once. Genetic programming is employed to evolve the estimator from data. A set of computational experiments with a meteorological data set documents the usefulness of the proposed evolutionary approach and shows that it is able to deliver results on par or better than a widely–used kernel–based machine learning algorithm, support vector regression.

The rest of this work is organized in the following way. Related approaches, dealing with the artificial evolution of fuzzy systems, are briefly summarized in section 2. The proposed fuzzy rule forest and the underlying method of evolutionary fuzzy rules are detailed in section 3. Experimental evaluation of the proposed approach on a real–world data set is presented in section 4 and major conclusions are drawn in section 5.

2 Related work

Evolutionary methods have been used in the area of fuzzy systems and linguistic modelling extensively [14–16]. They were employed for system learning [14,15,17], parameter optimization and tuning [16], and e.g. rule selection [16]. The need for bio–inspired learning and optimization in the area of fuzzy systems is often underlined by the need to process high–dimensional and high–volume data [17].

The use of evolutionary computation in fuzzy systems is the field of study of *genetic fuzzy systems* [15]. The symbolic nature of evolutionary algorithms such as genetic programming makes them a suitable tool to search for interpretable fuzzy models and rules. There are two main approaches to evolutionary fuzzy system learning [15]. In the *Pittsburgh* approach, each chromosome models the whole evolved system (e.g. a complete rule base) and uses the artificial