ARTICLE IN PRESS

Future Generation Computer Systems ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Future Generation Computer Systems

journal homepage: www.elsevier.com/locate/fgcs

IoFClime: The fuzzy logic and the Internet of Things to control indoor temperature regarding the outdoor ambient conditions

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HIGHLIGHTS

- Creation of a fuzzy system that controls the indoor temperature efficiently.
- Automation of indoor temperature using external climate conditions.
- Use of platforms from the IoT to improve the manage of the indoor temperature.
- Fuzzification of humidity and temperature variables.

ARTICLE INFO

Article history:
Received 20 November 2015
Received in revised form
17 November 2016
Accepted 21 November 2016
Available online xxxx

Keywords:
Internet of Things
Fuzzy logic
Temperature control
Temperature sensors

ABSTRACT

The Internet of Things is arriving to our homes or cities through fields already known like Smart Homes, Smart Cities, or Smart Towns. The monitoring of environmental conditions of cities can help to adapt the indoor locations of the cities in order to be more comfortable for people who stay there. A way to improve the indoor conditions is an efficient temperature control, however, it depends on many factors like the different combinations of outdoor temperature and humidity. Therefore, adjusting the indoor temperature is not setting a value according to other value. There are many more factors to take into consideration, hence the traditional logic based in binary states cannot be used. Many problems cannot be solved with a set of binary solutions and we need a new way of development. Fuzzy logic is able to interpret many states, more than two states, giving to computers the capacity to react in a similar way to people. In this paper we will propose a new approach to control the temperature using the Internet of Things together its platforms and fuzzy logic regarding not only the indoor temperature but also the outdoor temperature and humidity in order to save energy and to set a more comfortable environment for their users. Finally, we will conclude that the fuzzy approach allows us to achieve an energy saving around 40% and thus, save money.

1. Introduction

The Internet of Things (IoT) is a term very popular nowadays. Every day we can listen people taking about Smart Homes [1,2], Smart Cities [3,4], Smart Earth [3], and many other kinds of distributed intelligence around heterogeneous and ubiquitous objects. The IoT allows gathering a huge quantity of data that can be processed to help making different decisions. These data may be very varied and confused and processing them might become inoperable.

Humans and computers make decisions in a different way. Whereas human reason uses words, computers use numbers [5]. Moreover, even though the logic applied by humans seems more primitive, they can make better decisions in the real-world when an unexpected problem appears. Computing with words could improve the capability of computers to deal with problems of real-world and thus, improving decision making [5].

The human capability to take decisions without computations is usually referred as 'common sense'. Common sense allows us to take decisions quickly although they are not always the best ones. For example, in the past, we thought that the Earth was flat due to common sense [5]. Moreover, common sense provides a way to get solutions to problems with incomplete or imprecise information

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http://dx.doi.org/10.1016/j.future.2016.11.020
0167-739X/

whereas classical logic is better to resolve problems well defined. Furthermore, if we always used classical logic, we would take only a few decisions throughout the day.

While classical logic deals with binary sets of values, 0 (false) and 1 (true), fuzzy logic deals with a range of values that represents different degrees of truth on a scale between completely false and completely true [6]. A range of values allows having more states and thus, making decisions knowing more information. For instance, fuzzy logic is able to optimise the moment when collected data should be pushed to a server [6]. Applying classical logic, we would have only two states, push or wait, whereas if we applied fuzzy logic, we could have many states which would indicate the best moment to push data to the server and what data should be pushed.

Our daily life could be benefited with the combination of the IoT and fuzzy logic. For example, local businesses could enhance the management of temperature systems that involve the use of heating systems and air-conditioning systems in order to adapt the indoor conditions taking into consideration the outdoor conditions. Following this path, we would be able to achieve a really Smart City where the indoor locations will be capable of adapting themselves to the outdoor conditions. Using fuzzy logic will allow us to decide the best moment to heat up or to cool down the environment considering the outdoor conditions.

Moreover, fuzzy logic could help to reduce the energy consumption of cities' buildings in order to achieve the zero energy building (ZEBs). The ZEBs are a part of the way towards achieving the Smart Cities [7].

In addition to use fuzzy logic in the IoT, there are also several platforms which allow not only publishing data gathered from our sensors but also consuming data gathered from third-party sensors that could help us to achieve our proposal.

The aim of this research is the development of a prototype that will combine fuzzy logic applied to the IoT and the use of IoT platforms in which the prototype where it will able to consume third-party data. The prototype will be able to automate a system that will control the environmental conditions of a specific place. Moreover, the prototype will address different issues in the world of the IoT like the energy savings and some points of the livability according to [8]. Our goals are the following:

- Consuming data from online open IoT platforms.
- Consuming data from sensors located in microcontrollers like Arduino or microcomputers like Raspberry Pi and working with actuators located in these devices.
- Setting fuzzy rules to achieve a better performance in the suggested solution.
- Keeping an optimum temperature inside a room for a long time.
- Saving energy. Moreover, this can help to achieve economic savings.
- Achieving some points of the livability.

The remainder of the paper is organised as follows. In Section 2, we will introduce involved topics in this research like fuzzy logic, the IoT, IoT platforms, and the works related with this research. Section 3 will show the case of study, how it works, and how its architecture is. Section 4 will show the software and hardware used in this research. In Section 5 we will cover the evaluation and discussion of the data obtained from comparing the behaviour of our approach with the behaviour of the traditional approach. Section 6 will contain the conclusions of this paper and finally, in Section 7 we will describe the possible future work that can be done from here.

2. State of the art

The principal aim of this research is to use fuzzy logic in the IoT context. However, before talking about the case study, it is necessary to review the involved concepts. Moreover, inside the IoT context we want to review a special concept, the IoT platforms. These platforms were created to bring the IoT to more people, industry, and researches and thus, to increase the possibilities of the IoT. With these platforms we can intercommunicate objects which are separated by thousands of kilometres or located in places that we cannot imagine. Maybe behind the enemy lines in a battlefield, inside a nuclear plant, in a sealed room full of chemicals or radioactive products, or even in places where they cannot be reached after being set [9,10].

The fuzzy logic is also a technology presents in many researches. The uses of this technology are multiples and it could be useful in a wide range of fields. For example, the fuzzy logic can be used in the health field achieving the simulation of an artificial pancreas that is able to regulate blood glucose levels in an automatically way [11] or sending health data in the best moment without draining the batteries of the involved devices [12].

In the context of industry, the combination of the IoT and fuzzy logic can help in many situations like controlling the products life cycle [13], monitoring and detecting fires [14], and making decisions about when doing certain procedures in industries [15].

Thus, in this section we will talk about the concepts which are involved in this research: Sections 2.1–2.3.

2.1. Fuzzy logic

The term fuzzy logic was introduced on 1965 by Lotfi Asker Zadeh as a way to deal with common sense problems. He introduced fuzzy sets firstly in [16] and after, fuzzy logic was defined and presented in [17]. Since then, many researches have addressed topics related with fuzzy logic. A frequent issue where fuzzy logic is usually applied is the battery saving. For instance, Larios et al. [18] succeeded in locating a device avoiding many location errors and therefore, reaching a better accuracy. Besides, their approach allows decreasing the energy consumption of different elements like the GPS. Chamodrakas and Martakos [19] proposed to use the fuzzy set representation method to select a network in order to be connected in an efficient way, with a low energy consumption, with a high Quality of Service (QoS), and with good performance. Bagchi [20] used fuzzy logic to keep the quality of playback of multimedia streaming and to achieve improvements in the energy consumption. Cueva-Fernandez et al. [6,21] made two proposals about how to use fuzzy logic in vehicles. In [6], they proposed the improvement of information exchange between vehicles sensors and servers in order to save energy whereas in [21], they proposed a system to create applications through the voice using fuzzy logic. All of these researches have in common the use of fuzzy logic to make difficult decisions without having clear options to consider.

Fuzzy logic emerged to resolve problems that classical logic cannot address. Classical logic can only deal with binary sets of values (0 or 1), but there are many contexts in which dealing with more values is required. Having more than two values allows having more states and thus, making decisions with more information. These states are usually called linguistic variables and they can represent characteristics like 'size' whose values could be 'small', 'very small', 'big', 'very big', and so on. This approach tries to resolve questions like how big a building is. The answer to this question depends on individual cognition because not everyone would respond the same. For example, for a person who lives in the countryside, a building composed by 6 floors could be big, but

Please cite this article in press as: D. Meana-Llorián, et al., IoFClime: The fuzzy logic and the Internet of Things to control indoor temperature regarding the outdoor ambient conditions, Future Generation Computer Systems (2016), http://dx.doi.org/10.1016/j.future.2016.11.020