Scientific Research and Essays Vol. 5(6), pp. 592-605, 18 March, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Designing a smart multi-agent system based on fuzzy logic to improve the gas consumption pattern

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Accepted 26 February, 2010

A wireless sensor network (WSN) is composed of many sensor nodes that are distributed in the environment to gather information. One of the most common application of this technology is the monitoring of environments where there are constraints regarding the setting up of wired networks. In this paper, the design of a control system based on fuzzy logic to monitor and control gas consumption with the help of smart wireless sensor agents was dealth with. Moreover, fuzzy logic was used to assess gas pressure, gas volume, temperature and time in order to obtion an optimum structure for improving the urban gas consumption pattern. The results obtained showed that the method used, as apposed to conventional method, optimized gas consumption.

Key words: Wireless sensor network, fuzzy logic, multi agent system, consumption pattern.

INTRODUCTION

Wireless sensor networks (WSN) which are a subset of ad hoc networks, have attracted a lot of attention recently. These networks consist of many sensor capable of receiving, sending and processing a series of data in a wireless environment (Mauri et al., 2004). Urban sewage pipes have been studied in a city in USA with the help of a wireless sensor network [Montestruque and Lemmon, 2008]. In this city, the use of this wireless sensor network has resulted in a reduction in and control of sewage overflow and also in the chanelling of sewage to the rivers. Fuzzy logic has been used to increase the productivity and the quality of wireless sensor networks [Xia et al., 2007; Xia, 2008]. To achieve this , fuzzy logic is used to examine the traffic in the network and the energy of the nodes in order to find the appropriate route for the transmission of information. Fuzzy algorithm has been efficiently used to control completely saturated intersection (shamshirband, 2007). In this paper, the use of WSN in urban gas pipes is introduced. The pressure fluctuations in gas branch lines is dealt with, taking into consideration fluids characteristics and the effectiveness of pressure in the performance of fluids, in order to obtion anoptimum structure which can be ued to control and coordinate gas consumption among consumers so as to prevent probable drops in gas pressure (Streeter and Benjamin, 2008). Fuzzy logic in the method was propose to attain this control. It is a method for mathematicalrepresentation of nonlinear system and it has many practical applications due to its capability in carring out approximate reasoning [Zadeh, 1965]. This paper is organized as follow: section two includes the definition of the problem together with fuzzy logic and multi-agent system. In section three the proposed method was introduced and the strategies and purposes of the paper were presented. Section four contains results and simulation.

Definition of the problem

Due to the fact that underground resources are limited, their depletion has always been and will always be, of concern to countries whose economies are based on these resources. Gas is one of the underground resources Iran is endowed with. Since many industries need gas to continue functioning and because gas has domestic uses, it has always been felt that gas consumption must be carefully monitored and controlled [http://www.nigc.ir].

Although Iran is the second biggest gas producer in the

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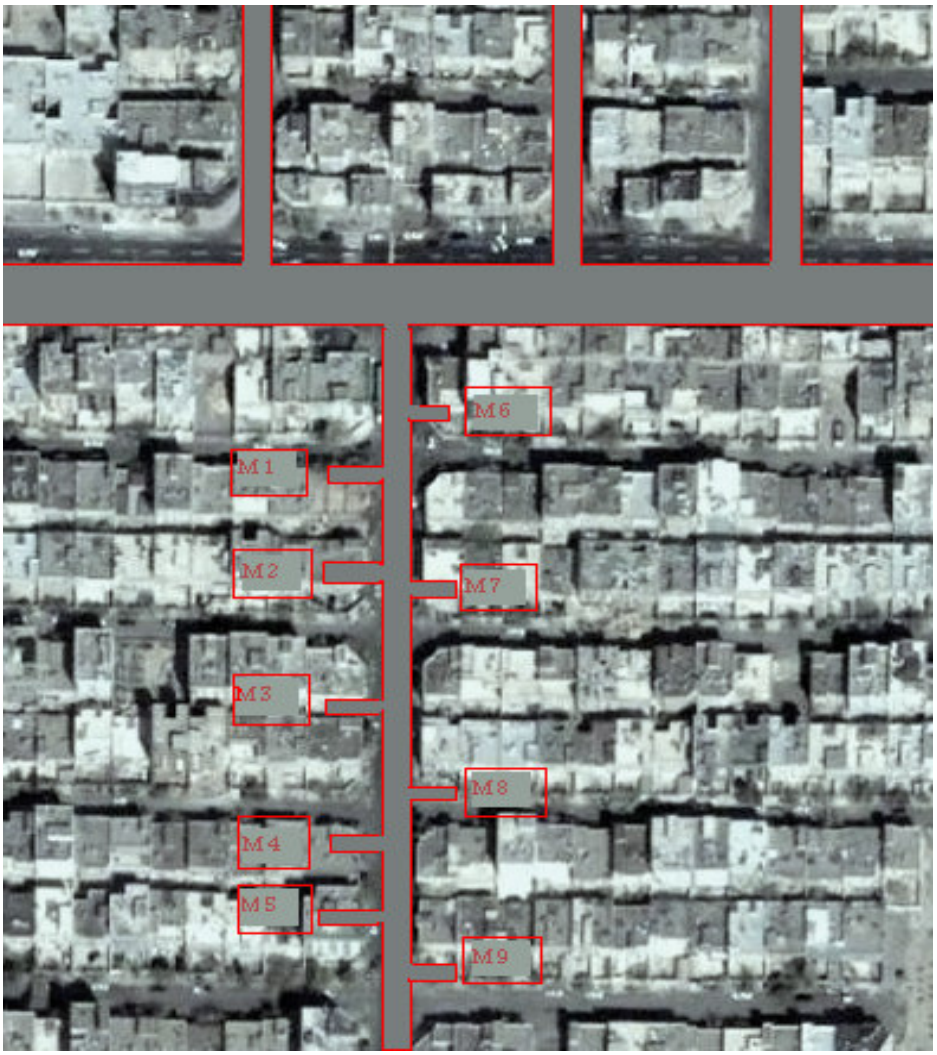

Figure 1. The location of consumers along a specific branch line.

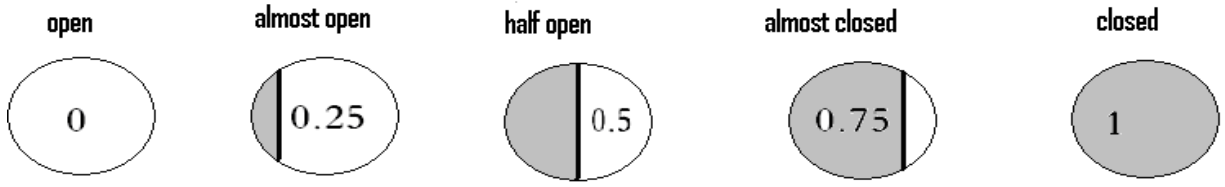

Figure 2. Position of the FC.

world, the gas generated can still be preserve for future generations if used correctly [http://fa.wikipedia.org]. According to studies carried out by experts of the gas company, there are two methods to prevent drops in gas pressure: to produce more gas at refineries and to control gas consumtion by consumers. The second method is recommended because the first one requires the changing of gas delivery infrastructure and also due to the fact that increases in gas production depend on the general policies of governments. Furthermore, the second method is simple and at the same time feasible under the current conditions in Iran.

Two areas will be examined in order to be able to better control gas consumers. One area is related to each individual consumer present along a certain route (Figure 1) and the other area relates to the main branches (Figure 3). In Figure 1, one consumer (m1) was considered. The incoming line for this consumer should include sensors to

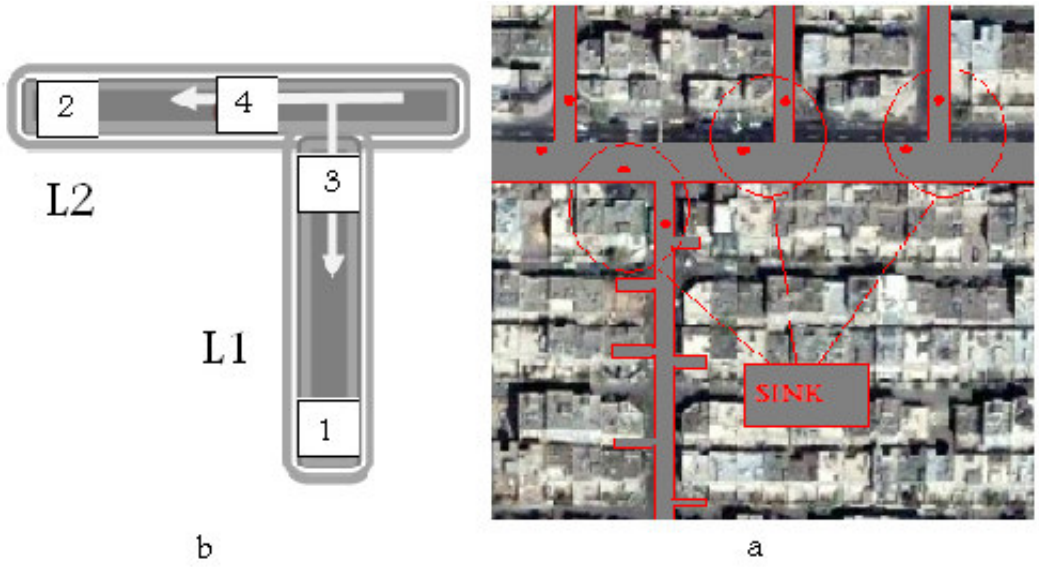

Figure 3. (a) Main branching off in gas pipes. (b) Q1= volume of gas passing through the cross section of pipe L1 per unit of time; Q2 = volume of gas passing through the cross section of pipe L2 after the branching off per unit of time; Q3 = volume of gas passing through the cross section of pipe L2 before the branching off per unit of time; S1= sensor measuring Q1 at point number 1; S2 = sensor measuring Q2 at point number 2; FC2 = fuzzy controller installed at point number 3. This controller can open and close.FC2 = fuzzy controller installed at point number 4. This controller can also open and close.

measure the volume of gas used (V) and the air temprature (T). This information is delivered to the fuzzy control system which uses the paramters t (the hours at which tangible changes in gas consumption occur), T (the air temperature) and V (the volume of gas used by the consumer in cubic meters) to make decisions conserning fuzzy controllers at specific time intervals .

A fuzzy controller (FC) is installed in the incoming line of every consumer. This FC has the following positions: open, aimost open, half- open, almost closed and closed (Figure 2).

The FC sets gas consumption at standard levels. To determine these standard levels fuzzy logic is employed. This process will be explained in the proposed method.

In all cases consumers use gas at the standard level and a drop in gas pressure occurs in route L1, decisions are made to prevent the accurrence of this problem in the second route (which is related to Figure 3).

Figure 3 shows one main branching off. The arrows in Figure 3b represent the direction of gas flow, L1 is the side branch and L2 is the main branch. In Figure 3a, sensors have been installed at each branching off so that information concerning gas pressure at each branching off is gathered and sent to the Sink to prevent a drop in gas pressure in these branches. The Sink in WSNs is the center for gathering information. Since sensors in WSNs are faced with limited memory and limited processing, they only gather information about a part of the network, while the node Sink has complete information about the characterisitics of the network and about the way the sensors are connected to each other. Therefore, the node Sink is responsible for processing information received from sensor in WSNs [Stefano et al., 2007].

Since the rate of the transmissivity of gas per unit of time is the flow rate per unit of time, or Q, the following equation can be used:

$$Q = CA\sqrt[2]{2\Delta P/\emptyset} \quad (1)$$

Where P (pressure) is the main parameter in obtaining the flow rate (Q). In practical applications, the flow rate is more commonly used than the pressure, here , Q have been substituted for P in solving the problem.

Since sensor S1 measures Q1, if there is an increase in gas consumption in branch L1, this unusual increase is measured by S1 and through the exchange of gather informatin with sensor S2, decisions based on fuzzy logic are made and if it is concluded that Q1 is more than the usual flow rate, decisions are made concerning the performance of fuzzy controllers FC1 and FC2 so as, if possible, avoid a drop in gas pressure in L1. The flow rates measured by S1 and S2 are dependent on each other and according to the law of the conservation of energy:

$$Q = Q1 + Q2 \quad (2)$$

Therefore, it can be concluded that Q1 and Q2 are dependent on each other. To show this dependence and

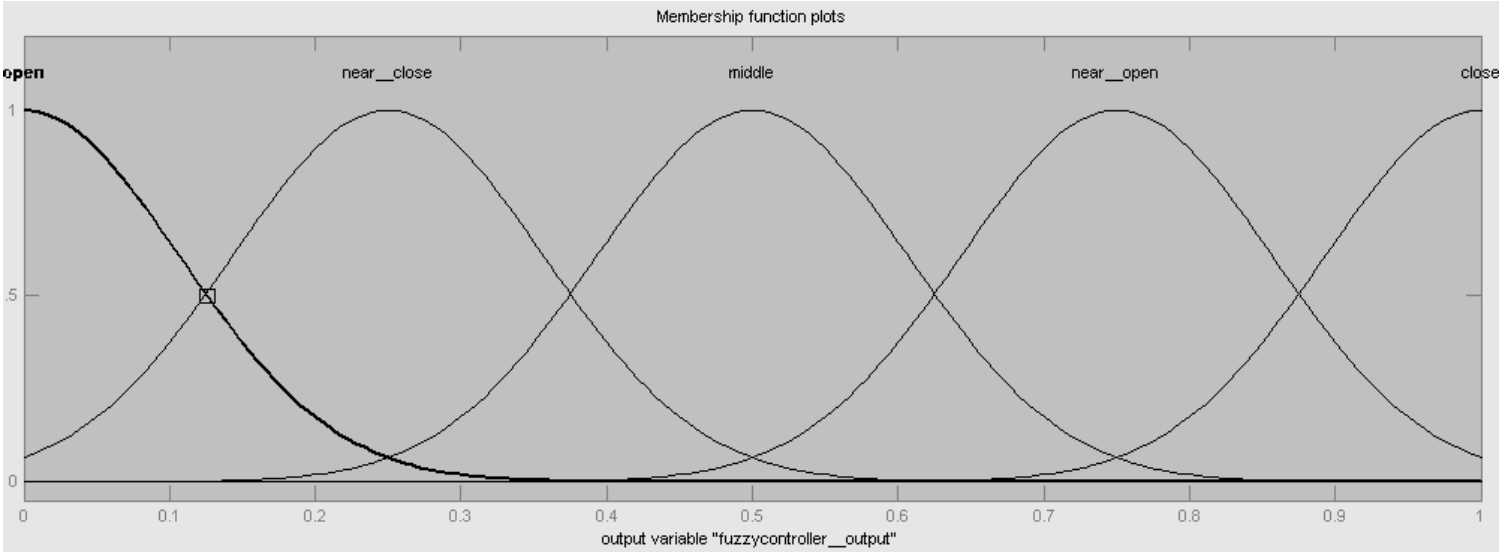

Figure 4. Membership function of FC.

to apply it in the performance of fuzzy controllers FC1 and FC2, fuzzy controllers will be used and ultimately, use gas correctly.

MULTI-AGENT SYSTEM

A multi-agent system is a system consisting of agents. These agents, each in its own turn, have internal interactions and are also related to each other in the external environment (CIA, 2005). An agent is a computersystem or program capable of carrying out independent actions. In other words, agents are autonomous (CIA, 2005). Agents need to cooperate with each other, to have harmony amongst themselves and to carry out interactive conversation in order to have successful internal communication (Yoav, 2002). Temperature, volume and time sensors and the fuzzy controllers are the smart agents in our study.

FUZZY LOGIC

The concept of fuzzy logic was introduced by Dr. Lotfizadeh, an Iranian professor at university of California in Berkley, not only as a control methodology but also as a way to process data based on authorizing the use of membership in a small group instead of making use of membership in a cluster group (Hellmanna , 2001). For example, the performance of the fuzzy controllers is described as open, almost open, half open, almost closed and closed (Figure 2). These terms are experssed as functions of every point of which has one of the values stated above (Figure 4).

Fuzzy logic is a simple rule based on:

If X and Y Then Z

Fuzzy mathematics is a metaset of boolean logic and denotes relative correctness. Although fuzzy systems describe uncertain and indefinite phenomena, the fuzzy theory is still a precise theory. A fuzzy system has the following structure:

i. Fuzzification: making something fuzzy.
ii. Fuzzy rule base: in the rule base, the if-then rules are fuzzy rules.
iii. Fuzzy inference engine: produces a map of the fuzzy set in the space entering the fuzzy set and in the space leaving the fuzzy set, according to the rules if-then.
iv. Defuzzification: making something nonfuzzy [Xia et al., 2007] (Figure 5).

PROPOSED METHOD

The purpose of the proposed method is to prevent excessive use of gas by consumers through controlling gas consumption so as not to experience a drop in gas pressure in the pipes. As mentioned earlier, the proposed method consist of two parts: individual consumers and T-shape structure.

INDIVIDUAL CONSUMERS

Since gas consumption fluctuates in different sensors due to changes in air temperature, it is not possible to always use one standard level for the volume of gas consumed. Furthermore, gas consumption rate changes at different hours of the day because of changes in air temperature. Therefore, a standard level of gas consumption

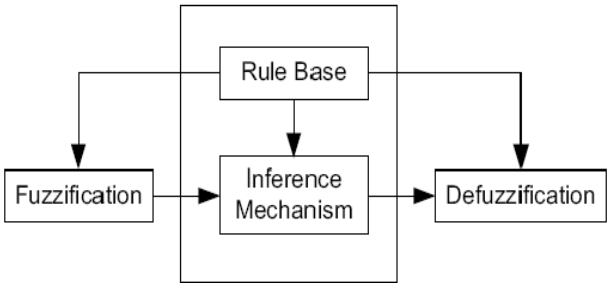

Figure 5. The structure of a fuzzy system.

can be obtained by combining the parameters air temperature and the time of the day when gas is used. To do this, one fuzzy controller was placed together with sensors in the route the pipe takes to reach each consumer (the Ms in Figure 1). The sensors measure the parameters of air temperature, the volume of gas used and the time periods which influenced gas consumption and if the volume of gas used by consumers exceeds the established standard level, changes were made in the position of the fuzzy controlled in the incoming pipe. These changes were made according to fuzzy instruction (Tables 1 and 2). The sensors installed in the incoming pipe for each consumer measured the following parameters:

1. Temperature: the accepted range was [-10…40]℃ and the subintervals were: [-10...10], [10…25], [25...40].
2. Time of the day: the accepted time intervals were: [6 - 10], [10 - 14], [14 - 22], [22 - 6].
3. Volume of gas consumed: the accepted range was [0…1.25] and the subintervals were: [0…0.33], [0.33…0.62], [0.62…0.75], [0.75…1], [1…1.25].
4. FC: The accepted positions were: {0.25 , 0.5 , 0.75}.

As was previously pointed out, in fuzzy logic the above-mentioned parameters were used to make decisions on the FCs. A few examples are presented in Table 3. In the last column advatages include consumers with low level of gas consumption.
In the proposed method, sensors installed in the incoming pipe for each consumer and at the main branching off can be used to gather and send information such as the volume of gas consumed, to the gas company. These operations are carried out with the help of a wireless sensory network (WSN) and they will be explained at the end of part two. The different stages of designing a fuzzy system will then be explained (Figures 6, 7, 8, 9, 10 and 11).

T-SHAPED STRUCTURES

As can be seen in Figure 3, under normal conditions Q1 and Q2 are in a state of balance in relation to the consumer and if this balance is upset, the program of presure will drop in each of the branch lines. For example, since L1 is a side branch, an increase in gas consumption in L1 will cause a pressure drop in it. Therefore, to control this imbalance, the fuzzy system method was used (Table 4) as follows:

The sensors installed in the main branching off measured the following parameters:

1. Q1: the accepted ranges were: [zero - 0.33] , [0.33 - 0.66] , [0.66 - 1].
2. Q2: the accepted ranges were: [zero - 0.33] , [0.33 - 0.66] , [0.66 - 1].
3. FC: the accepted positions were: {0.25 , 0.5 , 0.75}%.

The degree to which the FC is open or closed is determined by using fuzzy logic (Table 5). Results obtained from simulations of this system in the software matlab on the basis of Mamdani fuzzy logic were as follows:

1. If (Q1 is High) and (Q2 is High) then (FC1 is Open) (FC2 is Open).
2. If (Q1 is High) and (Q2 is Middle) then (FC1 is Open) (FC2 is Ajar).
3. If (Q1 is High) and (Q2 is Low) then (FC1 is Open) (FC2 is Limited).
4. If (Q1 is Middle) and (Q2 is High) then (FC1 is Ajar) (FC2 is Open).
5. If (Q1 is Middle) and (Q2 is Middle) then (FC1 is Ajar) (FC2 is Ajar).
6. If (Q1is Middle)and (Q2 is Low)then (FC1 is Ajar) (FC2 is limited).
7. If (Q1 is Low) and (Q2 is High) then (FC1 is Limited) (FC2 is Open).
8. If(Q1 is Low)and (Q2 is Middle) then (FC1 is Limited) (FC2 is Ajar).
9. If (Q1 is Low) and (Q2 is Low) then (FC1 is Limited) (FC2 is limited) (Figures 12 and 13).

These showed the nature of changes in Q1 and Q2 with regard to output AC1 that is, the volume of gas contused influences the performance of the fuzzy controller (Figure 14).

Table 1. Fuzzy linguistic variables in the control system of each consumer.

Parameters	Type of pipe	Linguistic variables
Temperature	Input	Low, medium, high
Time of the day	Input	Morning, noon, evening, night
Volume of gas consumed	Input	Very low, low, medium, high very high.
The current position of FC	Input	Open, ajer, half closed, almost closed, closed.
The position of FC	output	Open, ajer, half closed, almost closed, closed.

Table 2. Characteristics of the variables of the system.

Parameters	Highest	Lowest	Unit
Temperature	40	10-	℃
Time of the day	5:59	6.00	Clock
Volume of gas consumed	1.25	0	M3/h
The current position of FC	1	0	%
The position of FC	1	0	%

Table 3. Some rules for the performance of the control system of each gas consumer.

Temperature	Time of the day	Volume of gas consumed	The current position of FC	The position of FC	Advantage
(10_10-)	(6_10)	(0.3_0)	0.25	0.25	+
(10_10-)	(6_10)	(0.3_0)	0.75	0.25	
(0_10-)	(6_22)	(1.25_1)	0.75	0.75	-
(25_10)	(6_10)	(1.25_1)	0.75	0.75	-
(40_25)	(6_22)	(1.25_1)	0.25	0.75	
(40_25)	(6_22)	(1.25_1)	0.5	0.75	-
(40_25)	(6_22)	(1.25_1)	0.75	0.75	-

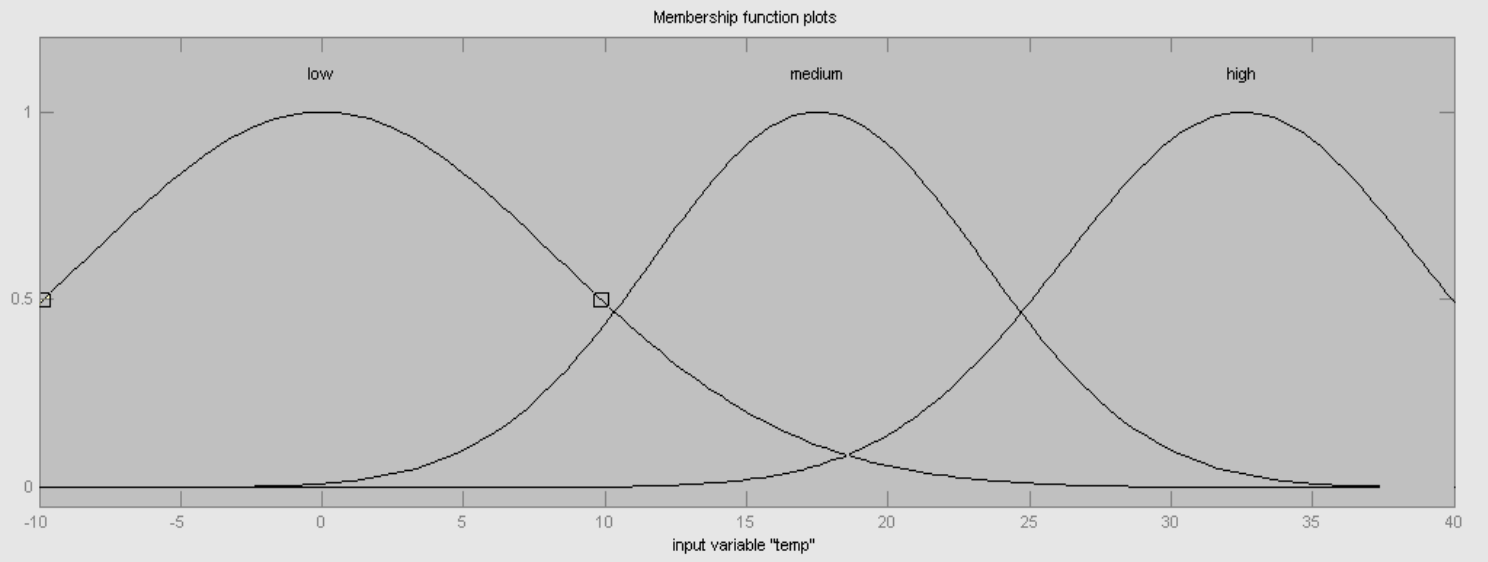

Figure 6. Temperature membership function.

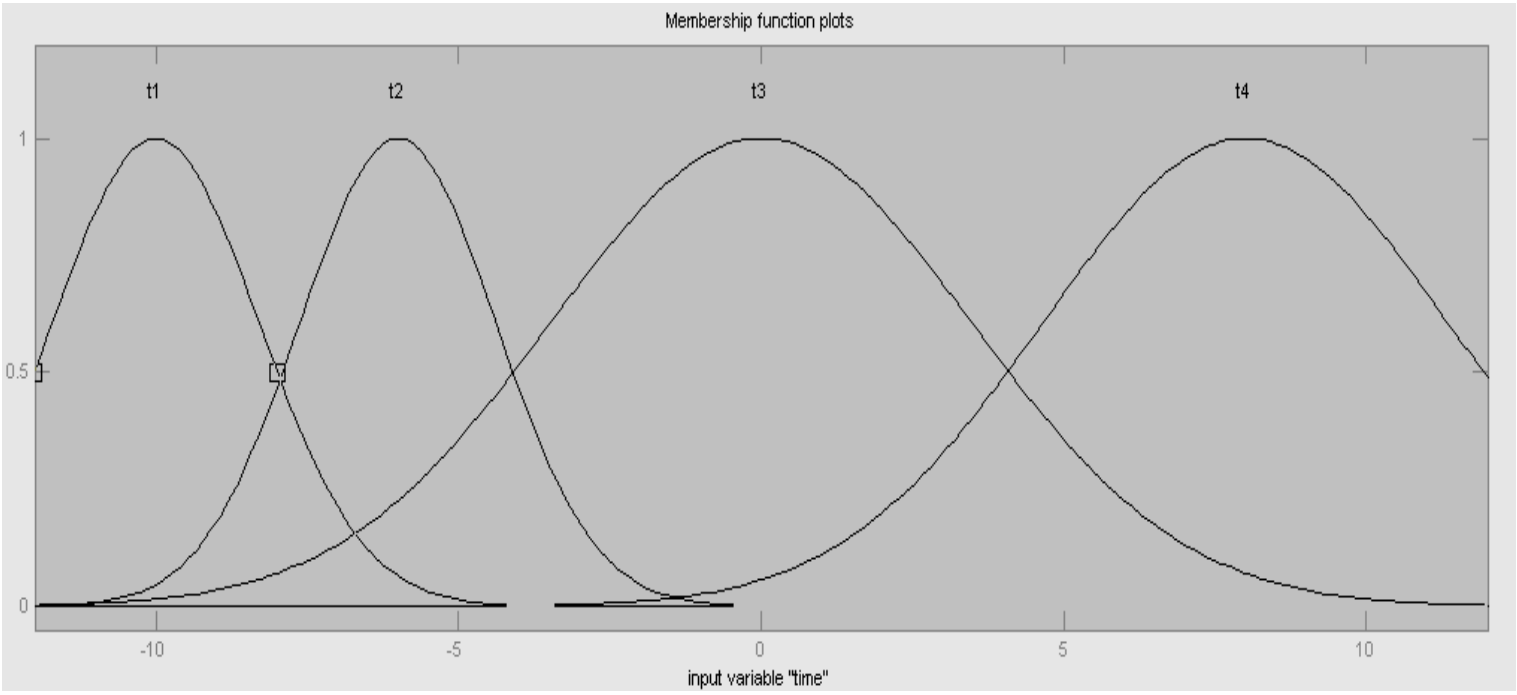

Figure 7. Time membership function.

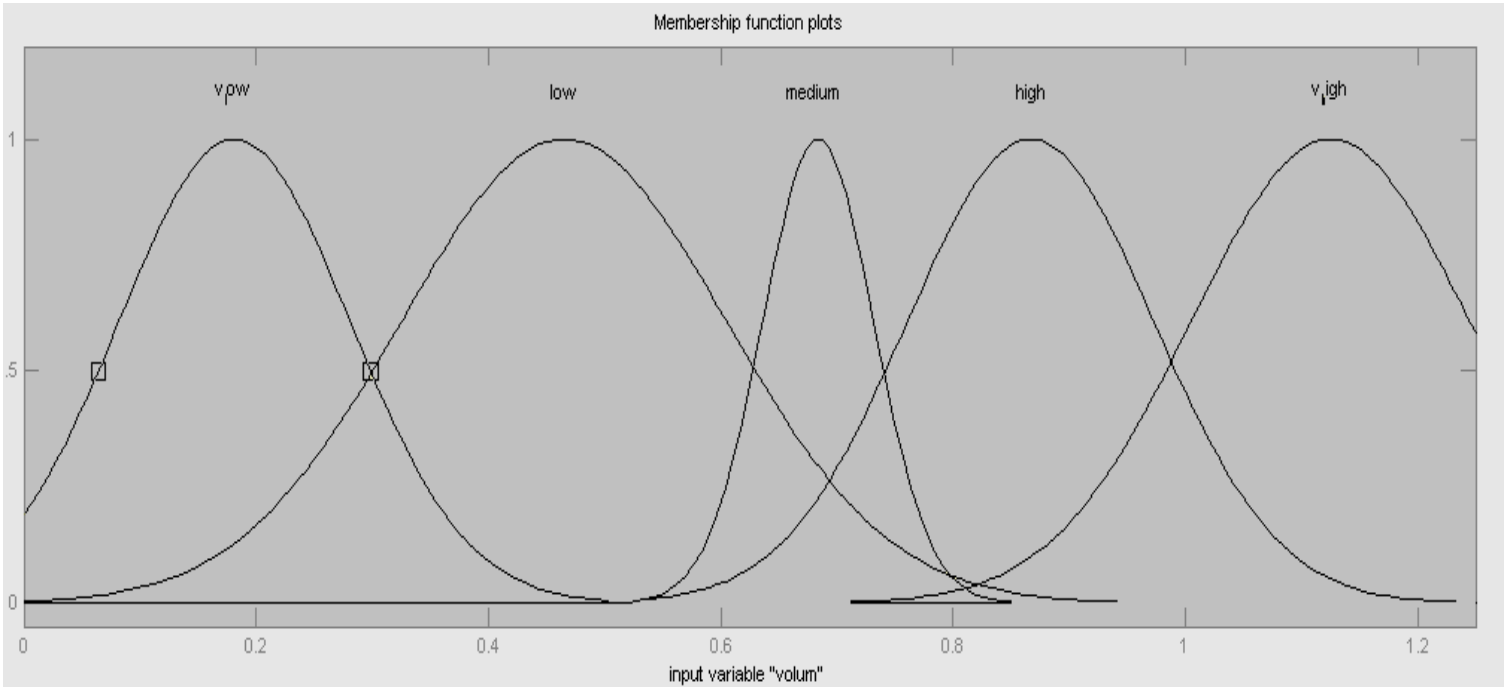

Figure 8. Volume membership function.

Since sensores in the main branching off have memory for retaining information, sensors installed in the side branches leading to individual consumers measure the volume of gas consumed and send this information to sensors installed in the main branching off. The sensors in the main branching off form a table in their memory.

Each consumer is given a record in this table. The information stored in each record is updated at definite

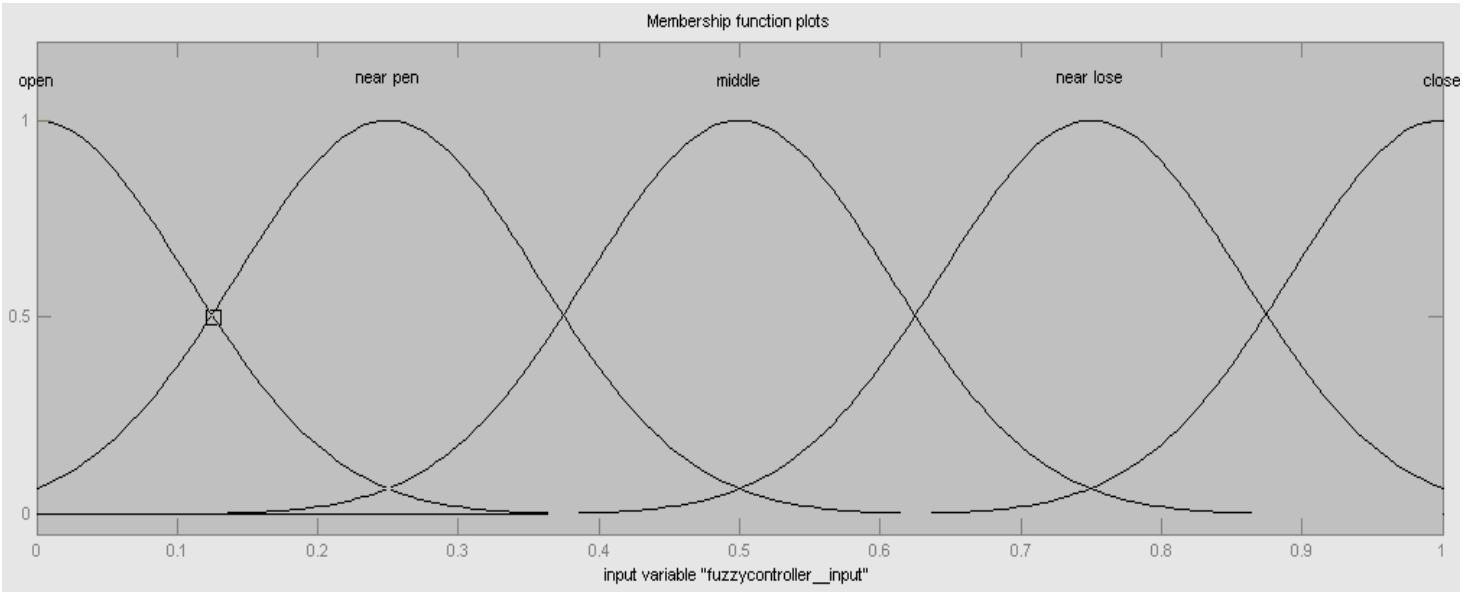

Figure 9. Fuzzy controller_input membership function.

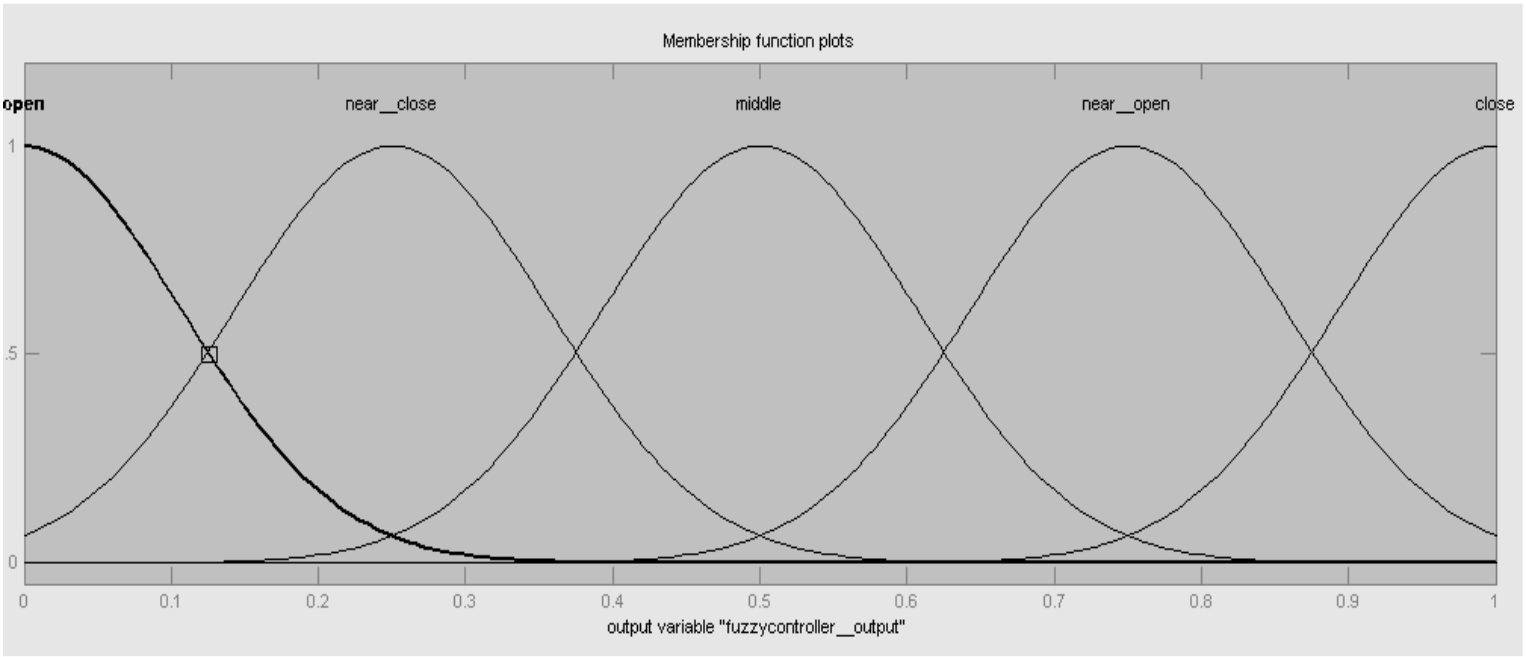

Figure 10. Fuzzy controller_output membership function.

time intervals and is then trasmitted by other sensors in a step-by-step fashion to be gathered at the main center of the gas company. In this method, the system is optimized so that employees of the gas company will not have to call at every gas consumer's house.

The agent present in the structure of WSN need interactive conversation to send information (Figure 15). The purpose of this control system is to standardize the volume of gas consumption and the success of this method was compared to conventional methods (Figures 16 and 17).

CONCLUSION AND SIMULATIONS

The purpose of this paper was to reduce the drop in gas pressure resulting from gas consumption. Through dividing parts of the gas pipe into separate wireless

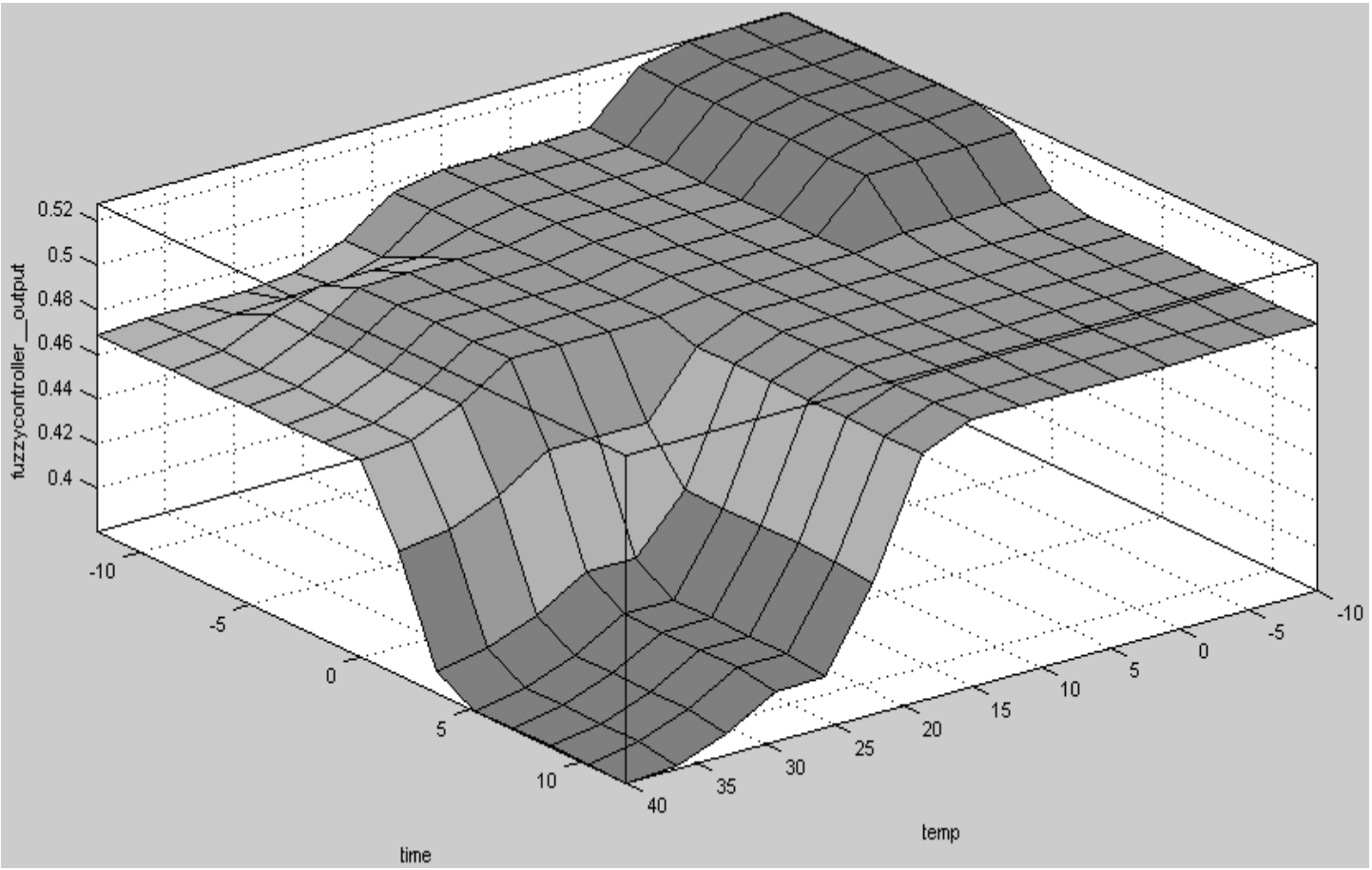

Figure 11. The preformance of the FC in relation to changes in temperature and time.

Table 4. The fuzzy linguistic variable in the control system of the main branching off.

Parameters	Type of pipe	Linguistic variables
Gas transmissivity in L1 (Q1)	Input	Low, medium, high
Gas transmissivity in L2 (Q2)	Input	Low, medium, high
Position of the fuzzy controller (FC1)	Output	Open, ajer, half closed, almost closed, closed
Position of the fuzzy controller (FC2)	output	Open, ajer, half closed, almost closed, closed

Table 5. Rules for the performance of FC in the control system of the main branch.

Q1	Q_2	AC_1	AC_2
High	High	0.33	0.33
high	Medium	0.33	0.66
high	Low	0.33	1
medium	High	0.66	0.33
medium	Medium	0.66	0.66
medium	Low	0.66	1
low	High	1	0.33
low	Medium	1	0.66
Low	Low	1	1

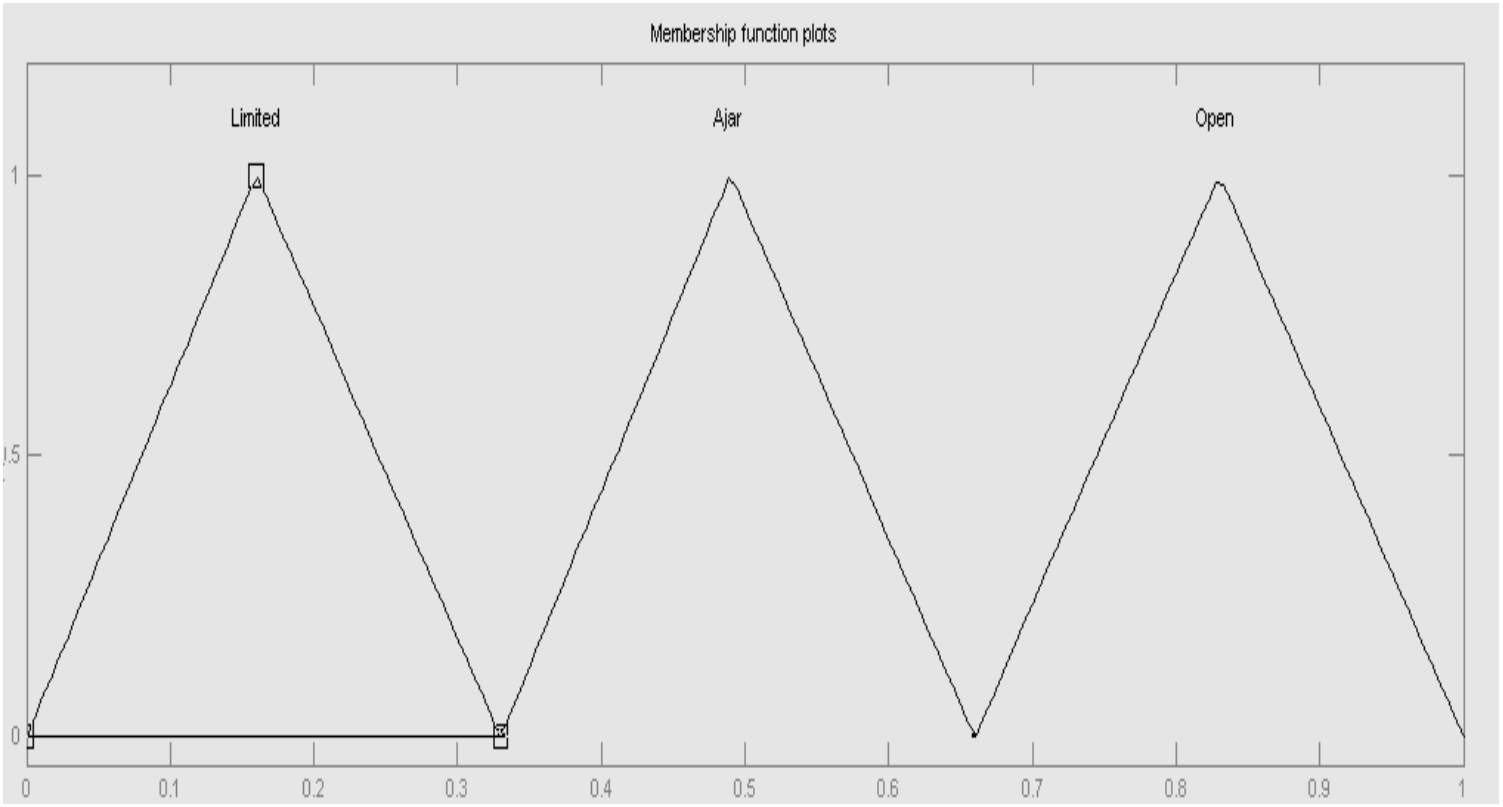

Figure 12. FC membership function of the main branching off.

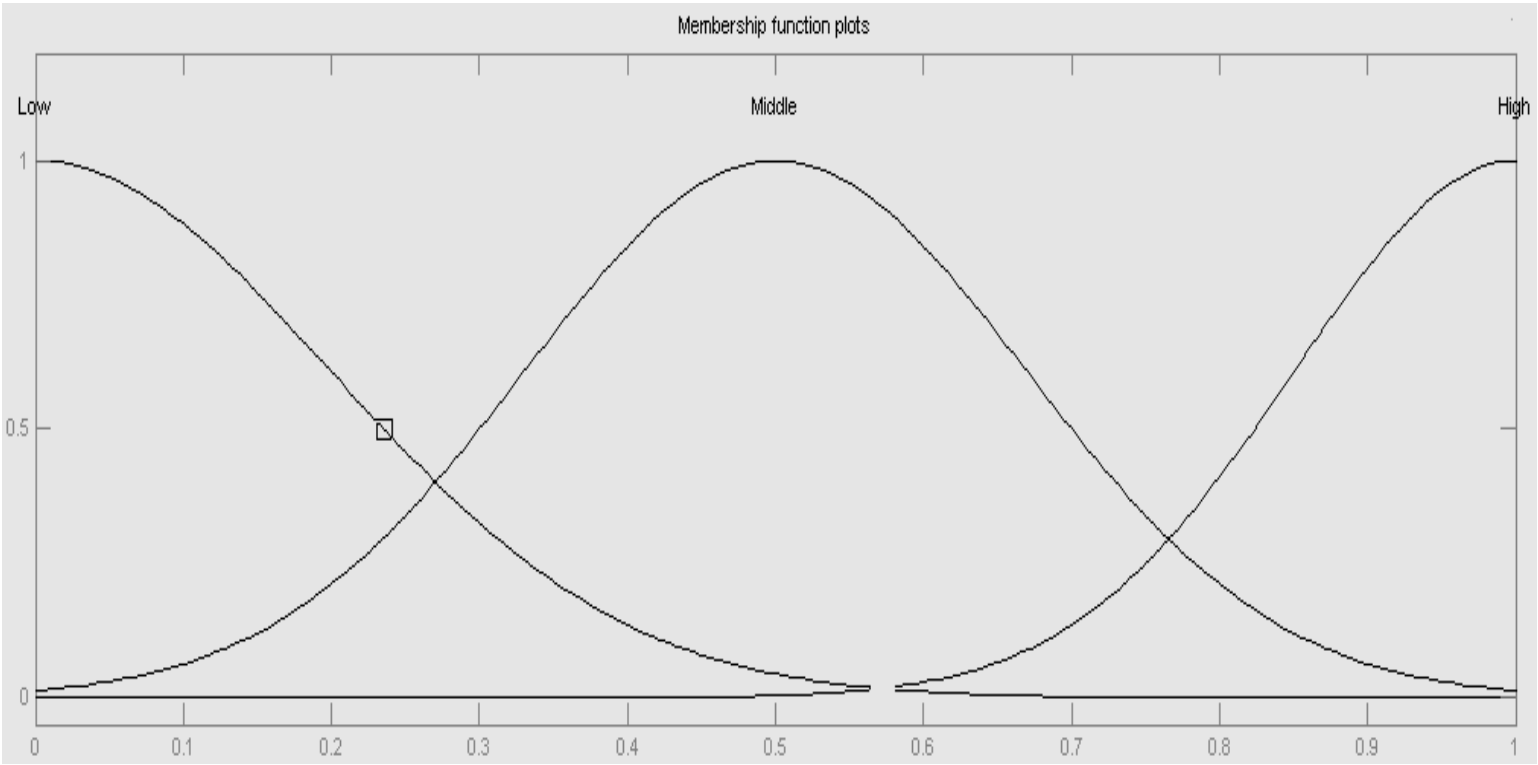

Figure 13. Q membership function.

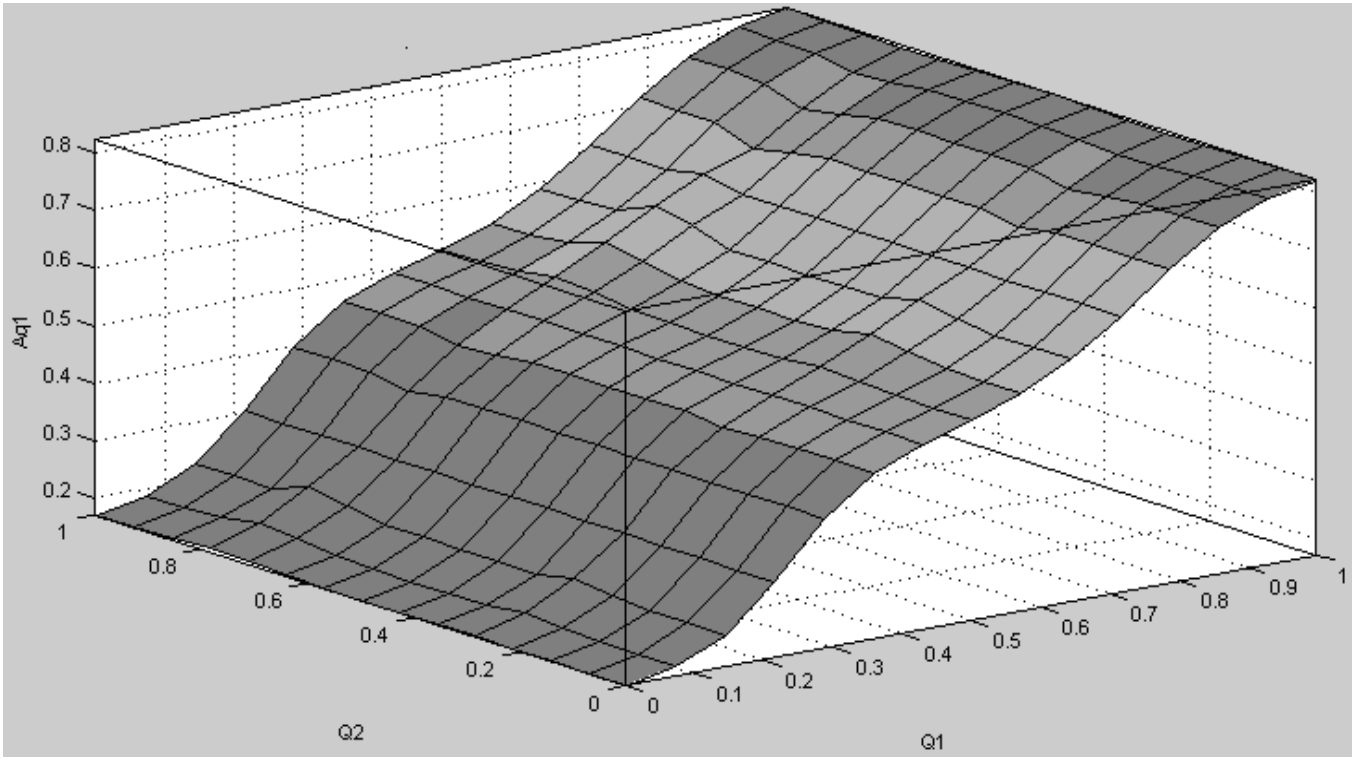

Figure 14. The performance of FC with respect to changes in Q.

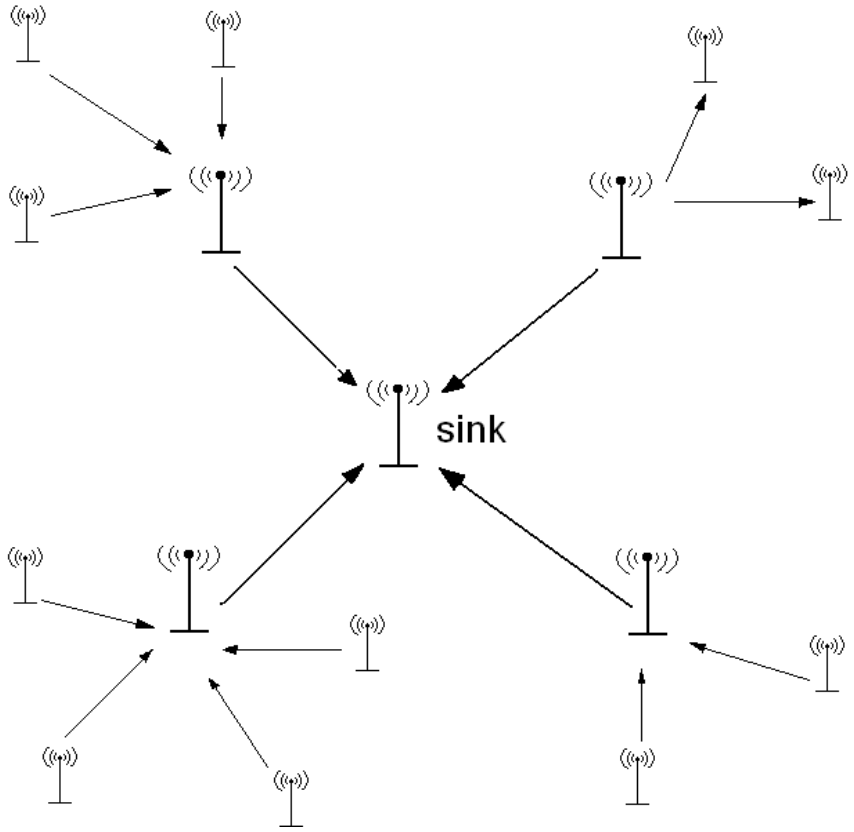

Figure 15. Cooperation among agents present in the wireless sensor network.

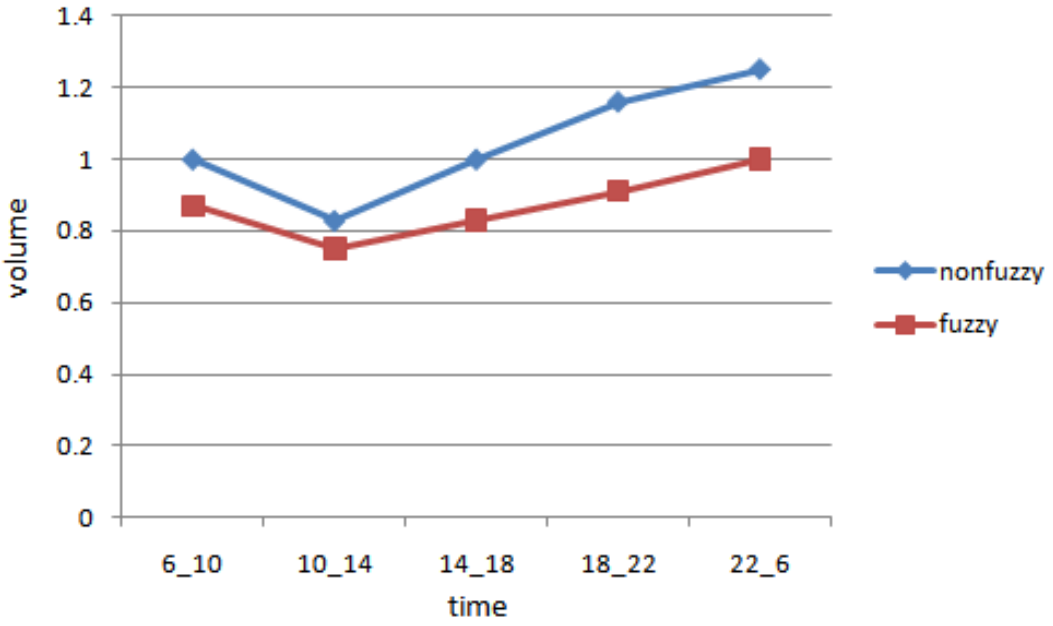

Figure 16. Diagram showing gas consumption in relation to time at constant temperature in fuzzy and nonfuzzy (conventional) syatem of control at the side branch of every consumer.

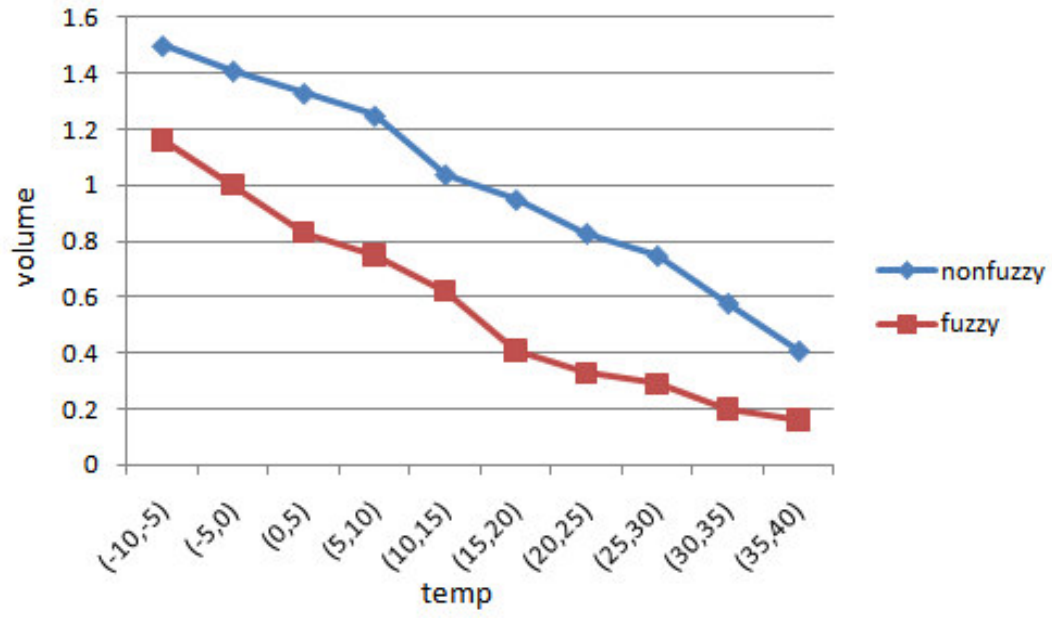

Figure 17. Diagram the volume of gas used in relation to temperature at a specific time in fuzzy and nonfuzzy (conventional) syatem of control at the side branch of every consumer.

sensor networks and by imposing rules based on Mamdani fuzzy logic on these netwoks, gas consumption can be controlled.

Simulation of the system controlling gas use at the branch leading to each consumer is implemented by using vb.net. In Figure 18, an example of simulation in

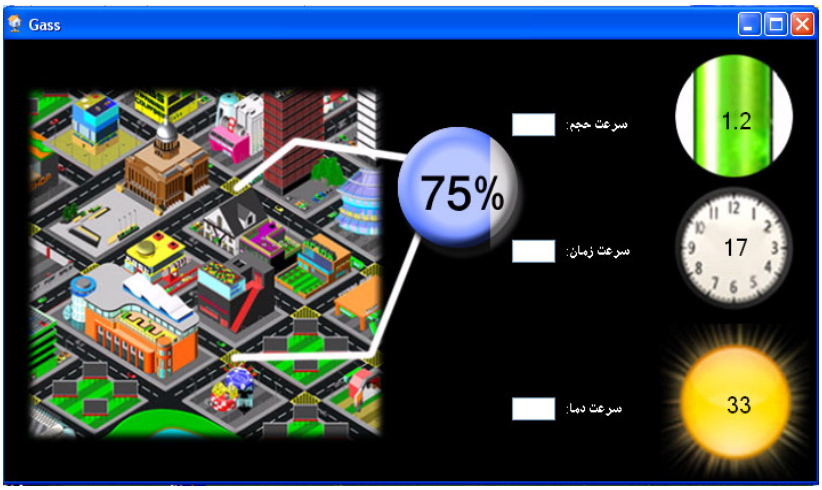

Figure 18. An example of simulation in visual studio.net.

Figure 19. Diagram showing cooperation amonge agent.

the Visual Studio.net is presented. It can be seen from this example that at air temperature of 33° and at 5 p.m. the volume used by the consumer was 1.2 m^3 per hour, which was verey high compared to the established standard level. Therefore, the control system sets the fuzzy controller at the 0.75 position.

FUUTURE RESEARCH

It is anticipated that taking more parameters into consideration and using interconnected networks (T-shaped structures) pertaining to a greater area will make it possible to obtain better and more precise results. As can be seen in Figure 19, each network can tramist information to the central node (the Sink) to be processed and hence gas consumption can be controlled in a wider area.

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