Low quality data management for optimising energy efficiency in distributed agents

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Abstract Energy efficiency represents one of the main challenges in the engineering field. The benefit of the energy efficiency is twofold: the reduction of the cost owing to the energy consumption and the reduction in the energy consumption due to a better design minimising the energy losses. This is particularly true in real world processes in the industry or in business, where the elements involved may be considered as distributed agents. Moreover, in some fields like building management systems the data are full of noise and biases, and the emergence of new technologies -as the ambient intelligence can be- degrades the quality data introducing linguistic values. In this contribution we propose the use of the novel genetic fuzzy system approach to obtain classifiers and models able to manage low quality data to improve the energy efficiency in intelligent distributed systems. We will introduce the problem and some of the challenging fields are to be detailed. Finally, a brief review of methods considering the low quality data is related.

Key words: Genetic Fuzzy Systems, Low quality data, Energy Efficiency, Building Automation

1 Introduction

Analysing and optimising energy efficiency in processes has shown a promising field in different areas such as electric energy distribution [18, 29], energy saving

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and sharing [5], efficient design and operation [2, 14], modeling and simulation [6], etc. In these areas, the main problem varies from how to fulfil the electric energy demand with the lowest cost or with the minimum line losses [18] to obtaining better models and controllers in order to better simulate or share the energy between distributed devices [6]. In general, the energy efficiency can take advantage of the multi-agent architecture, distributing the control and the optimisation decisions among all the intelligent devices [3, 27]. In what follows, the field related with daylight dimming control in building management systems- is to be analysed for the sake of simplicity, although the main conclusions can be extended to any other area.

Building Management Systems (BMS), also known as Building Automation Systems, are responsible for integrating all the automated systems in a building like the heating and ventilation automated control systems (HVACS), or the lighting and dimming control, etc. In a lighting control system (see Fig. 1), the lighting system controller is the software responsible for co-ordinating the different islands and of integrating the information from the BMS. In each island, a controller establishes the operation conditions of all the controlled ballasts according to the sensor measurements and the operation conditions given by the lighting system controller.

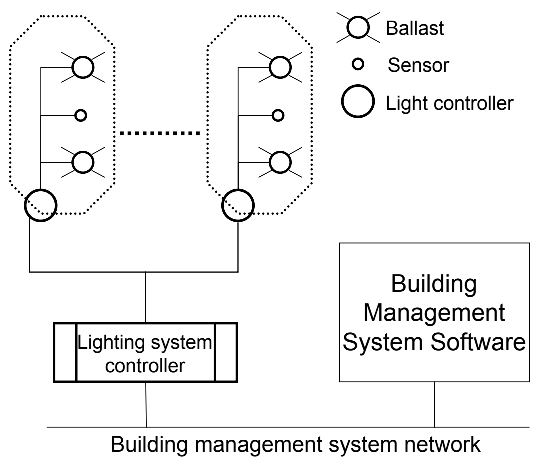

Fig. 1 The schema of a lighting control system. Each island includes a closed loop controller with the controlled gears, the luminosity sensors, the presence sensors, etc. The lighting system controller is responsible for the integration of all the islands.

In the literature of lighting control systems, the development of wireless sensor networks represents the main area of research [7, 17], introducing distributed sensors and deploying them, i.e., through web services. Researches related with simulation issues [6], sensor processing and data improvement [8], the effect of daylight in the energy efficiency [11] are also studied in depth in the literature. Moreover, the improvement in the energy efficiency and its measurement have been analysed in [11, 14, 16, 19].

Nevertheless, there is a lack in the use of all the information within the data gathered from the processes or the data sets. This meta-information is related with the low quality data due not only to the non stochastic noise or the precision of the sensors, but also due to the emergence of new technologies such as ambient intelligence and user profiles, which could be linguistic information. Genetic fuzzy systems (GFS) have been used in optimising energy saving and sharing in HVACS [1], but to our knowledge no GFS have been applied in lighting control systems. In our opinion, the use of GFS could improve the issues related with energy sharing and efficiency in distributed systems. We propose using the GFS able to deal with the meta-information to achieve a better the decision making process in the energy sharing among distributed agents -hence obtaining a better energy efficiency- and in the design of energy efficiency measures considering the low quality data.

In this research we propose the use of GFS for improving the energy efficiency in distributed systems taking advantage of the meta-data due to low quality data. We introduce a novel method for learning GFS with low quality data and then we propose how these methods can be deployed. We propose that a better decision making process and modeling through GFS can be carried out if the uncertainty in the data is managed. The remainder of this manuscript is as follows. First, a review of the literature concerned with considering the low quality data in modeling and in designing indexes is shown. Then, several different proposals for including low quality data are detailed. Finally, conclusions and future work are presented.

2 Issues in low quality data management

The need for algorithms able to face low quality data is a well-known fact in the literature. Several studies have presented the decrease in the performance of crisp algorithms as uncertainty in data increases [9, 25].

On the other hand, [15] analyses the complexity nature of the data sets in order to choose the better Fuzzy Rule Based System. Several measures are proposed to deal with the complexity of the data sets and the Ishibuchi fuzzy hybrid genetic machine learning method is used to test the validity of the measures. This research also concludes in the need to extend the proposed measures to deal with low quality data.

With low quality data we refer to the data sampled in presence of non stochastic noise or obtained with imprecise sensors. It is worth noting that all the sensors and industrial instrumentation can be regarded as low quality data. In our opinion, one of the most successful researches in soft computing dealing with low quality data is detailed in [4, 21]. In these works the mathematical basis for designing vague data awareness genetic fuzzy systems -both classifiers and models- is shown. The low quality data are assumed as fuzzy data, where each $\alpha-$cut represents an interval value for each data.

Finally, it is worth pointing out that the fitness functions to train classifiers and models are also fuzzy valued functions when faced with low quality data. Hence the learning algorithms should be adapted to such fitness functions [24].

The ideas and principles previously shown have been used in several applications with low quality data, with both realistic and real world data sets. [22] deals with the learning of fuzzy rule-based models with backfitting algorithms when the presence of missing data and discrepancies between the truth and the sampled data are included in the data set. Moreover, a filter-type feature selection, based on the Battiti mutual information feature selection method, is detailed in [23]. In this research a fuzzy extension of the mutual information measure is shown. A real world application is presented in [28], where the GPS measurements are considered inherently fuzzy data. A GFS is used to filter measurements and, thus, obtain a lower upper bound for the trajectory of a vehicle.

3 Enhancing the energy efficiency in distributed agents with low quality data management

As introduced in the previous sections, the use of the meta-information included in the data could improve the energy efficiency in processes, specifically, when the process is distributed among agents. The meta-information includes not only measurements -i.e., measurements from sensors- but also the precision of the sensors, their calibration, the non stochastic noise, etc. It is worth noting that non stochastic noise is the typical noise found in real world processes. On the other hand, multi-agent systems have been successfully employed in improving the energy efficiency in heating systems [20, 26], but always dealing with crisp data. We propose the use of GFS able to deal with quality data to enhance the energy efficiency in distributed agents. Three different examples of future work are outlined below.

3.1 Obtaining models for simulation of lighting systems

Simulation of lighting systems has been widely studied, some of them to improve the energy efficiency [6, 11, 19], while others are related to design comfort environments [13]. A lighting system simulation needs to analyse the light in a room to avoid the dark zones. A simulation will use models to estimate the values of the light any ballast produces, the output from the light sensors, etc. To our knowledge, no model has been obtained including the meta-information due to low quality data and, thus, the effect of the daylight and other variables are introduced artificially -i.e., by including such information within the input data set.

In our opinion, the use of GFS to obtain models for simulation of lighting systems would help in the integration of the meta-information. The use of GFS allows determining behaviour laws and interpretability of the phenomena. Moreover, if low quality data is included in obtaining the models of the lights, the sensors and the controllers, then the inputs to the models are not crisp data but low quality data. Therefore, the models should consider the ideas outlined in the previous section. Specifically, the GFS learning algorithms must deal with fuzzy inputs and non-crisp fitness functions, the fitness functions must be fuzzy valued functions.

Let us consider one simple case. Let us suppose the simulation of the lighting system shown in Fig. 2. It is clear that the shorter the distance to the windows the higher the daylight influence in the light measurements. The daylight should be estimated when no daylight sensors are available, from the inner light sensors,which are also influenced by the gears. Discriminating the daylight will be better when the meta-information from each sensor is considered than when it is not. Finally, we can introduce the multi-agent theory in the simulation design in order to represent the diversity of islands in the system. In the case of the example, each luminary, sensor and controller can act as an agent, behaving independently from each other.

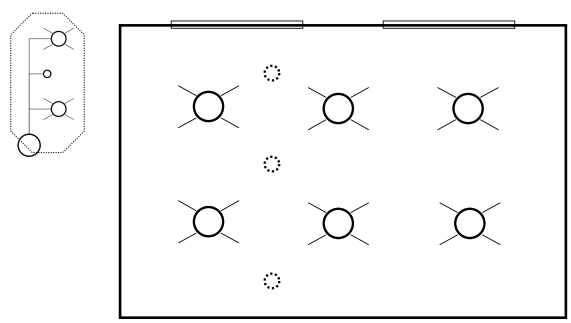

Fig. 2 The lighting system to simulate. Different places for the light sensor are proposed. The light measured will differ from one case to another.

3.2 Improving the control decisions in lighting

As in the former case, several studies can be found in the literature concerning with the lighting control systems. It can be said that the luminance is the controlled variable when control loops are studied [14], or that the energy efficiency is the variable to be optimised when BMS are analysed [10]. To the best of our knowledge, the study of lighting control systems does not consider both variables at the same time.

We assert that the control decisions in lighting systems can take advantage of the meta-information aware GFS and of the multi-objective techniques to develop controllers. The use of low quality data and fuzzy fitness functions in their learning will produce more general case knowledge bases, so they can be applied in different scenarios; that is, the controllers are to be more robust. Moreover, the performance of lighting control systems with more than one objective should also be analysed. In fact, including more control variables could in practice penalise the control action response by introducing delays or steady state errors: the benefit is that the control action can afford a more energy efficient system. Finally, it is interesting to mention that energy efficiency measures can be extended to include meta-information. These extended measures can then be used as fitness functions in the learning of GFS.

3.3 Computer assisted decision making

The more the information given the better the decisions are. As stated above, the meta-information has not been considered in the design of computer aided decision making assistants. On the other hand, the decision making process can be carried out by means of a GFS; the interpretability and robustness of the decision rules -the GFS knowledge base- represents a challenge in the literature. It is worth noting that in the decision making process the variables can be of numeric, crisp or linguistic types. Examples of each type are the measurements from sensors, the different levels obtained through thresholds or a set of possible values from human-machine interfaces; all of this information could be noisy or ambiguous.

We propose to include the meta-information -in the form of low quality data- in the learning of the knowledge bases of the GFS. The objective is twofold. On the one hand, the knowledge base will be robust due to the awareness of the noise in the numeric and crisp variables. On the other hand, as it will consider linguistic variables and their interpretability, will be made easier the integration of emergent technologies such as the ambient technologies.

Lastly, let us consider again the lighting control system shown in Fig. 1. If the energy efficiency in the whole system must be enhanced, then the energy efficiency in each island should also be accomplished. But as there are some objectives and restrictions fixed in each island, the problem can be viewed as a multi-agent system problem for which the energy efficiency must be improved on behalf of the management system while each agent should optimise its own objectives. In this case, we show that the three examples given in this section are highly related.

4 Conclusions

Improving the energy efficiency represents a challenge in the real world applications, especially distributed systems within building management systems. The higher the human interaction in field the higher relevance of intelligent techniques that consider the meta-information and interpretability. Meta-information refers to the information that is present in a process but rarely considered, such as the data non-stochastic noise or the sensor precision and calibration, but also the ambiguity in the linguistic and crisp data. Meta-information can be presented as low quality data.

GFS have been found valid in energy efficiency, but have also been extended to manage interval and fuzzy data. Interval and fuzzy data are mechanisms to represent the low quality data. In this work the extended GFS to manage fuzzy data is proposed to be used in the energy efficiency improvement. To illustrate the idea, three different cases are outlined, which represent the future work to be developed. We expect that fuzzy data awareness GFS will outperform the modeling and simulation process, but also the energy issues in distributed agents.

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