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IoT Heating Solution for Smart Home with Fuzzy Control

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Abstract: There is currently an era of Internet of Things in the computer systems, which consists in connecting all possible devices to the Internet in order to provide them with new functionalities and thus – to improve the user's life standard. One of such solutions could be Smart Home. The possibility of monitoring inner environment is required for such solutions. Such monitoring provides potential for e.g. better heating control. The authors of this paper propose some heating control method with Fuzzy Logic. The proposed method was tested in a special climate chamber. The authors provided conclusions at the end of the paper.
Key Words: IoT, Smart Home, Fuzzy Logic
Category: G.1.6, I.2.8

1 Introduction

Computer systems are presently a common element of everyday life. In this domain the world has entered the Internet of Things era, which consists in connecting all possible devices to the Internet in order to provide them with new functionalities and thus – to improve the user's life standard [Sundmaeker 10]. Its objective is to ensure access to any desired service to anyone at any place and by any possible transmission medium. The Internet of Things can currently be described as a solution under development. New architectures are being constantly developed and at the same time the technology allows development of new services. One of the presently available and commonly used services is the monitoring of all kinds of physical parameters of a house. They are called Smart Homes when they provide the opportunity to make some decisions depending on the conditions prevailing inside them. One of such conditions is the temperature which requires the heating and cooling system control.

The authors of the paper presented an attempt of developing an IoT (Internet of Things) solution for heating control in the house. Section II of the article concerns the Smart Home idea of the IoT. Section III presents the theory of OFN used in the project. Section IV describes the concept of the proposed solution. Section V presents the test results for the proposed model. Section VI provided conclusions of the paper.

2 The idea of IoT and Smart Home

The IoT enables physical objects to share information and to coordinate decisions. It changes traditional objects into so-called smart objects. It is achieved by equipping them with sensors, transmission protocols and software in order to allow them to process data and communicate with other devices.

Figure 1 illustrates the overall concept of the IoT, where every domain-specific application interacts with domain-independent services, whereas in each domain, sensors and actuators communicate directly with each other [Al-Fuqaha 15].

It is assumed that, in a course of time, more and more devices will be connected to the Internet and altogether they will create an intelligent environment. The synchronization of the solutions will make it possible, for example, to open the garage door in advance when the car is approaching the premises. Use of intelligent transport systems will enable more efficient traffic control, including preventing congestions or ensuring the emergency vehicles right-of-way by appropriate traffic lights control.

One of the most interesting concepts is a Smart Home. There are lots of concepts how to build it. Some authors provided examples where they proposed the management systems using IEEE 802.15.4, zigbee or PLC [Han 2010] [Han 2014]. Agent-based architecture with Markov models of decision making were presented in some studies [Cook 2003]. Some authors present the concept of using Software Oriented Architecture for creating smart home functionalities [Ricquebourg 2006]. There are some heating solutions proposed for this process using Gaussian Process Prediction [Rogers 2011]. Some methods use clustering techniques for the same purposes [Iglesias 2011]. And, finally, some solutions are covered by the patents [Bell 1992].

3 Theoretical background description of OFN

Each operation on fuzzy numbers, regardless if it is addition, subtraction, division or multiplication, can increase the carrier value. Several operations per-

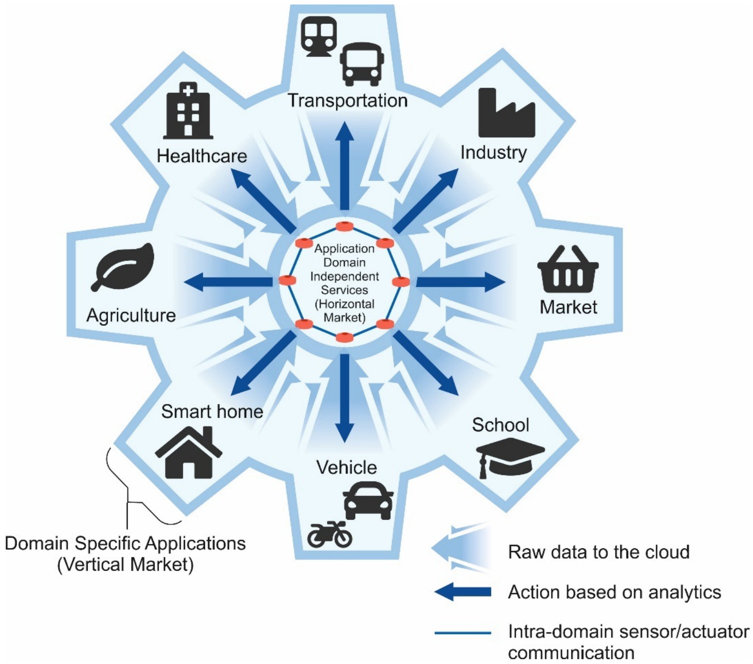

Figure 1: The overall picture of IoT emphasizing the vertical markets and the horizontal integration between them.

formed on given L-R numbers can result in numbers that are too broad and as a result they can become less useful. Solving equations using conventional operations on fuzzy numbers is usually impossible either. An A+X=C equation can always be solved using conventional operations on fuzzy numbers only when A is a real number.

First attempts to redefine new operations on fuzzy numbers were undertaken at the beginning of the 1990-ties by professor Witold Kosiński and his PhD student – P. Słysz. Further studies of prof. W. Kosiński published in cooperation with P. Prokopowicz and D. Ślezak led to introduction of the ordered fuzzy numbers model – OFN [Kosinski,Prokopowicz, Slezak 2003] [Kosinski 2003] [Kosinski, Prokopowicz 2004] [Kosinski 2004] [Kosinski 2006] [Kosinski 2010] [Ewald 2017].

Def. 1

An ordered fuzzy number A is an ordered pair of functions

$$A = (x_{up}, x_{down})$$

where $x_{up}, x_{down} : [0, 1] \longrightarrow R$ are continuous functions. Respective parts of the functions are called: part *up* and *down*, and are presented in Figure 2.

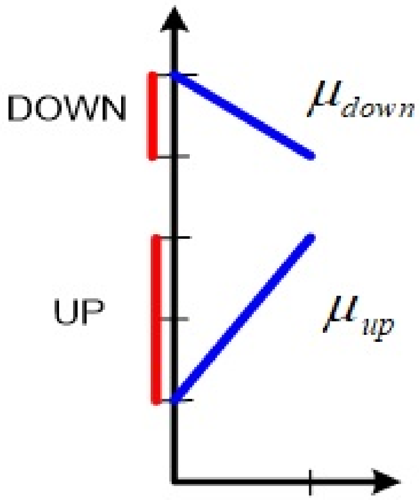

Figure 2: Ordered fuzzy number

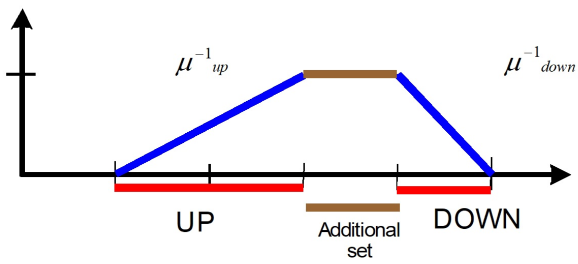

Figure 3: OFN presented in a way referring to fuzzy numbers

Continuity of those two parts shows that their images are limited by specific intervals. They are named respectively: UP and DOWN. The limits (real numbers) of those intervals were marked using the following symbols: $UP = (l_A, 1_A^-)$ and $DOWN = (1_A^+, p_A)$.

If both functions that are parts of the fuzzy number are strictly monotonic, then there are their inverse functions x_{UP}^{-1} and x_{down}^{-1} defined in respective intervals UP and DOWN. Then the following assignment is valid:

$$l_A : x_{UP}(0), 1_A^- : x_{UP}(1), 1_A^+ : x_{down}(1), p_A : x_{down}(0)$$

If a constant function equal to 1 is added within the interval$[1_A^-, 1_A^+]$ we get UP and DOWN with one interval (Fig 3, where:$\mu_{down} = x_{down}, \mu_{up} = x_{up}$), which can be treated as a carrier. Then the membership function $\mu_A(x)$ of the fuzzy set defined on the R set is defined by the following formulas:

$$\mu_A(x) = 0 \text{ for } x \notin [l_A, p_A] \ ,$$

$$\mu_A(x) = x_{UP}^{-1} \text{ for } x \in UP \ ,$$

$$\mu_A(x) = x_{DOWN}^{-1} \text{ for } x \in DOWN \ ,$$

The fuzzy set defined in that way gets an additional property which is called order. Whereas the following interval is the carrier:

$$UP \cup [1_A^-, 1_A^+] \cup DOWN$$

The limit values for up and down parts are:

$$\begin{gathered} \mu_A(l_A) = 0 \\ \mu_A(l_A^-) = 1 \\ \mu_A(l_A^+) = 1 \\ \mu_A(p_A) = 0 \end{gathered}$$

Generally, it can be assumed that ordered fuzzy numbers are of trapezoid form. Each of them can be defined using four real numbers:

$$A = (l_A, l_A^-, l_A^+, p_A)$$

The diagrams in Figure 4 show sample ordered fuzzy numbers including their characteristic points. Functions f_A, g_A correspond to parts $up_A, down_A \subseteq R^2$

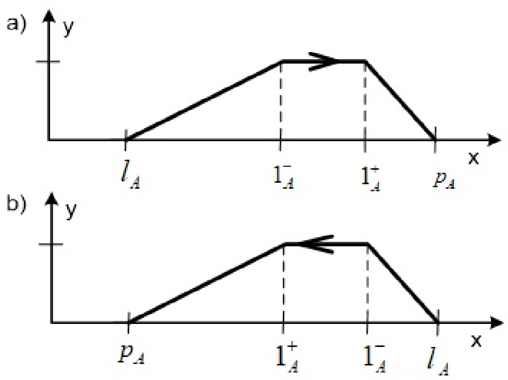

Figure 4: Fuzzy number that is ordered a) positively b) negatively

respectively, so that:

$$up_A = \{(f_A(y), y) : y \in [0, 1]$$
$$down_A = \{(g_A(y), y) : y \in [0, 1]$$

Orientation corresponds to the order of graphs f_A and g_A. The figure 5 shows the graphic interpretation of two opposite fuzzy numbers and the real number χ_0. Opposite numbers are reversely ordered.

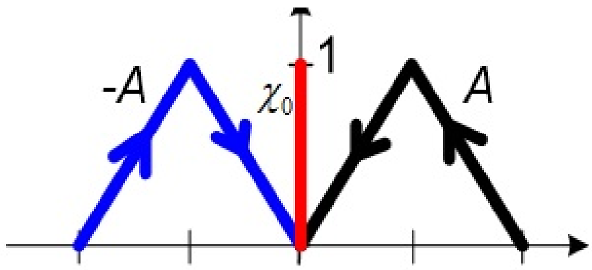

Figure 5: Opposite numbers and the real number

Def. 2
A membership function of an ordered fuzzy number A is the function $\mu_A : R \longrightarrow [0, 1]$ defined for $x \in R$ as follows:
if

$$x \notin supp_A \Rightarrow \mu_A(x) = 0$$
$$x \in (1_A^-, 1_A^+) \Rightarrow \mu_A(x) = 1$$
$$x \in supp_A \bigwedge x \notin (1_A^-, 1_A^+) \Rightarrow \mu_A(x) = max(f_A^{-1}(x), g_A^{-1}(x))$$

The above membership function can be used in the control rules similarly to the way membership of classic fuzzy numbers is used. All quantities that can be found in fuzzy control describe selected part of the reality. Process of determining this value is called fuzzy observation.

Def. 3
Reversal of the orientation of the ordered fuzzy number A is replacement of the part up (function f_A) with the part down (function g_A). That operation is described as follows:

$$B = A \,|^- \Leftrightarrow g_B = f_A \wedge f_B = g_A$$

where: A means an ordered fuzzy number defined by the pair of functions (f_A, g_A), B is the result of the operation consisting in reversal of OFN orientation, the sign "$|^-$" is a symbol of OFN orientation reversal.

The number obtained in that way is called a reversed OFN number or a reversed orientation number.

4 IoT heating system with Fuzzy Logic

The diagram of the house temperature control system for the Smart Home solution is presented in Figure 6.

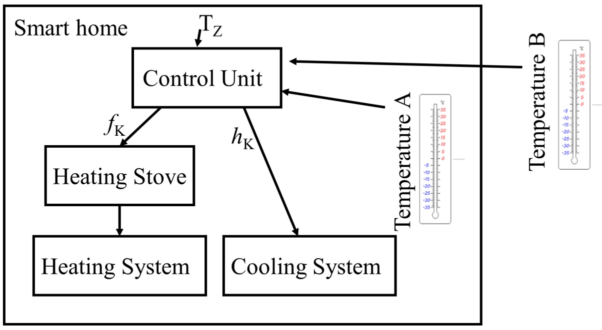

Figure 6: System diagram

In the presented system, the temperature set-point of the enclosed building is controlled by means of:

- setting the temperature set-point by setting the oven temperature using function F_K by the controller or the cooling system control using function h_K also by the controller.
- the oven controls the temperature by supplying heat to the heating system, which gives up the heat to ambient air (in a closed room, in a house),
- the controller acquires to its control system at least two temperature values, one of which is the internal temperature A, while the other one is the external temperature B.

The A and B temperature sensors connected to the control system measure the ambient temperature T_A and T_B and return its value in analog form. The analog value is converted to a digital value by the controller. The temperature is measured at specified time intervals t_0 set in the controller The target/set temperature of the system is T_Z. Measurement values measured by each sensor at specific time intervals generate a series of results. The control for each sensor from four consecutive measurement moments, i.e.:

$$t_i, t_{i-1}, t_{i-2}, t_{i-3} \text{ for } t_0 = t_i - t_{i-1}$$

where $t - i$ is a consecutive measurement moment, creates an ordered fuzzy number. According to the theory of ordered fuzzy numbers, where for OFN [Apiecionek 2017][Apiecionek 2018]:

- $f_A(0)$corresponds to the moment t_{i-3} ,
- $f_A(1)$corresponds to the moment t_{i-2},
- $g_A(1)$corresponds to the moment t_{i-1},
- $g_A(0)$corresponds to the moment t_i.

Then the ordered fuzzy number (OFN) is created as shown in Figure 7.

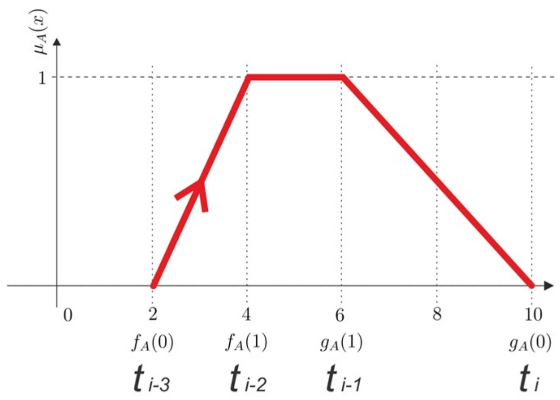

Figure 7: Ordered fuzzy number

An OFN is created for each temperature sensor and marked as for the sensor, respectively:

- for temperature sensor A as A_{OFN},
- for temperature sensor B as B_{OFN}.

The control is translated from the domain of real numbers R to the domain of ordered fuzzy numbers OFN. In other words, real values of temperatures T_A and T_B are fuzzyfied to their extended representation containing information about the change in the value of OFN, i.e. to the numbers A_{OFN} and B_{OFN}:

$$F_{OFN}(t_A, t_B) \longrightarrow \{A_{OFN}, B_{OFN}\}$$

Using the properties of OFN numbers, the controller calculates and anticipates the settings for the stove f_K, which supplies the heating system, and for the cooling system h_K.

The calculations are performed as follows:

- If A_{OFN} and B_{OFN} increase then F_{OFN} down high and H_{OFN} up high,
- If A_{OFN} rises and B_{OFN} decreases then F_{OFN} down high and H_{OFN} up low,
- If A_{OFN} decreases and B_{OFN} rises then F_{OFN} up low and H_{OFN} down high,
- If A_{OFN} and B_{OFN} decreases then F_{OFN} up high and H_{OFN} down high

Whereas *high* means high control setting of the stove and the cooling system, while *low* a small one. It is characteristic that the use of OFN allows to determine the temperature value and its trend (positive or negative). The value of the function F_{OFN} should therefore be adjusted depending on:

- stove type and cooling type,
- temperature values,
- temperature trend (this is characteristic for this control).

The values *high* and *low* are therefore dependent on the set temperature. Table 1 specifies the rules for controlling the system outputs based on the temperature A and B settings and readings.

Table 1: Table of set-points

in			**out**	**out**
Temp A	Temp B	$T_Z - T_A$ is	% of the stove power	% of the cooling power
is rising	is rising	$T_Z - T_A > 0$	40,00%	
is rising	is falling	$T_Z - T_A > 0$	70,00%	
is falling	is rising	$T_Z - T_A > 0$	60,00%	
is falling	is falling	$T_Z - T_A > 0$	90,00%	
is rising	is rising	$T_Z - T_A < 0$	10,00%	
is rising	is falling	$T_Z - T_A < 0$	30,00%	
is falling	is rising	$T_Z - T_A < 0$	20,00%	
is falling	is falling	$T_Z - T_A < 0$	50,00%	
is rising	is rising	$T_Z - T_A = 0$	0,00%	50,00%
is rising	is falling	$T_Z - T_A = 0$	10,00%	
is falling	is rising	$T_Z - T_A = 0$	10,00%	
is falling	is falling	$T_Z - T_A = 0$	20,00%	

The control points have been set in the empirical process using the climate chamber. The authors have carried out many tests of the designed heating control system. We have used different types of heating systems: heater with a fans of different power (i.e. 50 W, 100W), heating mat also of different power (i.e.50 W, 100W, 200W). There were also many tests with covers of varying dimensions (1U, 2U, 3U and 4U rack size). During the climate chamber tests appeared many problems with an increase of the temperature inside the simulator cover when the temperature was set below 0^oC degree. The authors spent lot of time to choose the proper cover and to adopt it to heating and cooling system. The goal was to choose a proper cover that would allow for simulation tests. As a cooling system, two possibilities could have been used: fans and holes in the cover that would allow the hot air to be blown out of the cover or the Peltier module. Finally it was decided to use the fans and holes and heating mat (100 W). Aluminum 1U cover was selected. Many tests have been carried out to set the rules for heating and cooling. The chosen system allowed to control of heating power, and also fans speed for cooling. The control points have been determined during the experimental tests and were attained in the following steps:

- the climatic chamber has been programmed in such a way as to generate the same test conditions, and its settings are shown in Figure 10,
- the tests of heating system have been carried out as to get the possibility to increase the temperature inside the house simulator in a controlled way this means to increase temperature fast or slow,
- the tests of cooling system settings have been carried out to get the possibility of decreasing the temperature inside the simulated house in a controlled way. In this particular case it meant that it not would take place too fast,
- the place of temperature measure (placing thermometers) had to be the same for all tests. This place as well as has been chosen in the course of tests, because the measurement too close to the heating system provided different results than the measurement with the thermometer placed closer to the cooling system. This problem occured in different ways for every type of cover dimensions. So, finally to minimize this factor the smallest model of housing was chosen with permanent thermometers location.

Finally, as it could be noticed in table 1, the cooling system was activated only in one case: when the temperature inside and outside increased. Only in this case the hot air from inside of the cover was blown out. In this case it was no foreseen that the temperature condition will be changed and that the control system can wait with cooling because the system expects that the outdoor temperature will start falling. When the temperature inside is rising but outside is falling, the heating system was working with low power, because:

– the control system anticipated the temperature decrease,

– the heating system was prepared and could start heating system faster being powered of 10% power , than starting 0% power. This situation was noticed during the tests with the heating mat. It has also been noticed in other projects where the heating mat was used.

The assumptions determined in a such manner were also dependent on the type of cover used to simulate the house, because it was made of aluminum. The authors understand that using other type of materials used in buildings: e.g. wood, or concrete, will generate a little bit different settings of the control system. In the end, however, such control will allow to reduce temperature oscillations around the set temperature in the building simulator than a traditional controller equipped with a thermometer and thermostat.

5 The test result of the proposed model

In order to verify the proposed method, a Smart Home simulation device was built. The device is shown in Figure 8. It is equipped with a heater simulating the stove. The controller was built on the basis of the Arduino solution. The device was placed in a climate chamber made available by TELDAT Sp. z o.o. sp.k. (figure 9).

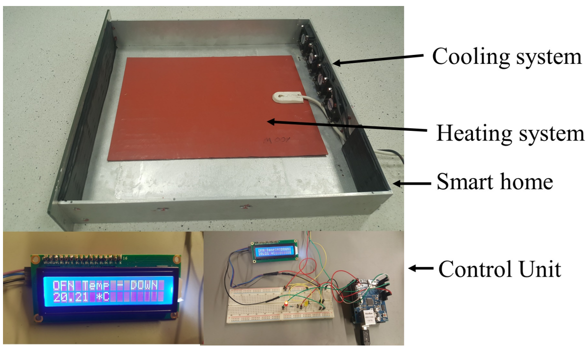

Figure 8: The appearance of the Smart Home simulator

The external ambient temperature shown in Figure 10 was preset as part of the test. The controller was designed in two variants. Variant A included control without the use of Fuzzy Logic, it was a binary offset mechanism used, while variant B using the proposed solution. Figure 11 shows a temperature chart for

Figure 9: The Smart Home simulator in a climate chamber

both controller variants. In the actual system - i.e. a house - the results obtained will differ in terms of the temperature increase and decrease rate. This is due to the fact that in the simulation the model had a metal housing, which allowed to obtain a higher response of the internal temperature to changes in the external temperature. Actual houses are equipped with better thermal insulation, but such simulations would require longer research. As illustrated in the graph, variant B allows to achieve smaller temperature oscillation with reference to the set-point inside to be maintained.

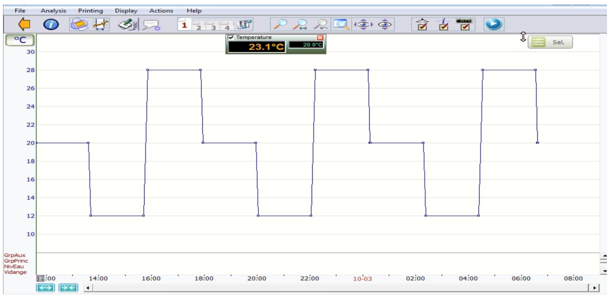

Figure 10: The graph of ambient temperature set-point

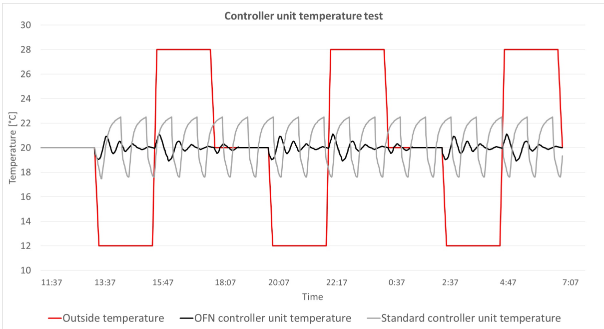

Figure 11: The results of internal temperature control

6 Conclusions

The IoT solutions are not only a matter of the future, but also of the present-day life. Numerous new technologies and capacities, as well as virtualization methods are developed nowadays with regards to them. Existing technologies and open source software solutions allow quick achievement of new capabilities and launching new services for the users. By combining them with fuzzy logic, especially Ordered Fuzzy Numbers, it is possible to achieve better energy control using the heating system of the Smart Home. The results achieved by means of the proposed solution have been confirmed by tests in the climatic chamber simulating the external conditions. The authors understand, that such experiments could be interesting also according to the power consumption: what is better to heat on higer value or do it slower.

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