A Sociometric Sensor Based on Proximity, Movement and Verbal Interaction Detection

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Abstract—This work proposes the development of a sociometric sensor capable of detecting proximity, movement and verbal interaction between people. The sensor will allow measuring the level of existing interrelations between the collaborators of an organization, in order to determine and to measure the organizational climate. The way to evaluate the current organizational climate is subjective, through surveys that are not accurate and that make the results are not adequate. The sensors developed until now focus on proximity or movement, but not on the 3 proposed variables: movement, proximity and speech. The proposed portable device consists of a proximity detector using RSSI (Received Signal Strength Indicator) based on the NodeMCU WIFI ESP 8266 module. It also has a motion detector that uses an accelerometer and finally a voice detection algorithm, acquired via microphone, aimed at determining verbal interaction between people. The validation of the equipment was done by measuring the 3 variables in a sample of 50 people. The results show a percentage of proximity detection of 90% up to a distance of 3 meters between individuals, a percentage of success of 92.5% in the detection of posture and physical activity and a percentage of success of 87.5% in the detection of verbal interaction between people.

***Keywords*- sociometric sensor, RSSI, voice detection, motion detection, proximity detection, organizational climate.**

I. Introduction

The organizational climate is defined as a collective emotional state that is determined by the perceptions that people have about the organizations in which they work and, in turn, these perceptions depend on the interactions that occur between the members of the organization and the activities that take place there. A variable that evaluates the organizational climate is the number of interactions that exist among the members of the organization.

Globally, organizations are betting on organizational climate assessment, as there is a relationship between organizational climate and performance. For example, in Peru, there are at least 27 human management consulting firms that provide organizational climate measurement services. However, none of these services have technological devices to measure interactions in workspaces. Therefore, the imprecision of current methodologies for the evaluation of the study of the work environment, because they are based on the subjectivity of the specialist at the time of taking surveys and focuses mainly on observable experiences. Data collected in surveys and other organizational climate assessment methods are subject to the veracity of the responses and the collaboration of the person being assessed. Therefore, the results obtained from the psychological assessment of the organizational climate are not absolutely accurate and may be biased by the subjective nature of the data.[1].

A solution proposal has been made at the commercial level of products such as Humanyze that was created by students of MIT (Massachusetts Institute of Technology), which offers companies to analyze social interaction data for organizational climate, business optimization processes and work strategy. However, this type of product does not exist in Latin America and is not customized for the research area of verbal interactions

On the other hand, scientific literature has made proposals such as those described below.

Daniel Olguín et al. present in [2] the design, implementation of a device that measures and analyzes human behavior. They propose the use of electronic modules capable of measuring face-to-face interaction, conversation time, physical distance from other people and motor activity in order to measure individual and collective behavior. In addition, his proposal was submitted to an experiment in the Marketing area of a company for a period of one month, in which data was collected for 2200 hours. Each employee was instructed to use them during the workday and that they were subject to a psychological study so that there was no violation of privacy. The experiment yielded results of how employees on the same floor related to other floors. On the other hand, this design has a final weight of 110 grams, which is greater than the proposal put forward.

On the other hand, Oscar Mozos et al. presents in [3] an article that aims to detect stress-related behaviors, analyzing data that are provided by a non-invasive sensor. In this case, a portable sensor is used to record electrodermal activity (EDA) or a photopletismograma (PPG), which are sensors of brain activity in real time. In addition, a sociometric sensor is used to measure social activity including movement of the person and voice. It can be concluded, based on this article, that the development of sociometric sensors is very useful for psychologists because the data are measurable making subsequent evaluations more reliable and above all of higher quality. However, this sensor does not contain a proximity measurement which does not allow us to know how sociable one person is with another.

Trinh Do et al. present in [4] an analysis of the social activities through bluetooth and infrared sensors of 50 people, which used the sociometric sensor for 6 weeks. The article makes 3 important contributions; first they create an algorithm to manage in space-time context the social interactions with the Bluetooth and IR sensor data. Second, an automatic method for defining activities is introduced. And, finally, the article

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presents a case study of interactions in a real organization in which they give real details of the quality of the sensors and that precision can reach the recognition of activities. The presentation of the information is rescued from this article by means of interaction networks in people sensed by Bluetooth and infrared sensors. The final product does not include a voice activity register, which is necessary, since the most common interaction between people is verbal.

Oren Lederman et al. present in [5] a prototype of badge that records social interaction through the RSSI of Bluetooth and a microphone to detect if the person interacts with speech. In addition, they also developed software for phones where they try to reduce the cost of hardware by making the sociometric sensor over the phone. This prototype is very small and has duration of 40 hours. However, it does not have an accelerometer to capture the person's physical activity, nor an SD module to store the information.

Jun Watanabe et al. presents in [6] an approach to the study of the work environment with a sociometric sensor in a call-center company, which demonstrated, through the data recorded by the sociometric sensors, that the level of activity during working hours is not correlated with the performance of the work team. They also came to the conclusion that face-to-face interaction leads to a high level of activities, much more than teamwork. The authors made use of a sociometric sensor and an IR (infrared) module to capture the signals of social interaction and thus be able to make the analysis of organizational climate. However, this proposal consists of two separate modules, so this depends more on the user's use.

Based on the above, this paper proposes a sociometric equipment weighing less than 100 grams, capable of jointly detecting the level of proximity, verbal interaction and motor activity. The acquired information is stored in a microSD memory for later offline analysis. In addition, an important contribution is the exchange of the Bluetooth module for a WIFI module, which offers greater range and the possibility of easily connecting to a base station.

The parts that make up the proposed sensor, as well as the validation and results obtained are described in the following sections.

II. DESCRIPCIÓN DEL MÉTODO PROPUESTO

The good organizational climate generates positive consequences; the main ones are productivity, integration, talent retention and a positive image of the company among others.

The study of the organizational climate provides the specialist psychologist, information to detect the origin of problems such as maladjustment, absenteeism, low productivity and discomfort at work among others.

The sociometric sensor will acquire information on the proximity between the individuals evaluated, the motor activity in the work schedule, the verbal interaction of each one of them and the time in which each variable is recorded. Therefore, the sensor will provide the specialist with very reliable data to improve his interpretation of the organizational climate and take the corresponding corrective actions.

Fig. 1 shows a sociometric sensor acquiring social interaction data in a work area. Note that each person must previously authorize the use of the sensor (for privacy reasons) in order to be able to install it preferably hanging from the neck and attached to the chest.

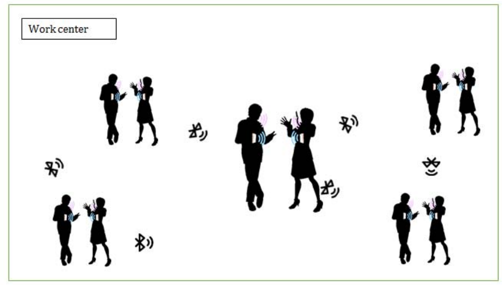

Fig. 1. Final product working in the application scenario.

Fig. 2 shows the block diagram of the proposed sensor. It is important to note that the central processor of the sociometric sensor is a WIFI NodeMCU ESP8266 module that has a clock frequency of $80MHz/160\ MHz$ and a Tensilica Xtensa LX3 CPU. The CPU is 32-bit and ultra-low power [7]. This last one was very taken into account for the choice of the processor since the sociometric sensor is portable and therefore the consumption of energy must be very controlled.

The details of the parts that make up the proposed sensor will be described in the following sections.

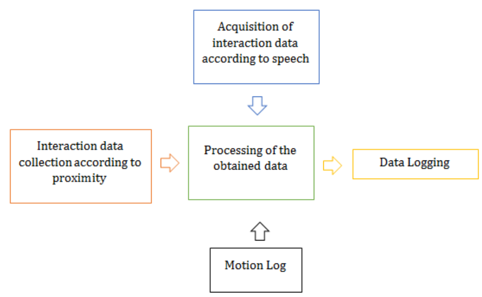

Fig. 2. Block diagram of the proposed system.

A. Proximity data acquisition.

ESP8266 WIFI NodeMCU module enables easier collection of proximity data and saves physical space because it includes a WIFI device and a sufficiently fast processor on the development board.

Proximity is analyzed by obtaining the RSSI that exists between the WIFI modules that each sociometric sensor will possess. The RSSI (Relative Received Signal Strength) is an indicator of the perceived power in a receiver device [8]. The RSSI unit is the decibel-milivatio (dBm) which is calculated using the following expression:

$$dBm = 10 \times \log(P) \quad (1)$$

Where P is received power expressed in milliwatts (mW). Theoretically the value of RSSI in dBm at a distance of d meters is calculated as follows [8]:

$$RSSI_d = -10n \log_{10} d + A \quad (2)$$

Where A is the value of RSSI in dBm in the receiver at a distance of one meter and n the loss constant.

In a real environment, the level of RSSI detected among sociometric sensor is affected by obstacles in the work area. It is for this reason that many times the loss constant n must be measured empirically.

Then the distance between the sensors can be calculated using the following expression [9].

$$d = 10^{-\frac{RSSI-A}{10n}} \tag{3}$$

To map RSSI values to distance values between devices, tests were performed by acquiring RSSI data every 10 seconds so as not to saturate the memory. The acquisition was done at different distances and the values were recorded as shown in Table I. The distances used were 0.5m, 1.5m, 2.5m and 3.5m. This is because an interaction is positive for a distance threshold of 1.5m.

Table II shows the average values resulting from the RSSI samples received for each distance evaluated. A graph of the values in Table II is shown in Fig. 3.

TABLE I. TABLE OF SAMPLES RSSI

Samples/Distance	1	2	3	4	5	6
0.5 m	-49	-50	-48	-51	-50	-51
1.5 m	-53	-53	-53	-54	-53	-52
2.5 m	-58	-58	-57	-56	-55	-57
3.5 m	-61	-62	-60	-62	-61	-60

TABLE II. AVERAGE OF RSSI SAMPLES

Distance (m)	Average
0.5	-50
1.5	-53.1
2.5	-56.6
3.5	-61.1

B. *Acquisition of movement data.*

The acquisition of motion data is obtained through the MPU6050 module which is an IMU (Inertial Measurement Units) with accelerometer and gyro that acquires the change of speed in the 3 axes [10] in order to detect the degree of activity possessed by the user of the sociometric sensor. The data are acquired every 1 second with 16 bits of precision, so as not to saturate the available memory space.

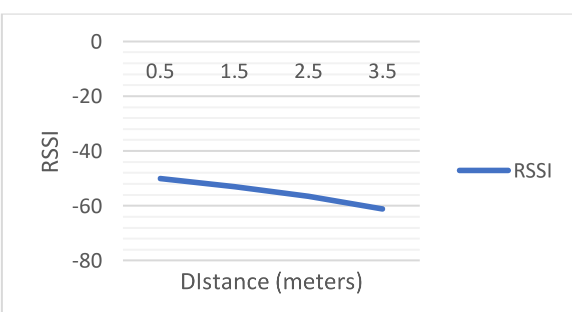

Fig. 3. RSSI vs Distance Graphic.

The flowchart of the motion data acquisition process is shown in Fig. 4. The data is acquired by the central processor of the development board and then stored in text format in SD memory. In this case the information provided by RTC (Real-Time Clock) and the accelerometer of the MPU6050 module is stored.

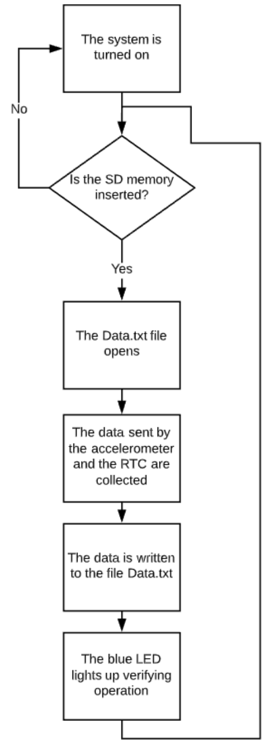

Fig. 4. Flowchart for acquisition and recording of motion data.

Fig. 5 shows the data obtained from the accelerometer. It can be seen that in column A is the time register and in column B the accelerometer data. A movement is considered to have existed when the values of the accelerometer are much higher than those recorded at rest, as can be seen in rows 11 and 12.

	A	B	C	D
1	Fecha	Datos del acelerometro		
2	17:23:07|29/11/18	X= -137 Y= 101 Z= 129		
3	17:23:08|29/11/18	X= -147 Y= 115 Z= 101		
4	17:23:08|29/11/18	X= -143 Y= 77 Z= 102		
5	17:23:09|29/11/18	X= -131 Y= 97 Z= 107		
6	17:23:10|29/11/18	X= -152 Y= 138 Z= 119		
7	17:23:10|29/11/18	X= -170 Y= 105 Z= 98		
8	17:23:11|29/11/18	X= -148 Y= 85 Z= 119		
9	17:23:12|29/11/18	X= -128 Y= 72 Z= 110		
10	17:23:12|29/11/18	X= -164 Y= 110 Z= 108		
11	17:23:13|29/11/18	X= -16999 Y= -829 Z= 2869		
12	17:23:13|29/11/18	X= -2820 Y= -3454 Z= 1270		

Fig. 5. Information provided by the accelerometer.

C. *Verbal Interaction Data Acquisition*

For voice activity detection (VAD), the MAX9814 module was used, which includes an omnidirectional microphone and a low noise amplifier [11].

The microphone of the module was adapted to ensure unidirectionality and avoid interference from signals that do not correspond to voice signals emitted by the user carrying the sensor.

In the acquisition, a window of 50 ms was considered for the taking of each sample sent by the voice module. These samples were digitized by an ADC of 12 bits of precision. Then a block of 18 samples is formed which is processed for the decision of presence or no voice activity, which will be reflected visually every second with the following words: VAD (presence of voice activity) or NO VAD (no presence of voice activity). Two metrics were used for this processing: The short term average energy and zero cross rate of each of the 18 samples. Fig. 6 shows the flowchart for voice activity detection.

The calculation of the short term quadratic energy [11] applied to the 18 samples per block is expressed as:

$$E_{s1}(m) = \sum_{n=m-L+1}^{M} S(n)^2 \qquad (4)$$

$$m = 0,1,2 \ldots..$$

Where m is the block index, (m) is the short term average energy of the block m, (n) is the acquired voice signal and M is the block size. In this case we have $M = 18$.

The number of zero crosses refers to the number of times voice samples change sign in a given time [12]:

$$Z_{s1}(m) = \sum_{n=m-L+1}^{M} \left| \frac{sgn(s(n)) - sgn(s(n-1))}{2} \right| \qquad (5)$$

Where $Z_{s1}(m)$ is the zero cross rate of the block m and $sg(n)$ the function sign.

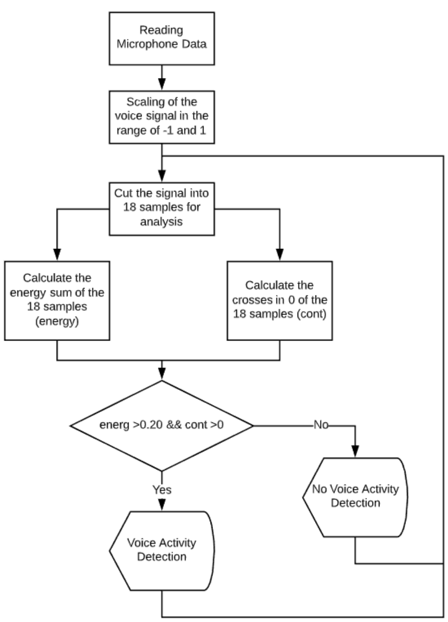

Fig. 6. Verbal Interaction Detection Algorithm Flowchart.

From experimental tests carried out in a working environment, it can be verified that an energy value greater than 0.2 and the presence of at least one crossing by zero is a sufficient condition to determine the presence of voice activity (VAD). Whatever other conditions are present, it will be considered as no voice activity (NO VAD).

A graph of the detection for VAD and NO VAD over time is shown in Fig. 7.

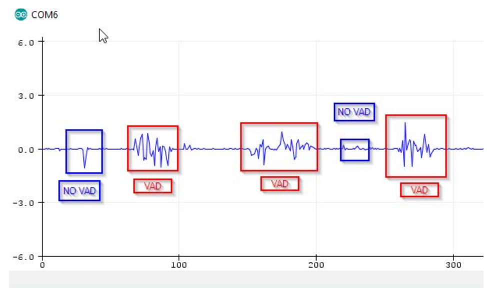

Fig. 7. Speech Detection Differentiation Graph.

D. Data processing and recording.

The algorithms shown in the flow diagrams for proximity detection, motor activity detection, verbal interaction detection and data logging are executed using the CPU of the WIFI NodeMCU module ESP8266.

Data logging is achieved using the DS3231 RTC module and the microSD card adapter. The first module is used to organize information with date and time in real time when the data are acquired. The second module stores proximity, movement and speech information in a text file that is later visualized by the specialist psychologist.

III. Results

For the validation of the sensor, a comparison was made of real data and data sent by the proposed sensor for 40 cases of possible interaction. The comparison was divided into 3 stages: register of motor activity, register of voice activity and register of proximity.

Motor activity detection: These results reflect an individual's activity during working hours. That is to say the time that remains seated, stopped or moving. The sensor in this case detects whether or not there is motor activity. The percentage of error and success obtained is indicated below:

- Number of cases: 40
- Number of hits: 37
- Number of errors: 3

$$\%e_{mov} = \frac{Number\ of\ errors}{Number\ of\ cases} x100 \qquad (6)$$

Where $\%e$ is the motion detection error

With the values obtained in the tests of register of motor activity it was obtained:

$$\%e_{mov} = \frac{3}{40} \times 100 = 7.5\ \% \qquad (7)$$

Then the percentage of success in detecting movement was 92.5 %. The errors presented are mainly due to the sampling times of the information sent by the sensor (1s), i.e. fast movements are often not detected.

Voice activity recording: These results represent the verbal activity of an individual with another individual. The percentage of error and success in the detection of speech was obtained.

- Number of cases: 40
- Number of hits: 35
- Number of errors: 5

The value of the error percentage in voice detection $\%e_{voz}$ is also obtained from (6):

$$e_{voz} = \frac{5}{40} \times 100 = 12.5\ \% \tag{8}$$

The value of the percentage of success in speech detection in this case was 87.5 %. As in the case of motion detection, the adjustments of the sampling times of the sensor information generate some detection errors.

Proximity recording: These results represent the proximity of one individual to another. It was obtained the percentage of error that the sensor has in the proximity metric.

- Number of cases: 20
- Number of hits: 18
- Number of errors: 2

The value of the percentage error in proximity detection $\%e_{prox}$ is also obtained from (9):

$$e_{prox} = \frac{2}{20} \times 100 = 10\ \% \tag{9}$$

The percentage of success in proximity detection in this case is 90%. Proximity errors are mainly due to the presence of obstacles that alter the signal reception level (RSSI) between devices.

Among the 40 cases analyzed, 3 circumstances of data acquisition for the sociometric sensor were established.

Case 1: Possible Interaction, Voice Recording and Close Proximity:

Fig. 8 shows the data acquired by the sociometric sensor.

```
12:21:06 01/07/2019 $ X=-236 Y=-200 Z=65 | VAD
12:21:07 01/07/2019 $ X=87 Y=-214 Z=-805 | VAD
12:21:08 01/07/2019 $ X=-87 Y=631 Z=-39 | VAD
12:21:09 01/07/2019 $ X=-156 Y=298 Z=25 | NO VAD
RSSI
TP-Link_19D6/-59/D8:0D:17:C5:19:D6
ESP_8D4490/-47/86:0D:8E:8D:44:90
WLAN_1D70/-72/98:97:D1:69:1D:72
```

Fig. 8. Data in .txt file provided by the sociometric sensor for case 1.

Case 2: No Interaction, no voice recording and proximity greater than 1.5 meters:

Fig. 9 shows the data acquired for this case by the sociometric sensor.

```
17:05:41 30/06/2019 $ X=-31 Y=135 Z=129 | NO VAD
17:05:42 30/06/2019 $ X=-49 Y=126 Z=130 | NO VAD
17:05:43 30/06/2019 $ X=-40 Y=168 Z=121 | NO VAD
RSSI
TP-Link_19D6/-71/D8:0D:17:C5:19:D6
hhhh/-93/90:8D:78:CD:15:8F
WLAN_1D70/-75/98:97:D1:69:1D:72
ESP_8D25BE/-56/86:0D:8E:8D:25:BE
17:05:46 30/06/2019 $ X=-38 Y=155 Z=108 | NO VAD
17:05:47 30/06/2019 $ X=-36 Y=143 Z=136 | NO VAD
17:05:48 30/06/2019 $ X=-27 Y=151 Z=131 | NO VAD
17:05:49 30/06/2019 $ X=-27 Y=145 Z=129 | NO VAD
```

Fig. 9. Data in .txt file provided by the sociometric sensor for case 2.

Case 3: Possibility of the user speaking alone, voice logging and no one near.

Fig. 10 shows the data acquired for this case by the sociometric sensor.

```
RSSI                                        Nadie cerca
TP-Link_19D6/-60/D8:0D:17:C5:19:D6
19:25:58 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:25:58 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:25:59 29/06/2019 $ X=-1 Y=-1 Z=-1 | VAD
19:26:00 29/06/2019 $ X=-1 Y=-1 Z=-1 | VAD
19:26:01 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:26:02 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:26:03 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:26:04 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:26:05 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
19:26:06 29/06/2019 $ X=-1 Y=-1 Z=-1 | NO VAD
```

Fig. 10. Data in .txt file provided by the sociometric sensor for case 3.

These three cases are the most common ones recorded in a day-to-day assessment of the organizational climate. The main contribution of this work is focused on the coupling of the 3 measurement variables for a more complete evaluation of the organizational climate; in addition to providing a good success rate for such evaluation.

CONCLUSIONS

In this work it was possible to develop a sociometric sensor capable of providing additional reliable information for the decision of the specialist psychologist.

The area of application of organizational climate evaluation can affect, however, in the percentage of success of the proximity detection.

Excessive noise in the evaluation application area could affect the acquisition of voice activity data.

As a future improvement, other hardware modules that improve the current success rate will be evaluated.

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