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IoT PHYSICAL VARIABLES MONITORING FOR ERGONOMIC RISK ASSESMENT OF WORKPLACES

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ABSTRACT

Industrial engineering objective is to increase productivity and seek continuous improvement in every labor task. His focus is on improving working methods, reducing time, increase product quality and minimizing costs, among others. The environmental conditions are very important because they affect the productivity of the workers; physical variables such as: temperature, luminosity, noise, and working postures, condition the worker's degree of comfort with his work station. This satisfaction is reflected in less stress and, therefore, in making less impulsive and more logical decisions, improving quality and performance. In this project, a prototype is design to sense various environmental conditions of ergonomic interest; stores them in a database and allows them to be consulted online. This accomplishes the use of sensors, webcam and the Arduino and Raspberry Pi platforms.
Keywords: Ergonomics, IoT, Raspberry Pi

RESUMEN

La ingeniería industrial desea elevar la productividad en las tareas laborales. Su atención se centra en la mejora de métodos de trabajo, la reducción de tiempos, el incremento de la calidad del producto y la minimización de costos, entre otros. Las condiciones ambientales son de suma importancia porque afectan la productividad del trabajo; variables físicas tales como: temperatura, luminosidad, ruido, y posturas de trabajo, condicionan el grado de comodidad del trabajador con su estación de trabajo. Esta satisfacción se refleja en menor estrés y por lo tanto, en una toma de decisiones menos impulsivas y más lógicas, mejorando la calidad y el rendimiento. En este proyecto se diseña un prototipo que censa diversas condiciones ambientales laborales de interés ergonómico, las almacena en una base de datos y permite consultarlas por internet. Lo anterior se logra utilizando sensores, cámara web y las plataformas Arduino y Raspberry Pi.
Palabras Clave: Ergonomía, IoT, Raspberry Pi

1. INTRODUCTION

The ultimate goal in the design of any workstation is to seek greater productivity from all the factors related to it. However, on numerous occasions, the design of the workstations is done without considering important factors from the ergonomic point of view; this, in the long term, can lead to occupational injuries and illnesses, that is why companies are currently interested, in a more significant way, in the ergonomic assessment of workplaces, however, this task implies a direct observation, on the part of the ergonomist and the use of several measuring instruments, which causes this function to alter the performance of the workers being observed.

The ergonomic assessment of workplaces involves the monitoring of all variables that are related to the work environment, including physical/environmental factors such as temperature, relative humidity, ventilation, noise, illumination; it also includes analysis of physical and mental loads, postures, types of workplaces, tools, unsafe conditions, communication relation between worker and employer, schedules, etc.

Ergonomics is the most important of the improvements that can be made from the scientific work study, because it manages to make physical work more comfortable and safe for the operator [1], as a result, an increase in productivity is achieved.

In [2] it is illustrated, in a graphic way the interrelation between the human being, his psychology and anthropometry, biomechanics, psychomotor skills, tools and controls related to work activities, the design of controls, the workplace, the design of exhibitors, instruments and psychophysical perception, all these factors influenced/affected by the variables constituted by luminosity, ventilation, temperature, noise, postures, etc.

As ergonomics objectives various authors such as [1]-[4] establish:

a) Reduction of occupational injuries and illnesses, consequently reducing compensation to workers, their illnesses and accident costs.
b) Increase the comfort of the worker, seeking to adapt the position and working conditions to the characteristics of the operator.
c) Increase motivation and satisfaction at work, also seeking to reduce work stress.

This article describes the design details of a measurement instrument that takes into account several physical variables at the same time (temperature, relative humidity, luminosity, and noise) generates a data base with the measurements, being able to register when the results come out of the pre-established limits by the ergonomic guidelines, obtaining statistics and publishing them online. It also monitors workplace activities producing video clips and stream the video to internet, ex. Internet of Things (IoT). This means that the ergonomist's interference with the worker is minimal, which does not affect their performance in any way. On the other hand, the process of ergonomic analysis of the workplace is done in a much shorter time and there is a record of all the evidences that support the obtained results.

2. ENVIRONMENTAL VARIABLES

In [5] it is mentioned that the work environment is one of the most significant elements of clear incidence in the behavior, performance and motivation of the worker, affecting him directly in his health, performance and comfort.

In [6] it is presented a checklist of the work environment that allows in an easy way to verify the general conditions of the workplace with an ergonomic approach, to later carry out a more in-depth analysis of the different variables to issue recommendations for improvement based on the guidelines of occupational ergonomics [8]-[16]. The following Sections describe the physical variables being monitored.

2.1. SHT15 Temperature and Humidity Sensor

With regard to temperature, [5] states in his Ergonomics Guide that the relationship of the effect of temperature with the physiology of the operator is as follows:

a) At 10°C appears the physical stiffness in the extremities.
b) At 18°C they are optimal.
c) Physical fatigue appears at 24°C.
d) At 30°C, agility and mental speed are lost; the answers become slow and the errors appear.
e) At 50°C an hour with the above limitation is tolerable.
f) At 70°C they are tolerable for half an hour, but well above the performance of physical or mental activity.

The aforementioned citations says that the worker's optimum internal temperature of 18°C should be correlated with the ambient temperature, which leads to determine the following comfort zones according to the season of the year, in Summer from 18° to 24°C and in Winter from 17° to 22°C. If the type of work activity is also taken into account, the recommended comfortable work temperatures are for sedentary professions 17° to 20°C, for light manual work 15° to 18°C and for heavy work of 12° to 15°C.

A temperature sensor is required to measure this important variable, there is a compact and easy to use temperature and relative humidity sensor from Sensirion; the SHT15 digital humidity and temperature sensor, it is calibrated and offers high precision, long-term stability and low-cost [17].

The device integrates sensor element plus signal processing on a tiny foot print and provide a fully calibrated digital output. A unique capacitive sensor element is used for measuring relative humidity while temperature is measured by a band-gap sensor.

Both sensors are seamlessly coupled to a 14bit analog to digital converter and a serial interface circuit. This results in superior signal quality, a fast response time and insensitivity to external disturbances. Figure 1 shows the SHT15 breakout board.

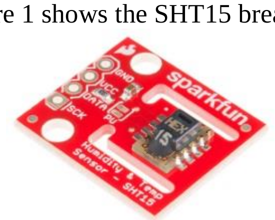

Fig. 1. SHT15 Temperature & Humidity Sensor.

When temperature data is available and analyses are performed, action measures are taken: for example, [7] proposes the most usual preventive measures to manage temperature in workplaces are: first controlling the sources of heat at its source, acting on the environment through natural or artificial ventilation and performing actions on the individual, either rotating him, managing fluid intake and protecting him with the appropriate clothing. Other proposal, [5] says that ventilation, either by natural or artificial means, allows the elimination of accumulated dust in warehouses, dilution of flammable vapors that are concentrated in the operating processes and tempering extreme temperatures of cold or heat, reducing fatigue.

2.2. Microphone ADMP401

In [5] it is mentioned that the effects of noise on work performance can range from a masking effect, in which a sound is not detectable due to the presence of another sound, which results in the effect of bad communication, passing through the impairment of cognitive performance in a minor and temporary degree, decreasing the concentration capacity of the worker and/or producing a subjective discomfort according to the desire or not of the noise, which can lead to demotivation in the workplace due to difficulty in the dialogue, among others.

It is stipulated in [7] that according to the regulations, 8 hours of exposure to a sound level of 85 dB is the permissible limit without harmful consequences for the worker's health, although psychological discomforts may occur that cause the reduction of attention, concentration and interest on the part of the worker.

A sound sensor for this variable is included in the system. The ADMP401 is a high quality, low cost analog output bottom ported omnidirectional MEMS microphone [17]. The device presents a wide frequency response and low current consumption, making it perfect for embedded applications.

This tiny breakout board features the ADMP401 MEMS microphone. One of the key advantages to this breakout and microphone is the bottom ported input. This means the microphone’s input fits flush against the enclosure of the board´s project.

The amplifier on the breakout has a gain of 67 and more than meets the bandwidth requirements of the mic. The amplifier’s AUD output will float at one half Vcc when no sound is being picked up. The amplifier produces a peak-to-peak output of about 200mV when the microphone is held at arm’s length and is being talked into at normal conversational volume levels. So the AUD output can easily be connected to the ADC of a micro. Figure 2 shows the ADMP401 microphone amplifier.

Fig. 2. ADMP401Noise Sensor.

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2.3. TEMT6000 Light Sensor

With regard to the lighting environment, [7] notes that the ability of the visual organs to adapt to non-optimal conditions of lighting brings as a consequence the importance of this factor; even though, more than 80% of the information that workers receive is visual, so here lies the importance of illumination in optimal performance in the workplace.

A very basic light sensor for this variable may be the breakout board for the TEMT6000 Ambient Light Sensor [17]. The sensor contains a photo-transistor - the greater the incoming light, the higher the analog voltage on the signal pin.

The Figure 3 shows the TEMT6000 light sensor.

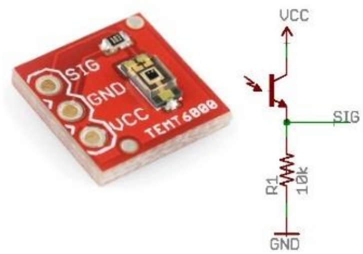

Fig. 3. TEMT6000 Light Sensor.

3. ARDUINO

The sensors describe on the previous Sections contain libraries and/or applications examples to interface with the Arduino Uno platform, which is a dedicated real-time slave processor [18]. The Arduino is a popular, low-cost, and powerful controller that here is used as a very capable companion controller for the Raspberry Pi (RPi). Arduino boards are designed as an introductory platform for embedded systems. It's programmed using the Arduino programming language, in the Arduino development environment (IDE), which are both user friendly.

In this project, Arduino is used as a framework for a Raspberry Pi (RPi) application, as an embedded system slave processor; Arduino contributes with high-speed workload, while still RPi maintains high-level control. Figure 4 shows the hardware elements that include Arduino and sensors.

Fig. 4. Arduino framework for sensing application.

Figure 5 shows the Arduino system and commercial meter instruments that it is substituting: Thermometer/Hygrometer, Decibel meter and Light meter (Luxes).

Fig. 5. Commercial meters substituted by our system.

3.1. Validation

SHT15 is an intelligent device that provides directly to the Arduino a valid temperature and relative humidity. But, both: ADMP401 and TEMT6000 are very basic sensors that don´t provide adequate measurement units: Decibels and Luxes. Polynomial equations were calculated in order to validate our instrument with the commercial ones.

3.1.1 Decibel Meter

Table 1 represents the measurements that were obtained from the ADMP401 sensor (x) and a commercial decibel meter (y) in very diverse conditions.

x is the input and y is the output for the Matlab´s `polyfit` command [19].

Table 1.Validation for Decibel Meter.

Sample	ADMP401(x)	Decibel Meter (y)
1	4	50
2	82	82
3	155	88
4	255	93
5	411	97
6	640	97
7	667	100
8	667	100

An order 3 polynomial equation was the best behave one, as shown in equation (1).

$$y = 8.2165e^{-7}x^3 - 0.0010x^2 + 0.3844x + 51.0603 \qquad (1)$$

Figure 6 shows the comparison between the commercial Decibel Meter and the validation polynomial.

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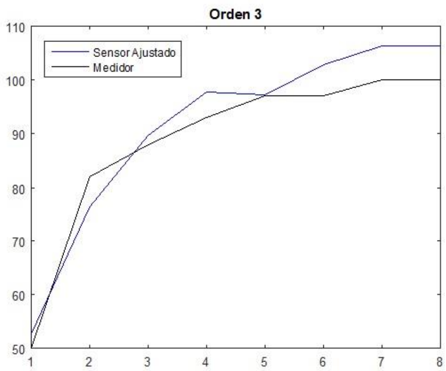

Fig. 6. Comparison Decibel Meter and polynomial.

3.1.2 Lux Meter

Table 2 represents the measurements that were obtained from the TEMT6000 sensor (*x*) and a commercial lux meter (*y*) in very diverse conditions.

x is the input and *y* is the output for the Matlab´s polyfit command [19].

Table 2.Validation for Lux Meter.

Sample	TEMT6000 (*x*)	Lux Meter (*y*)
1	23	42
2	55	119
3	75	203
4	120	325
5	170	765
6	245	852
7	430	1030

An order 3 polynomial equation was the best behave one, see equation (2).

$$y = -2.5503e^{-5}x^3 + 0.0095x^2 + 3.1870x - 64.4382 \quad (2)$$

Figure 7 shows the comparison between the commercial Lux Meter and the validation polynomial.

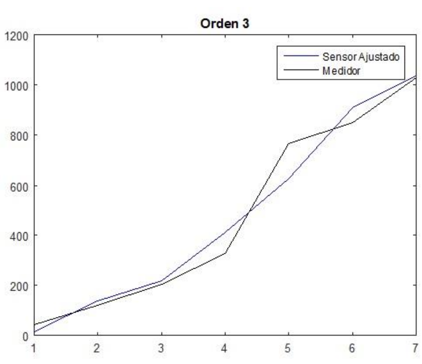

Fig. 7. Comparison Lux Meter and polynomial.

3.2 Serial Interfacing

Arduino is effectively interfaced to the Raspberry Pi using UART serial. UART connection between the Arduino and RPi is the most straightforward method of establishing a slave-processor framework [18].

4. RASPBERRY PI

Raspberry Pi offers an embedded operating system version of Linux, called Raspbian, it contains a vast amount of software and device drivers that are freely available [20].

The RPi is also capable of handle physical computing devices, as the Arduino embedded system thru UART communication interface, C language and for internet-attached applications.

4.1 WiringPi

WiringPi is an extensive GPIO control library for the RPi platform; this is written and maintained by Gordon Henderson [21]. The library function syntax is similar to that in the Arduino Wiring library, and it is a popular choice among RPi users. The wiringPi library also has third-party bindings for Python, Ruby, and Perl.

WiringPi utilizes the sysfs and memory-mapped techniques to create a highly efficient library and command set that have been custom developed for the RPi platform.

WiringPi contains also a comprehensive library of C functions for controlling RPi on-board serial communication port by means of the wiringSerial specific library. Functions as: `serialOpen`, `serialFlush`, `serialDataAvail`, `serialGetchar`, `serialClose`, etc. are very useful to read data form the Arduino, which is sending sensor measurement continuously.

4.2 LAMP

LAMP is a web development platform that uses Linux as the operating system, Apache as a web HTTP server, MySQL as a relational database management system and PHP as an object-oriented programming language.

Linux is a Unix-like computer operating system assembled under the model of free and open source software development and distribution.

The Apache server is an open-source platform that implements HTTP protocols for the creation of internet sites. The Apache web server is a lightweight server that has an overhead that is suitable for running on the RPi. Running a web server on the RPi provides it with a number of application possibilities, including the following:

a) Present general web content to the world.
b) Integrate sensors and display their values to the world.
c) Integrate sensors and use it to intercommunicate between devices.
d) Provide web-based interfaces to tools that are running on the RPi.

MySQL is an open source multi-thread and multi-user relational database management system (RDBMS), based on structured query language (SQL) [22][23]. MySQL runs on virtually all platforms, including of course Linux. Although it can be used in a wide range of applications, MySQL is associated with web-based applications and online publishing

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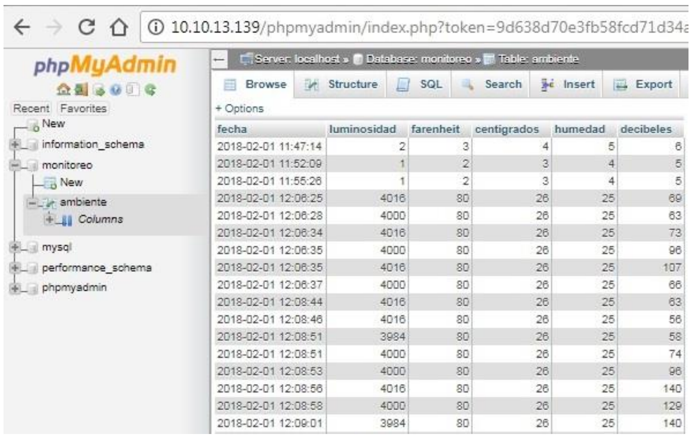
and it is an important component of the LAMP open-source business stack.
To support database administration, the phpMyAdmin application was installed (Figure 8), it is a free tool and it is programmed in PHP.



fecha	luminosidad	farenheit	centigrados	humedad	decibeles
2018-02-01 11:47:14	2	3	4	5	6
2018-02-01 11:52:09	1	2	3	4	5
2018-02-01 11:55:26	1	2	3	4	5
2018-02-01 12:06:25	4016	80	26	25	69
2018-02-01 12:06:28	4000	80	26	25	63
2018-02-01 12:06:34	4016	80	26	25	73
2018-02-01 12:06:35	4000	80	26	25	96
2018-02-01 12:06:35	4016	80	26	25	107
2018-02-01 12:06:37	4000	80	26	25	66
2018-02-01 12:08:44	4016	80	26	25	63
2018-02-01 12:08:46	4016	80	26	25	56
2018-02-01 12:08:51	3984	80	26	25	58
2018-02-01 12:08:51	4000	80	26	25	74
2018-02-01 12:08:53	4000	80	26	25	96
2018-02-01 12:08:56	4016	80	26	25	140
2018-02-01 12:08:58	4000	80	26	25	129
2018-02-01 12:09:01	3984	80	26	25	140

Fig. 8. phpMyAdmin.

To store the information that is being collected with the prototype, a database was created in MariaDB [24].
PHP (Hypertext Preprocessor) is a server-side scripting language designed for web development but also used as a general-purpose programming language. PHP code is interpreted by a web server via a PHP processor module, which generates the resulting web page. PHP commands are embedded directly into an HTML source document or it can call an external file to process data. Also it includes a command-line interface capability and is used in standalone graphical applications.

4.3 Motion

A webcam was attached to the RPi so that it can be used for capturing video data using low-level Linux drivers and the Motion application program. The RPi and Logitech C920 webcam (Figure 9) is used for workplace monitoring; the RPi is a platform for capturing high-quality video and saving the data on the RPi file system, .avi format. The durations of the video streams are limited only by the available storage.
Motion is a is a highly configurable program that monitors the video signal from many type of cameras and is able to detect if a significant part of the picture has changed [25], in other words, it can detect motion.

Fig. 9. Webcam Logitech C920.

4.4 IoT

The Raspberry Pi is used here as a core building block of the Internet of Things (IoT). In this research, the networking programming, the IoT, the connection of sensors (thru Arduino) and the webcam workplace monitoring to the internet were developed. Communication architecture configures the RPi to be a web server and uses various server-side scripting techniques to display sensor data and streamed video.
The IoT concept envisions that if physical sensors and actuators can be linked to the Internet, then a whole broad range of applications and services are possible.
The switches and routers to communicate the Raspberry Pi to the internet and the local network, as well as the HTTP protocol with the Apache server, in order to create an application to show the information to the end user.
By storing the data generated by the sensors in a database in MySQL, allows the best use and analysis for decision making by the user.
The programming of a script in PHP allows creating the graph results in a web page with the Apache server. With the information stored in the database we proceeded to graph the data, with code developed in PHP, and the script creates CANVAS JS graphics, obtaining four different graphs, one for each sensor to be analyzed.
Figure 10 shows the data obtained during the time in which the tests were performed.

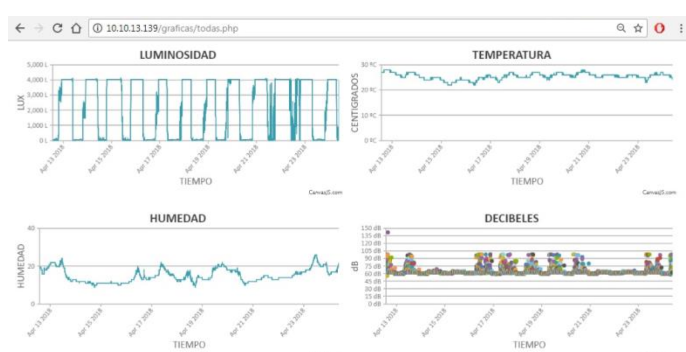


Fig. 10. Physical variables.

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Also RPi is used to capture and stream live video. The Logitech C920 camera is particularly useful for this purpose, as it has built-in H.264 hardware support. The raw 1080p H.264 data can be passed directly from the camera stream to the network without transcoding, which means that the computational load on the RPi is reasonably low. Figure 11 shows an area being internet monitored.

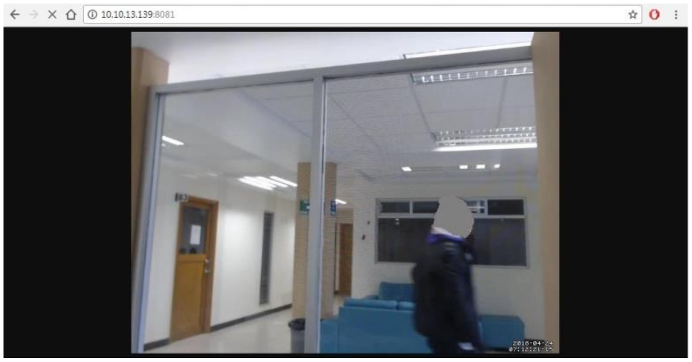

Fig. 11. Workplace monitoring.

5. TRACING & STORAGE CONSIDERATIONS

The four environmental values (Centigrade, Farenheit, Humidity and Lux) are measured every .5 sec and averaged into a 2 minutes period (50 samples) because of their slow change nature; however the Decibel value, which change suddenly, only the higher value of the 50 samples is stored in the same period. There are 30 Registers into the Data Base with 1.61KB storage for the five measurements into a one hour. The .avi video file stored for the Motion program with a 640x480 resolution and mpeg4 codec occupies 3.6MB for one minute. So, the measurements performed every 2 minutes are good enough for the tracing of the environmental working conditions, and the storage required for the system doesn´t compromise the RPi resources.

6. CONCLUSIONS

This paper presented a prototype able to read sensors thru Arduino, and the configuration of a web server on a RPi providing a simple and intuitive way to present useful ergonomics information to an analyst client web browser application. So, when retrieving a web page from the RPi using its Apache web server, a user's desktop computer's web browser is a client of the RPi's web server.

The main contribution of this work was the organization of all the required elements needed to the implementation of the software communication architecture used to realize the IoT monitoring of environmental ergonomic interest physical variables as was described on the paper.

The RPi web server is an RPi that is connected to an Arduino, which in turn, is reading data from sensor; it´s running a web server that is used to present information to the web when it is requested to do so by a web browser. Communications take place using the Hypertext Transfer Protocol (HTTP).

The desktop web client is a computer that initiates contact with a web server using HTTP requests to receive data from sensors and may visualize stored information.

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7. REFERENCES

[1] J.A. Cruelles, Ingeniería Industrial: Métodos de trabajo, tiempos y su aplicación a la planificación y a la mejora continua. México, Alfaomega, 2013.
[2] S.J. Bradley, H. Kilduff, & D.S. Bloswick, Ergonomía en la Fabricación, MAYNARD, Manual del Ingeniero Industrial, McGraw Hill Quinta Edición, 2005, pp. 6.57-6.82.
[3] J.P. Becker, Plan Integral para el Desarrollo del Proceso Ergonómico. Medellin, Colombia, Ergon, 2007.
[4] C. Roth, Diseño, Implementación y Justificación de un Programa Ergonómico, MAYNARD, Manual del Ingeniero Industrial, McGraw Hill, Quinta Edición, 2005, pp. 6.9- 6.40.
[5] C. Ramírez, Ergonomía y Productividad, México, Limusa 2a. Ed., 2008.
[6] B. Niebel & A. Freivalds, Methods, Standards & Work Design, McGraw-Hill 10th Edition, 1999.
[7] P.R. Mondelo, E. Gregori, J. Blasco & P. Barrau, Ergonomía 3: Diseño de puestos de Trabajo, México, D.F., Alfaomega 2da. Edición, 2001.
[8] L.J. Bannon, From Human Factors to Human Actors. The role of Psichology and Human-Computer Interaction studies in System Design. Design at Work: Cooperative design of computer systems, Lawrence Enbaun Associates, 1991, pp. 25-44.
[9] D. Cerovec & J.R. Wilk, Herramientas de Evaluación Ergonómica para el análisis del trabajo, MAYNARD. Manual del Ingeniero Industrial, McGraw Hill Quinta Edición. 2005, pp. 6.219-6.244.
[10] J.A. Cruz & A. Garnica, Ergonomía Aplicada. Bogotá, Colombia, Starbook Editorial, 2011.
[11] M. Endley, Measurement of situation awareness in Dynamic Systems, Human Factors, Vol. 37, Num. 1, 1995, pp. 65-84.
[12] P.R. Mondelo, E. Gregori, S. Comas, E. Castejon & E. Bartolome, Ergonomía 2: Confort y estrés térmico, México, D.F., Alfaomega 3era. Edición, 2001.
[13] P.R. Mondelo, E. Gregori, O. González & M.A. Gómez, Ergonomía 4: El Trabajo en oficinas, México, D.F., Alfaomega, 2002.
[14] M. Parraga, Importancia del diseño de la estación de trabajo y la buena postura. Industrial Data, ©UNMSM, Facultad de Ingeniería Industrial, Vol. 4, Num. 1, 2001, pp. 51-53.
[15] J. Reason, Understanding adverse events: Human Factors, Quality in Health Care, Vol. 4, 1995, pp. 80-89.
[16] G. Salvendy, Handbook of Human Factors and Ergonomics, Wiley John Wiley & Sons, Inc, 2012.
[17] Sparkfun, Available on: www.sparkfun.com, Visited: 07/06/18
[18] Arduino, Available on: www.arduino.cc, Visited: 07/06/18
[19] Matworks, Available on: www.mathworks.com, Visited: 07/06/18
[20] Raspberry Pi, Available on: www.raspberrypi.org, Visited: 07/06/18
[21] Wiring PI, Available on: www.wiringpi.com, Visited: 07/06/18
[22] Ch. Fehily, SQL Database Programming, San Francisco, Questing Vole Press, 2015.
[23] A. Silberschatz, H.Y. Korth, S. Sudarshan, Fundamentos de Bases de Datos, McGraw-Hill 5a. Edición, 2006.
[24] Maria DB, Available on: www.mariadb.org, Visited: 07/06/18
[25] Motion Project, Available on: https://motion-project.github.io/index.html, Visited: 07/06/18