Function Models Associated Sensor Networks Fusion to Monitor the Quality of the Environment in Accordance with the Brazilian Technical Standards

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Abstract. *Sensor networks are important because they are able to collectively monitor and report any measurable phenomena of interest. The objective of this work is to present the formulation of the mathematical model for the environment quality index according to Brazilian standards, ABNT and ANVISA. The index is a value that ranges from zero to one and is calculated according to membership functions. The importance of the index comes from the need to monitor the work environment or study so that they are always according to standards, ensuring comfort and health. The tests are performed for temperature, humidity, gas and light sensors, using the star topology to assembly the sensor network. As a result, the mean index of the environment is composed to evaluate its quality, this index is used to display a graphic alert scheme that informs the lab's conditions to the users.*

1. Introduction

A wireless sensor network (WSN) is a system that consists of multiple sensing elements distributed spatially with a specific objective to measure different physical quantities and communicate those measurements between themselves and the central gateway. These sensing elements (sensors) are used to observe and instrument several physical and environmental conditions such as motion, pressure, temperature, sound, etc [Selmic et al. 2016].

The deployment of smart home and building automation systems are getting popular with the advancement in Information and Communication Technology. The work of [Tariq et al. 2012] reviews the main smart grid standards proposed by different organizations for home and building automation in terms of different function fields. The results of an experimental case study of ten offices in Torino (Italy), in which a custom-design building automation and control system has been designed to control both the lighting plants and the air conditioning system [Aghemo et al. 2014]. Also involving the environment [Silva et al. 2016]. In general, laboratories or labs are workplaces that provide controlled conditions for experiments and measurements to be performed. For this reason, controlling temperature and humidity is an important requirement that needs to be achieved in order to guarantee the reproducibility of processes carried out in laboratories.

The quality of the environment is very important for health. The purpose of [Conceição Ferreira and Cardoso 2014] is to determine if there is an association between indoor air quality in schools and the prevalence of allergic and respiratory diseases in the children who attend them. It is evaluated 1,019 students from 51 elementary schools in the city of Coimbra, Portugal. There is a statistically significant association between lack of concentration in children and exposure to high CO_2 levels.

The objective of this work is to present the formulation of the mathematical model for the environment quality index according to Brazilian standards. The index is a value that ranges from zero to one and is calculated according to membership functions. The importance of the index comes from the need to monitor the work environment or study so that they are always according to standards, ensuring comfort and health. The tests are performed for temperature, humidity, gas and light sensors, using the star topology to assembly the sensor network.

The paper is organized as follows: Section 2 summarizes the proposed sensor network architecture. Section 3 summarizes the Brazilian standards consulted for the development of the environmental quality index, Section 4 describes the methodology of the project and the mathematical Fuzzy models. Section 5 shows the results and analyses of the environmental quality index for each of the sensors. Finally, the conclusion is presented in Section 6.

2. The proposed Sensor Network Architecture

The sensor network is deployed in environment that is as research laboratory. The chosen place layout is presented in Figure1 is the Process Control Laboratory (LCP-lab), the total area is $50m^2$, each room of the laboratory has a sensor node. Each sensor node of the LCP-lab that is represented in Figure 1 has the structure shown in Figures 2 and 3. In Space 1, besides the sensor node will contain four temperature sensors.

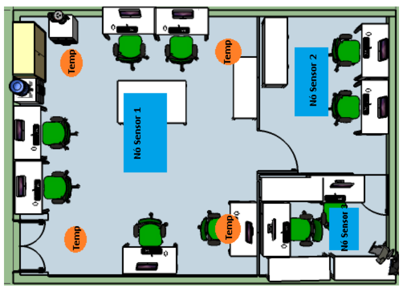

Figure 1. Laboratory Plant showing the location of sensor nodes

Sensor networks are composed of a large number of sensor nodes that are deployed to collectively monitor and report any phenomena of interest. Sensor networks are a superset of WSNs (Wireless Sensor Network) and, as such, share some common attributes that are integral to all sensor network systems [Selmic et al. 2016]. For this work the sensor node consists of those components on Figure 2, except for the actuators. Sensors of temperature, humidity, light and gas are used, those are connected to an $Arduino^{TM}$ microcontroller, which captures the data and through ESP8266 (radio and antenna), sends the data collected from the sensors to the *Internet* using the service platform of IoT *ThingSpeak* [ThingSpeak 2018], as seen in Figure 3.

The topology of a WSN refers to how the nodes are arranged within the network. The most common topologies are star, mesh and star-mesh hybrids topologies [Selmic et al. 2016]. Four our purpose, the star topology is chosen to support our project

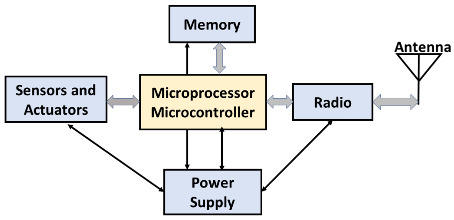

Figure 2. Wireless sensor node architecture.[Selmic et al. 2016]

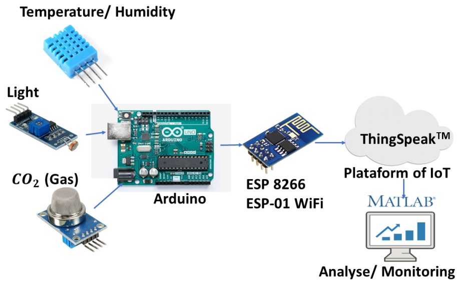

Figure 3. Proposed system architecture

objectives, the nodes are organized in the form of a star with the base station as the hub of the star. Sensor nodes broadcast data through the base station, and cannot directly exchange messages between each other. This topology offers low power usage as compared to other wireless sensor topologies. However, the base station cannot communicate with a node that is out of range. The sensor node is connected in a star topology, due to the simplicity and low power usage of this topology. The base station is the computer machine as is seen in Figure 3.

3. Brazilian Standards of Environment Quality

In the present work, the test environment is a research laboratory, so all the rules of this section were searches for use in a laboratory environment or another that most resembles this one. The quality and salubrity of the environments should be in accordance with objective criteria established by the ABNT (Brazilian Association of Technical Standards) and other regulatory organizations such as ANVISA (National Agency for Sanitary Surveillance). The following standards will be used for the determination of the environment quality index.

The **N17-Ergonomics** establish that at workplaces where activities that require constant intellectual solicitation and attention are performed, such as: control room, laboratories, offices, development room or project analysis, among others. The LCP fits this pattern and the following comfort conditions are recommended: effective temperature index between 20°C and 23°C and relative humidity of not less than 40% [MTPS 1990]. The **Resolution 9, January 16th 2003-ANVISA** [ANVISA 2003] establishes the Reference Standards for Indoor Air Quality in Artificially Air-conditioned Environments for Public and Collective Use. The recommended maximum chemical contamination values are : 1000 ppm (particles per million) of carbon dioxide - (CO_2), as an indicator of external air renewal, recommended for comfort and well-being. 80 $\mu g/m^3$ of total aerodispesoids in the air (dust), as an indicator of the degree of purity of the air and cleaning of the air-conditioned environment. The recommended operating range of Dry Bulb Temperatures, in indoor conditions are: for Summer, between 23°C and 26°C and for Winter, between 20°C and 22°C. The recommended operating range of Relative Humidity are: for Summer, between 40% and 65% and for Winter, between 35% a 65%.

4. Fuzzy Logic Models to Environment Quality Evaluation

The objective of the project is to establish an environmental quality index based on Brazilian standards. For this, the project is divided into two stages, as show the Figure 4: the first one consists in the formulation of the mathematical model of the environment quality index based on Section 3, the model uses the membership functions of the Fuzzy Logic [Eberhart et al. 2007]. This index is formulated for the following quantities that interfere with the quality of the environment: temperature, humidity, light, carbon dioxide.

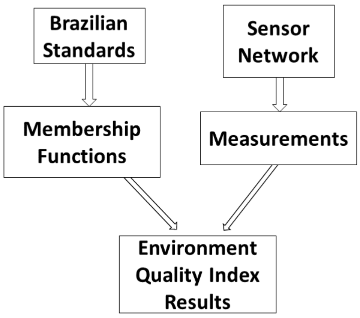

Figure 4. Methodology of the project

As it is worked with environmental magnitudes it is necessary to verify whether they are in or out of the standards. Sensors are the components capable of capturing these physical quantities. Therefore, the second stage is the design of the sensor network. Through a network, the measurements of these sensors can be communicated to a central base for monitoring, as seen in Section 2.

The quality index of the environment is a value that represents how close to the standard are the quantities measured by the sensors at a given moment, in a non-binary way but varying according to the value of x (temperature, humidity, light, carbon dioxide). It is developed based on the Brazilian standards described in Section 3.

Rather than just informing whether the measured quantity is within or out the range defined in the standard, the index ranges from zero to one. Therefore, a model that describes the mathematical behavior of the variables is developed. This model is described by membership functions derived from Fuzzy Logic [Eberhart et al. 2007].

4.1. The π-shaped Membership Function

The π-*shaped membership function (pimf)* is used for temperature, humidity and light, whose points is established according to the acceptable limits from the standards. The membership function is calculated at the points determined by the vector x. The parameters a and d locate the "feet" of the curve, while b and c locate the "shoulders". The function is given by:

$$f(x,a,b,c,d) = \begin{cases} 0, x \leq a \\ 2\left(\frac{x-a}{b-a}\right)^2, a \leq x \leq \frac{a+b}{2} \\ 1 - 2\left(\frac{x-b}{b-a}\right)^2, \frac{a+b}{2} \leq x \leq b \\ 1, b \leq x \leq c \\ 1 - 2\left(\frac{x-c}{d-c}\right)^2, c \leq x \leq \frac{c+d}{2} \\ 2\left(\frac{x-d}{d-c}\right)^2, \frac{c+d}{2} \leq x \leq d \\ 0, x \geq d \end{cases}$$

Each magnitude points a, b, c and d are chosen based on the rules. The maximum value of the index is one and it is obtained when x is between b and c.

The temperature has a higher index between 20°C (point b) and 23°C (point c), based on standard [MTPS 1990] this is the value for indoor comfort conditions. However on [ANVISA 2003] for summer should vary from 23°C to 26°C, therefore the point d is chosen 26°C which is the maximum value of the two standards, that point d will be 100% out of the range limit (value 0). The point a is chosen by induction, since point d is located 3 degrees more, then the point a is located 3 degrees less, and therefore is 17°C.

The highest humidity index is located between 40% (point b) based on the NR17, it only establishes the lower limit and 65% (point c) based on Resolution 9 (ANVISA) since this is the maximum value for indoor environment. Point d is chosen as 10% more than allowed (75%) and point a as 10% less (30%).

The point b-500 lux of the illuminance index is determined based on [ABNT 2013], which determines only the minimum value. However, a place with very strong illumination can cause annoyance, this way [ABNT 1992] is also used to choose the limit of 1000 lux as point c. Point d is chosen as 500 lux more and point a as 100 lux less than normative.

4.2. Z-shaped Membership Function

The *Z-shaped membership function (zmf)* is used for carbon dioxide. Parameters a and b are located at the extremes of the sloping portion of the curve given by:

$$f(x;a,b) = \begin{cases} 1, x \leq a \\ 1 - 2\left(\frac{x-a}{b-a}\right)^2, a \leq x \leq \frac{a+b}{2} \\ 2\left(\frac{x-b}{b-a}\right)^2, \frac{a+b}{2} \leq x \leq b \\ 0, x \leq b \end{cases}$$

For this function only the maximum value (point a) allowed is normative. For the carbon dioxide, the point a is 1000 ppm and b is considered to be 100 ppm more: 1100 ppm. The points of the standard discussed in this section are summarized by Table 1.

Table 1. Standard Range Index

	a	b	c	d
Temperature (°C)	17	20	23	26
Humidity (%)	30	40	65	75
Illuminance (lux)	400	500	1000	1500
Gas (ppm)	1000	1100		

4.3. The Environment Quality Index

The quality indexes for each measure are used for the calculation of the general index of the environment. This informs if the environment is within the standard considering all measures (temperature, humidity, gas, light) as a global index. The so called Mean Index is calculated based on the arithmetic mean of all indexes, according to the equation given by

$$MeanIndex = \frac{\sum_{i=1}^{n} Index(i)}{n},$$

where n is the number of measured values in the environment.

5. Validation Experiments

The sensors data acquisition, measurement-membership functions, mean index and the proposed monitoring system of the laboratory environment are the main topic that are presented in this section. Experiments are performed with the DHT11 temperature and humidity sensor, the LDR light sensor and the MQ-02 gas sensor, which are connected to an Arduino Uno and ESP8266 as shown in Figure 3.

5.1. Sensor Data Acquisition

The data of the $ThingSpeak^{TM}$ is read by the $MATLAB^{®}$ through the call of the *ThingSpeakRead*. The experiment ran for a full day, with a reading interval of 15 seconds. For this demonstration, the last 200 measurements are chosen, these are shown in the Figures 5 and 6. Under normal conditions the ambient temperature ranges from 21°C to 27°C degrees, Figure 5. The humidity ranged between 42% and 55%, under normal conditions, so it remains within the standard range throughout the measurement, Figure 6.

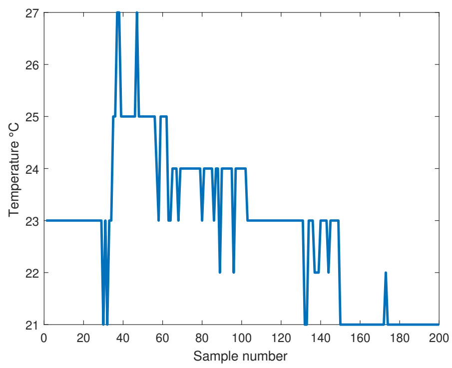

Figure 5. Temperature sensor

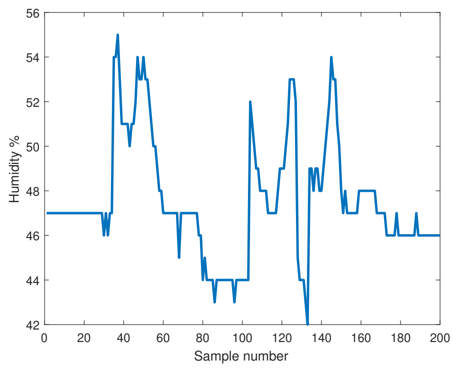

Figure 6. Humidity sensor

In similar manner of measurements obtained from humidity and temperature sensors of Figures 5 and 6, the light sensor and gas sensor is installed to measure the illuminance and carbon dioxide levels of the environment. The illuminance varies greatly during the measurement, ranges from 0 to 680 lux. The amount of carbon dioxide under normal conditions obtains an index equal to 1 with most of the measurement ranging from 200 ppm to 400 ppm. In the measurement 145 the insertion of smoke is carried out near the sensor to raise the carbon dioxide, at this point there is a peak in sensor measurement that starts to measure 1140 ppm. Although the behavior of illuminance and carbon dioxide levels are not presented the illuminance and gas membership functions are shown in this section.

5.2. Online Membership Funcions

The Sensor data of the measurements the membership function is applied in the points (data of the sensors) to obtain the index of quality. The result of the environmental quality index together with the membership functions developed on Section 4.1 are shown on Figures 7, 8.

The temperature quality index is 1 most often indicating that it is within the standard range. In some varies between 0.77, 0.222 and 0, as seen in Figure 7. The humidity remains within the standard range throughout the measurement, so the index is 1 as seen in Figure 8. In some points the illuminance it is out of the standard range (below the

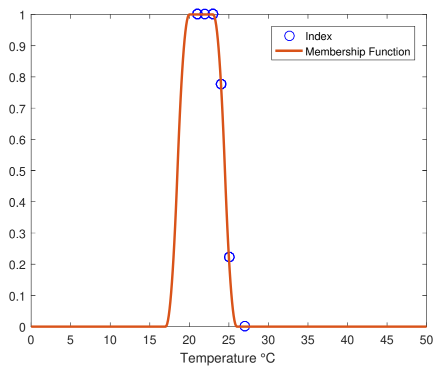

Figure 7. Temperature index

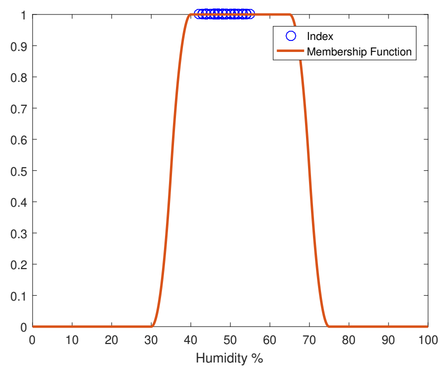

Figure 8. Humidity index

lower limit of 500 lux). This way, some index is 0.8750, 0.1352, 0.7550 as seen in Figure 9. With the peak of the amount of carbon dioxide caused by the insertion of smoke, the quality index becomes 0 as seen in Figure 10.

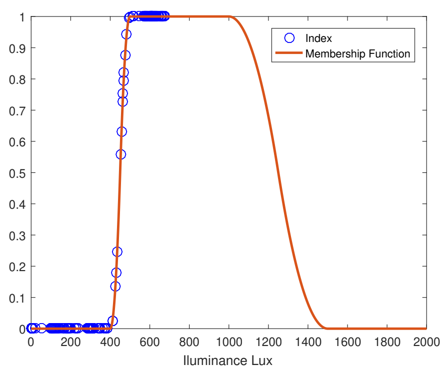

Figure 9. Illuminance index

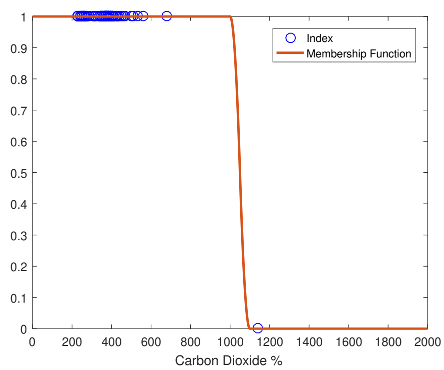

Figure 10. Gas index

5.3. The Mean Index of the Environment

According to Section 4.1, the Mean Index for the measurements of the environment is given by

$$MeanIndex = \frac{TempIndex + UmiIndex + IllumIndex + GasIndex}{4}$$

Table 2 shows the calculated Mean Index for three samples. Each sample was performed based on the measurements of Figures 5, 6. In the sample of number 10 all the measurements of the environment are according the standard, the index of each one individually is equal to 1 therefore the average is 1. In samples 65 and 145 some measurements were out the standard, therefore the average index was less than 1. The Figure 11 shows the average index for the latest measurements.

Table 2. Mean Index Calculation

Sample	10		65		145	
	Meas	Index	Meas	Index	Meas	Index
Temperature	23°C	1	24°C	0.7778	23°C	1
Humidity	47%	1	47%	1	54%	1
Gas	350 ppm	1	380 ppm	1	1140 ppm	0
Illuminance	609 lux	1	658 lux	1	186 lux	0
Mean Index		=1		=0.9445		=0.5

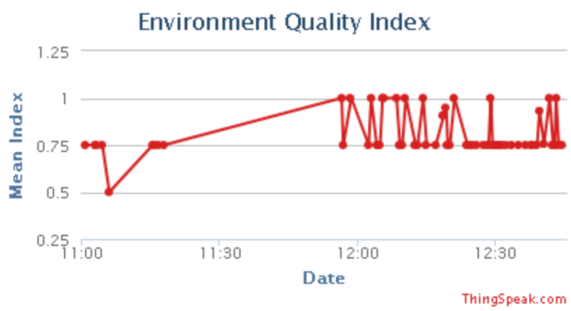

Figure 11. Environment Quality Index

5.4. The Proposed Monitoring System of the Lab Environment

To a general users understanding of what the systems is doing, the proposed monitoring system interfaces of the lab environment is presented in form of virtual meters. Both the Mean Index and the individual index for each magnitude are classified as ideal, reasonable and critical according to Figure 12. The colors are used to draw user's attention to the quality and security of the environment.

Monitoring is especially important in situations where users may be exposed to unhealthy conditions. Figures 13 and 14 show the *ThingSpeak* monitoring for the mean index and for each of the sensors. These graphs are intended to visually alert the user when environmental measurements are adequate or not. Figure 13 shows the average index calculated based on the measurements pointed out in Figure 14. In this example one of the measurements is out the standard therefore, as calculated the mean index is reasonable.

These indexes can be used for a global analysis of the environment, as well as to alert when a quantity is too out of the standard. For example, when an illuminance index indicates 0.1, it means that it is already far out of the standard and that an action must be

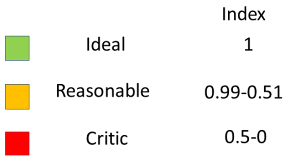

Figure 12. Quality Index Classification

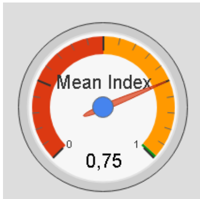

Figure 13. Mean Index Graph

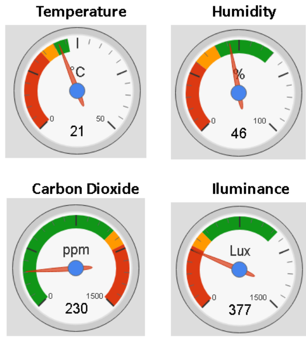

Figure 14. ThingSpeak Monitoring

performed, either by alerting or making the decision to dim a lamp to the minimum value allowed.

In this context, based on the membership functions developed, services are performed according to the Table 3 for each role. Services are performed by checking whether the environment is empty or with the presence of users performing activities such as meeting, reading, or experimenting. In order for the temperature to remain within the standard the actions must be performed and in addition if it enters a critical level it issues an alert. If the laboratory is empty, no action is taken.

Table 3. Situation models

Sensors	Situation	Role	Relation	Service
Temp	Presence	Ideal	20-23°C	Keep the temperature stable
		Reasonable Cold	17.1-19.9°C	Increase temperature
		Reasonable Hot	23.1-25.9°C	Decrease temperature
		Critic Cold	<=17°C	Increase temperature and sound a buzzer
		Critic Hot	>=26°C	Decrease temperature and sound a buzzer
	Empty			Air conditioning off

6. Conclusion

The mathematical models based on fuzzy logic performed a normalization of the four different variables evaluated – temperature, humidity, gas and light, in order to evaluate the individual index of each quantity and to calculate a global mean index of the environment. Those indexes provided a measure of how close the value measured by the sensors is to the Brazilian standards. The sensor network provided monitoring of quantities in the environment, this is important to provide the best level of comfort and health in places such as laboratory, since out of adequate levels may present lack of concentration, malaise, among other illness to their occupants. Therefore from the indexes a graphic alert scheme was created to inform the laboratory users of the current conditions. The index was developed for a research laboratory but can be applied to any other environment by modifying acceptable limits according to the standard for the specific site. For future work it is intended to include the dust and noise sensors in the evaluation of the quality index. It is also intended to include actuators in the network to automate the indexes when those are at a critical level.

Acknowledgment

The authors would like to thank the Federal University of Maranhão (UFMA), the Graduate Program in Electrical Engineering (PPGEE), the Laboratory of Integrated Systems and Intelligent Control (LABSECI) especially to the Automation Engineer Yan Ferreira da Silva due to the support in the assembly, the Coordination for the Improvement of Higher Education Personnel (CAPES) and CNPq by the financial aid. Due to infra structure support, the authors are thanked to Maranhão State Agency (FAPEMA) to the research support.

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