Hardware Design and Building of Industrial Environment Monitoring System

**Abstract:** In the present work, an industrial environment monitoring system hardware design is presented and successfully physically prototyped and tested. The system is designed to monitor, track, assess and register pollution sources levels, environment state and conditions in an industrial manufacturing factory. The suggested design is intended to ensure acceptable quality of industrial manufacturing factory's environment, to maintain safety of personnel, material and machinery, as well as, to result in more optimized factory operation. Hardware designs were accomplished utilizing the modern advances in different engineering fields including sensing, data processing and transmission. The suggested design consists of three main parts; the wireless sensor module for reading the state and condition of environmental parameters including pollution levels, the main control unit for data processing and decision making, and the wireless final control circuit for activating and deactivating the actuators. Each of these systems and subsystems was physically built and successfully tested. The optimal, acceptable and dangerous levels and limits of most of the parameters were identified and experimentally tested.

**Keywords:** Environment monitoring, smart system, Wireless communication, Design.

**INTRODUCTION**

Nowadays it is an essential industrial requirement to use the latest technology to save humans, machines and systems. Technologies have contributed many great things to people to enhance the human well-being in mainly four aspects; luxury, security, safety, and economy. Alongside with the industrial greatness, there are many negative impacts that considered harmful to world climate, the local production environment and human health. One of the main negative impacts is the industrial pollution. The industrial pollution affects not only human health but also the environmental resources; it is considered the root cause of many disease such as asthma, infant mortality, lung cancer and cardiovascular diseases.

The monitoring and registration of industrial environment with purpose of improvement of environment quality, can not only save humans, machines and systems, but also can increase the comfort, decrease adverse health effects, decrease absence rates, and increase the work and school work performance. The health benefits resulted from improving the quality of industrial working environment are discussed widely in [1][2]. It is of a great need, to suggest a dependable design of a remote industrial environment monitoring and registration system that will result in improved industrial environment quality, more optimized factory operation and in an acceptable manufacturing practice.

The present work extends writer’s previous work [3] and is developed with the aim to suggest a hardware design and building of a reliable and at low cost, of an industrial environment monitoring system. The suggested design is developed by utilizing the interdisciplinary advances in different engineering fields and is focused on enhancing the industrial environment system capabilities to include not only monitoring, tracking and registering of the pollution's sources’ levels in industrial manufacturing factory, but also providing an acceptable quality of factory's environment, ensure the factory’s industrial environment quality within an acceptable range, maintain the safety of workers, material and machinery.

Industrial Environment Monitoring (IMO) is a process where data about the current industrial environment state and conditions are collected, processed and compared to desired optimal references to suggest corrective actions to maintain the optimal environmental healthy levels. The data usually include information about Air quality, water quality, Light, Temperature, Humidity, Noise, combustible Gases levels and others.
LITERATURE REVIEW

Industrial environment monitoring system has been studied in a number of researches to study, evaluate, monitor, track and control pollution parameters values. In [4] authors suggested the use of an online pollution monitoring approach via MYSQL. Their approach was targeting controlling pollution caused by untreated disposal of waste. Both a website and an android application were developed to enhance the approach reliability. With the help of several sensors. In [5] authors described their design as an operative prototype based on Internet of Things (IoT) concepts for real time monitoring of various environmental conditions. In [6] covered the industrial air pollution monitoring system design through wireless sensor network. This design enables sensed readings to be send in a timely manner accompanied appropriate corrective action whenever pollution occurs. The substances that were covered in the study are ozone, particulate matter, sulphur oxides, nitrogen oxides, carbon monoxide, and lead. In [7], the authors suggested a design to minimize the problem of cost and regular pollution inspections using Labview and GSM. The advantage of this design are the ability to control the sources causing pollution and to minimize the effect of pollution without affecting the surrounding environment. In [8], to make sure that a healthy environment is provided to workers, authors suggested a robust system that has two main advantages: measuring industrial pollution and helping to decrease human interference in monitoring the industrial pollution. This system is functioned with continuous monitoring capabilities to make decision makers take proper correction actions using IoT technology. In [9], a low-cost environment monitoring system was introduced using IoT. In their study, was confirmed that IoT based platform is trustworthy approach to environment parameter monitoring. The transmission was achieved by data sensors to an API called ThingSpeak utilizing an HTTP protocol. In [10], design of environment monitoring and control system introduced to cover both monitoring and control. The monitoring was done using wireless sensor networks for reading the surrounding environment parameters such as the pressure temperature, and humidity. The control part of the system was achieved by utilizing ARM11 raspberry pi board. In [11], heavy metal concentrations of Al, As, Cd, Cu, Fe, Hg, Pb and Zn in colostrums and meconium were checked and found to be higher in samples from the industrial district than the non-industrial district. In [10], PM presence and concentration per unit volume were checked in air samples using the Equal Pay Act-29 technique, using Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS) and cold vapor Atomic Absorption Spectroscopy. The colostrum and meconium samples were analyzed using ICP-MS and Inductively Coupled Plasma Optical-Emission Spectroscopy. These findings show that industrial pollution has to be treated without delay to reduce air pollution and improve the public health. In [12], another research focused on measurement system to greenhouse gases (GHG) monitoring. GHGs are created from the emission of Carbon Dioxide (CO2) and Methane (CH4) from vehicles and near located landfills. In this design, a wireless system is developed using MOS sensors (MQ2, MQ4, TGS2611 and MQ-135), Arduino-nano, XBee wireless communications modules and the interface to the computer is written in Python. After testing procedure in a real field has been completed, results show that gas concentration difference in different points of the city. Due to lack of real-time water quality monitoring program in Egypt, [13] suggested a low-cost Early Warning Framework (EWF) to monitor the River Nile based on the Internet of Things (IOT). This process is conducted thorough physio-chemical and biological analyses. The suggested prototype main goal is to monitor the in-situ water quality parameters, pH, turbidity and temperature at different location along the River Nile within Egypt. On the other hand, the same parameters were also monitored using different method, the current state-of-the-art multi-probe EXO. After that, the comparison phase where both sets of data measurements were compared for differences. The results showed that there is no significant difference between the two measurements. In [14], authors reviewed the studies used different kinds of environmental sensors and highlighted related techniques to provide ideas that have the potential to drive an accurate pollution monitoring technique for the future usages. In [15], the design utilized different engineering concepts obtained from various engineering fields to suggest a new industrial environment monitoring system design that featured with a real time, reliable and efficient capabilities. The communication and control systems. In [16] for monitoring the indoor and outdoor of the environmental parameters are as follows; MemsicECO Pro wireless sensors network, Siemens PLCs and HMI devices.

The present work is organized into five sections including as follows; Section 1; provides introduction and design methodology. In section 2; system configuration, hardware design and integration. In section 3; control algorithm design and representation. In section 4; system experimental, testing, prototyping and evaluation. Finally Results, Discussion and Conclusions

METHODOLOGY AND WORKING PRINCIPLE

The suggested, in this work, design is intended for manufacturing industries, but also can be expanded to be applied to any industrial zone. The overall system and subsystems design integration, working principle and data flow, are represented using block diagram in Figure 1(a), the basic modules and components layout.
are depicted pictorially in Figure 1(b). The system consists of three main parts; wireless sensor nodes for reading the environment state and conditions. The main control unit for data processing and decision making, and the wireless final control circuits for activating and deactivating the actuators.

The design is developed around utilizing a group of specially designed wireless sensor nodes to read and monitor the industrial zone environmental state, conditions and pollution’s sources and levels in terms of information about air quality, water quality, Light, Temperature, Humidity, Noise, and combustible Gases levels. The gathered data is wirelessly transmitted to main control unit that is programmed with control algorithm to process the data, compared it to desired optimal references to suggest corrective actions to maintain the optimal environmental healthy levels, as well as, take notification and alerting actions. The decisions taken are transmitted wirelessly to the specially designed wireless final control circuits, to activate and deactivate the actuators that in turn adjust the industrial environment to maintain desired acceptable levels. The control algorithm is written such that the data about the environmental state are displayed on an LCD, also in case an environmental state meets critical condition, light LED and soft sound indicators are activated, with the LCD displaying the value and send an alerting notification to supervisor and/or personnel.

Short range wireless communication using radio transceivers or by wifi communications are utilized for wireless communications between sensor nodes, main control unit and final control circuit. Real time methodology in terms the data reading, processing, decision taking and implementing is to be applied.

The permissible amounts of harmful industries outputs

For world and working industrial ambient environment, the permissible amount of harmful industries outputs have been quantified, regulations are set by organizations like the world health organization (WHO) and occupational safety and health administration (OSHA). Table 1 show an example on pollution standards and guidelines of ambient air quality; it is shows comparison standards and guidelines as compared with recommendations of the (WHO) [17]. Table 2 shows examples on the acceptable limits of environmental factors and there units. In Table 3, are shown the pollutant, the permissible amounts and limit and the effect of exposing to this pollutant. The table was extracted from an official document from Saudi Arabia, Presidency of Meteorology and Environment, called. “These General Environmental Regulations and Its Rules For Implementation”. The main purpose of these standards is to provide appropriate guidelines for the evaluation and regulation of existing industrial activities. These guidelines will in help in the planning, design, implementation and operation of the industrial facilities and that to promote the health and safety of the people and the Kingdom’s environment in general. In section 3, when carrying the experimental testing of the physically built subsystems, these permissible amounts, ranges and limits for specific cases, are to be listed and discussed.

### Table 1: As an example on pollution standards [3]

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>WHO</th>
<th>EU</th>
<th>Australia</th>
<th>USA</th>
<th>Canada</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>NO2</td>
<td>21</td>
<td>21</td>
<td>30</td>
<td>53</td>
<td>53</td>
</tr>
<tr>
<td>Ozone(O3)</td>
<td>50</td>
<td>60</td>
<td>80</td>
<td>80</td>
<td>65</td>
</tr>
<tr>
<td>SO2</td>
<td>50</td>
<td>48</td>
<td>80</td>
<td>140</td>
<td>115</td>
</tr>
<tr>
<td>PM25</td>
<td>25</td>
<td>50</td>
<td>25</td>
<td>65</td>
<td>30</td>
</tr>
<tr>
<td>PM10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>-</td>
<td>0.5</td>
<td>0.5</td>
<td>1.5</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: A dash (–) indicates that no standard or guideline has been established for a particular parameter

### Table 2: The acceptable limits of environmental factors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>limits of acceptable values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>18 :24</td>
</tr>
<tr>
<td>Humidity</td>
<td>40:60</td>
</tr>
<tr>
<td>Noise level</td>
<td>50: 80</td>
</tr>
<tr>
<td>CO2</td>
<td>400 :800</td>
</tr>
<tr>
<td>Illuminance</td>
<td>250: 1000</td>
</tr>
</tbody>
</table>
Table 3:

<table>
<thead>
<tr>
<th>Air Pollutants:</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 days</td>
</tr>
<tr>
<td></td>
<td>12 months</td>
</tr>
<tr>
<td>Sulfur dioxide (SO2)</td>
<td>One-hour average SO2 shall not exceed 730 microgram/m³ (0.28 ppm) more than twice at any location.</td>
</tr>
<tr>
<td>Inhalable Suspended Particulates</td>
<td>One-hour average concentration shall not exceed 295 microgram/cubic meter (0.15 ppm) more than twice at any location.</td>
</tr>
<tr>
<td>Photochemical Oxidants Defined as Ozone</td>
<td>One-hour average NO2 concentration shall not exceed 660 microgram/cubic meter (0.35 ppm) more than twice at any location.</td>
</tr>
<tr>
<td>Nitrogen oxides defined as nitrogen dioxide (NO2)</td>
<td>(1) One-hour average Carbon monoxide concentration shall not exceed 40 milligram/cubic meter (35 ppm) more than twice at any location. (2) Eight (08) hour average Carbon monoxide concentration shall not exceed 10 milligram/cubic meter (09 ppm) more than twice at any location.</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Hydrogen sulfide (H2S): One-hour average H2S concentration shall not exceed 200 microgram/cubic meter (0.14 ppm) more than once at any location.</td>
</tr>
<tr>
<td>Fluorides (F-)</td>
<td>The monthly average fluoride concentrations shall not exceed 1.0 microgram/cubic meter (0.001 ppm) at any location.</td>
</tr>
</tbody>
</table>

System configuration, hardware design and integration

Overall system design and integration

The wireless sensor nodes are employed to detect, and read the environmental state and pollution levels in terms of each of the following: Air (Light, Humidity, Temperature, combustible Gases), Water (the PH level and Turbidity level), vibration, Noise, in addition, thermal Pollutions. The data readings are collected from different locations in the industrial workshop, wireless sensor modules are placed in the most suitable locations to detect and read the data. Examples on suggested sensor modules placement can be: a) beside pollution sources (e.g. fuels combustion, gases, noise), b) in a location that can reflect the pollution source impact on overall factory environment (e.g. factory ceiling to read gases or illumination levels).

The final control circuit for activating and deactivating the actuators can be placed near the actuators and power sources, to result in more efficient behavior.

System hardware design

The selected hardware for physical building of subsystems and overall system prototype including wireless transmitters, main control unit and wireless final control circuit are to be presented in this part. The hardware is to be selected voltage based, operating on 5VDC, miniaturized and easy to program and interface.

For measuring the ambient illumination level, the shown in Figure 2(a), LDR with voltage divider circuit or the shown in Figure 2(b) TEMT6000 phototransistor ambient light sensor are selected. For measuring the ambient Temperature, the shown in Figure 2(c) DHT11 Temperature and Humidity is selected, meanwhile for measuring the water temperature, the waterproof DS18B20 sensor shown in Figure 2 (d) is selected. The MQ-2, MQ-5 or MQ-7 gas sensors modules from EleSof Technologies can be employed to measured the concentration levels of the next ingredients in the ambient atmosphere; liquefied petroleum gas, LPG, carbon monoxide (CO) and smoke, in addition to these sensors, the MG-811 CO2 Sensor Module can be used, the selected for this work is the shown in Figure 2(e) MQ5 Sensor and the shown in Figure 2(f) MG-811 CO2 Sensor Module.

For measuring the ambient sound level, a simple option is the sound detection sensor module shown in Figure 2(e). For vibration level measuring at workshop location, the triple axis ADXL335 contact accelerometer shown in Figure 2(f) is employed. The dust particles level in the air can be read using optical
smoke and Dust Sensor GP2Y1010AU0F shown with wiring circuit in Figure 2(g). For measuring the water quality in terms of Turbidity level the shown in Figure 2(h) Turbidity level Sensors is selected. Pollution levels in water/solution in terms of pH levels is measured using the PHE-45P pH Sensor Model shown in Figure 2(i).

A suitable microcontroller-based control board for main control unit, that comes with 25 digital and analog I/O ports and wireless communication including transceiving capabilities, is the shown in Figure 2(j) Arduino due board. For both wireless sensor nodes and wireless final control circuit, the Arduino Nano board, shown in Figure 2(k), is a good choice.

The wireless communication between sensor nodes, main control unit and final control circuit, can be done via wireless Radio, Wifi, or GSM Communication. The radio wireless communication using, the shown in Figure 2(l), NRF24L01 transceiver module with range up to 1100 m is a good option.

Figure 1(a) the overall system working principle, data flow between its three main parts

Figure 1(b) Pictorial representation showing the overall monitoring system integration of all hardware, subsystems and components in one system prototype [3].

<table>
<thead>
<tr>
<th>Figure 2(a) illumination level using LDR and circuit</th>
<th>Figure 2(b) illumination level by TEMT6000 Light Sensor</th>
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<tbody>
<tr>
<td>Figure 2(c) DHT11 Temp. and Humidity sensor</td>
<td>Figure 2(d) Temp. waterproof DS18B20 sensor</td>
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</tbody>
</table>
## Experimental set up, Subsystems’ Hardware building and integration

To evaluate the selection and operation of each and all physically developed subsystems and components, as well as, its hardware and software integration, each of the subsystems, modules, components and circuits is physically built and experimentally tested. The theoretical designs, with corresponding physically built module, the testing processes and results are discussed in the section. In addition, to monitor, track, assess and register pollution’s sources states and conditions, the conditions limits of each measured variables are to be read and set in terms of: the optimal range, acceptable range, not acceptable range (soft alarm) and dangerous level (harsh alarm).

The overall system, subsystems and components hardware validation and experimental set up are shown in Figure 3(a). The pictorial representation of the main control unit, its suggested theoretical housing design and components layout is shown Figure 3(b), meanwhile in Figure 3(c) is shown, the experimental setup for testing and evaluating its operation. In Figure 3(d), is shown an example on suggested theoretical design and building of wireless sensor node, in particular, wireless node for measuring ambient temperature meanwhile the experimental setup for testing and evaluation its operation is shown in Figure 3(e). Another example on building wireless sensor node is the shown in Figure 3(f) for vibration measuring.

Final control elements are responsible for implementing the changes in the ambient environment state and conditions in terms to meet desired levels of ventilation, lighting, alarming and others. To activate the actuators, wireless final control interface module is developed. The simplest such model is the wireless relay interface module, for activating and deactivating any AC or DC based load shown in Figure 4(a). An example on theoretical design for building wireless relay interface module, in particular, interface circuit for activating sound alarm is pictorially represented in Figure 4(b). Meanwhile the built wireless module is shown in Figure 4(c). Wireless final control interface module for controlling light alarms is shown in Figure 4(d). In Figure 4(e) is shown the physically built wireless final control interface module for controlling electric motor motion in two directions. All other wireless actuator interface circuits were built in similar way.

<table>
<thead>
<tr>
<th>Figure 2(e)</th>
<th>MQ5 gas Sensors</th>
<th>Figure 2(f)</th>
<th>MG-811 CO2 Sensor Module</th>
</tr>
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<tbody>
<tr>
<td>Figure 2(e)</td>
<td>Sound Detection Sensor Module</td>
<td>Figure 2(f)</td>
<td>3-axis ADXL335 accelerometer</td>
</tr>
<tr>
<td>Figure 2(g)</td>
<td>Smoke and Dust Sensor with circuit diagram [18]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Figure 2(h)</td>
<td>Turbidity level Sensors</td>
<td>Figure 2(i)</td>
<td>PHE-45P pH Sensor Module</td>
</tr>
<tr>
<td>Figure 2(j)</td>
<td>Arduino due board</td>
<td>Figure 2(k)</td>
<td>Arduino Nano board</td>
</tr>
</tbody>
</table>
Figure 3(a) system validation and hardware experimental set up

Figure 3(b) suggested housing design and components layout for main control unit.[3]

Figure 3(c) experimental set up for testing the main control unit and components

Figure 3(d) Example on design for building wireless temperature module. [3]

Figure 3(e) the built wireless node for temperature measuring

Figure 3(f) the built wireless node for vibration measuring
Control algorithm design and representation

To monitor and assess the industrial environmental state and conditions in an industrial location site, each wireless sensor node is to read a value(s) assigned to it e.g., temperature, humidity and other industries harmful outputs (e.g. CO, PH and vibration), this value is to be wirelessly transmitted to main control unit. The transmitted data readings by all wireless sensor nodes, from industrial location site, are sent to the main control unit. The main control unit is programmed to read all the transmitted data, process, and compare its value to the identified ranges, and based on this, take corresponding decision(s) and send control signal(s) to corresponding actuator(s) to make needed adjustments. In addition to this, display these readings on LCDs, in case of environmental state meets critical conditions notify supervisor and personnel using sound and light alarms. For example; if the read value that represent one
environmental variable (e.g. temperature or dust level) is within the acceptable range or not?, if it is not!, a corresponding control signal will be send to the ventilation and fan system to reduce the temperature and dust levels to the optimal levels, then switch off ventilation and fan system.

The control algorithm is written to allow the main control unit, to read, save and process all the transmitted data from all wireless sensors modules. A matrix is generated with length equal to number of sensors nodes and variables measured; the main control unit reads each transmitted reading, save it to assigned matrix address, waits a specific time e.g. 2 ms, then read the following transmitted value, save it in another assigned matrix address, waits 2 ms, this will be repeated until the last value is read and saved, then each saved value will be compared to the identified limits and based on results take corresponding decisions and send control signal to corresponding final control element to make needed adjustment, the algorithm then waits for a finite time, and repeat the whole process. The algorithm flowchart representation is shown in Figure 5. Since most of the employed final control elements/actuators are of ON/OFF types, a suitable and applied control algorithm is ON/OFF control algorithms, to control the behavior of final control elements and achieve desired optimal levels of industrial environment norms.

Figure 5 Control algorithm and data flow, transmitting and receiving flowchart representation
Experimental testing and evaluation

The industrial environment monitoring system design is intended to ensure acceptable quality of industrial manufacturing factory’s environment, to maintain safety of personnel, material and machinery and finally to result in more optimized factory operation, the system is designed to monitor, track, assess and register pollution’s sources parameters, its state and conditions in industrial manufacturing factory. This purpose is achieved by developing the system design to acquire maximum possible data about factory’s environments in terms of levels of all and each of the following parameters; Light, Humidity, Temperature, Noise, vibration, Air, water, and combustible Gases.

In this section, the selected and designed Hardware components are integrated, realized and tested, experimental data readings are acquired and analyzed, based on experimental results and analysis of resulted data, ranges for each of environmental parameters are to be set, finally example on acquired and analyzed data are to be displayed graphically.

**Illumination level**: the acceptable illumination levels in work place in Lux is in the range [250: 1000]. when employing TEMT6000 Light Sensor to measure the ambient illumination level, the relationship between the generated output voltage and the illumination level in LUXs is calculated as given by Eq.(1) [19]: . Meanwhile, when LDR with voltage divider circuit is employed as illumination level measuring module. To test the module operation and set illumination levels and ranges, the lighting in the industrial workshop, was changed on purpose, based on testing experimental results and analysis of acquired data, the optimal illumination level in workshop, in terms or microcontroller ADC values, are defined to be within the range [400: 620]. Illumination level for soft alarm is within the range of [170:400]. Dangerous Illumination level is under 100. Examples on testing and readings results with these ranges are shown in Figure 6.

The ambient illumination level in Lux = 2.682*(ADC_read)⁰/²47⁰/(ADC_read) (1)

**Temperature level**: The temperature is measured in terms of both the ambient Temperature, and the Water temperature levels. The optimal ambient temperature level in industrial workplace for better working conditions is better expressed in terms of heat comfort. The optimal ambient temperature range is between [19:24] °C, the acceptable temperature range is between [16:19] °C and [24:29], the dangerous level is when temperature is less than 15 °C and greater than 30 °C. An example on reading ambient temperature in industrial workshop workplace using DHT11 Temperature and humidity sensor is shown in Figure 7(a), where temperature around sensor is changes on purpose. This sensor is calibrated using software integration by the specially designed library for it.

**Water temperature level**: the waterproof digital temperature sensor DS18B20 can be used to both measure ambient, as well as, the water temperature. Employing this sensor to read water temperature, when the temperature is changed increased and decreased on purpose, is shown in Figure 7(b). The acceptable water temperature limits can be defined based on water usage, this is because the water temperature has many effects including the following examples:(a) in a given solution to measure level of acidity or basicity, pH is the unit used. The acceptable pH range can be considered as (Max value of 7.5 and Min value of 6.5). pH is calculated by the number of hydrogen ions in solution. As water temperature decreases or increases, the concentrations of ion will also shift, therefore shifting the pH value. (b) the solubility and thus toxicity of certain compounds, are increased with high water temperatures. (c) as water temperature increases, the solubility of oxygen and other gases will decrease, (d) it can affect the existence and activity of aquatic organisms, see also reading Pollution levels in Water.

**Ambient Humidity level** the Optimum humidity levels in a workplace, are between [40% : 60%], the acceptable lower range is between [30% : 40%], and, the acceptable higher range is between [60% : 70%]. Based on this, the humidity levels in industrial workplace should be kept between [30%: 70%]. An example on reading ambient humidity level in workplace using DHT11 sensor is shown in Figure 7(c), when water spray and water evaporation are used to change on purpose the humidity level in the ambient space.

**The comfort heat index (HI)**: also called humiture; is an ambient environment measure that is calculated by Eq.(2). This measure is used to express how hot the ambient environment temperature feels like to the human’s body at a given humidity. Therefore its value can be estimated using two variables; the ambient temperature and ambient humidity. Two sensors can be used to calculate the heat index the waterproof DS18B20 sensor and DHT11 Temperature and Humidity Sensor. According to national weather service [20]. The acceptable comfort heat index value is, when its estimated value is less than 27°C (80°F), an example on resulted disorders from high value of the heat index and experienced by employees include fatigue when HI is between [27-32] °C, heat cramps and heat exhaustion can be experienced when HI is between [32-41] °C.

In Eq.(1), F: temperature in degrees Fahrenheit. H: relative humidity in decimal (divide the relative humidity by 100).
The carbon monoxide gas (CO) level; in a given environment is estimated in units 'Parts per Million, ppm, and percent (%)'. Calibration is required to have proper ppm CO readings. According to the ASHRAE Standard 62.1-2016, the optimal recommended and safe CO level is in the range between [0 : 0] ppm. The exposure to the average CO level in the range between [0 : 6] ppm with maximum exposure up to 24 hours can result in such physical symptoms like headache, fatigue dizziness and nausea. This sensor is calibrated using software integration by the specially designed library for it. An approximate expression used for calculating the CO level in ppm is given by Eq.(3) when an operational amplifier with gain = 7 is used and the sensor is powered by +6V. An example on CO level readings when a lighter is used as a gas source is shown in Figure 8.

The carbon monoxide gas (CO) level in ppm = 4.319*10^14 *HI + 8.328*10^-2 HI^2 + 1.22874*10^-3 F^2_H + 8.5282*10^-4 F^3_H^2 - 1.99*10^-6 F_2^2 * H^2 (2)

Noise, ambient sound level, shock and vibration pollution; at industrial workplace, these are generated from Industrial processes, working machinery, trucks and safety alarms. For measuring the ambient sound level, a simple option is the sound detection sensor module. Software integration, in terms of employing for loop was used to calculate the mean value of 300 readings. The linear regression method was applied to find the equation given by Eq.(4), that can be used to map and calculate the equivalent sound level value in dB for every microcontroller measured ADC value. The following sound standard limits can be presented; the value of 10 dB is when is almost quit just breathing, meanwhile 70 dB when busy traffic, the threshold for dangerous e.g. pain, when sound level is greater than 110 dB. An example on reading ambient sound (noise) level readings when random noise generated is shown in Figure 9(a).

Sound level in dB = (ADC_read +83.3) / 11.002 (4)

For vibration level measuring at workshop location; the triple axis ADXL335 contact accelerometer is employed. An example on vibration readings are shown in Figure 9(b). According to the control of vibration at work regulations 2005, defined the limits for the amount of vibration exposure, it is required to protect workers against the consequences caused by vibration, in referenced to the Average (A) exposure to vibration in the 'normal' working day of 8 hour, A(8), there exist limits for the combination of the maximum vibration magnitude amount in m/s² and the exposure time in hours on any single day. The exposure limit value (ELV) of Arm-hand vibration, can be defined as is the maximum vibration amount that human may be exposed to. ELV must not be exceeded is 5.0 m/s²; the exposure action value, EAV value is 2.5 m/s², to control the possible resulted risk. For whole human body, the vibration ELV is 1.15 m/s² A(8), meanwhile the daily EAV is 0.5 m/s² A(8). The dust Particles level in the air can be read using optical smoke and Dust Sensor GP2Y1010AU0F, this sensor is often used in air purifier systems, it can read such fine particles such as cigarette smoke. Eq.(5) is used, in software integration, to calculate the dust density in air in microg/m³, (ug/m³) units. In this equation: voltage: is the voltage value generated by sensor and read by microcontroller ADC, in response to dust density with a sensitivity as by Eq.(6). The Occupational exposure limit to respirable airborne concentration of dust particles depends on the dust type e.g. Quartz, Cristobalite and Talc. According to the work health and safety regulation 2011, Section 49, the recommended respirable airborne concentration of 'nuisance' dusts limit in occupational workplace is between [2.5 to 5] mg/m³ of total dust. an example on dust level readings, in the ranges between [0:0.75] is shown in Figure10.

Dust Density = 0.17 * voltage − 0.1 (5)

0.1 mg/m³ (6)

Water quality can be evaluated in terms of Water solution pollution in terms of the PH level and the degree of water transparency. Turbidity level is used to represent the degree of water transparency (haziness or cloudiness) due to the suspended particulates presence. Turbidity level in given water is measured in units of NTU, which is short for Nephelometric Turbidity Units. The relationship between turbidity level in NTU and generated by sensor’s output voltage is given by Eq.(7). The larger the turbidity, the smaller the generated voltage. To test the sensor, three glasses with tap water, with black Nescafe and in-between were used., the result of Turbidity level in these cases are shown in Figure 11.

Pollution levels in Water/ solution in terms of the PH level; pH can be defined as a measure of the acidic or basic (alkaline) nature of a solution. [21], the used PH level scale is in range [0:14]. Generally, the acceptable PH level is considered within the range [7.5: 6.5], if PH level in a given water, is less than seven [PH < 7], then this water is considered acidic and corrosive. If PH level is greater than seven [PH > 7], the water is considered basic. In industrial and municipal process applications, the PH level of an aqueous solution can be measured using PHE-45P PH Sensor Model.
\[ NTU = -1120.4 \times V^2 + 5742.3 \times V - 4353.8 \quad (7) \]

Testing wireless relay interface circuit, were done successfully for activating and deactivating ventilation in terms of AC fan, sound and light alarms. Examples on the built and tested circuits are shown in Figure 4 (a)(b)(c).

<table>
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<th>Figure 6</th>
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<td>an example on Illumination level testing and readings results when the illumination level is changed on purpose</td>
<td>an example on reading and defining ranges of ambient temperature in workplace</td>
<td>example ion reading water temperature when the temperature is increased and decreased on purpose</td>
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<td>an example on reading ambient humidity level in workplace, when its values is changed on purpose</td>
<td>an example on CO level readings when a lighter is used as a gas source</td>
<td>sound level readings in dB example</td>
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<th>Figure 10</th>
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<td>an example on dust level readings with range between [0:80]</td>
<td>three readings of water turbidity levels in three different glasses with: tap water, Nescafe and in-between</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

In addition to experimentally and separately testing the three main system parts, in terms of testing modules operating, identifying the acceptable ranges and other limits, finding the proper equations relating readings to measuring units of main environmental variables applying e.g. linear regression method, the overall system design was tested and evaluated.

To test and validate the overall system design, the following scenario was performed; the main three system parts were assembled and physically built, including the main control, four wireless relay interface module, for activating and deactivating light, sound
electric motor, and sucking fanes. Finally, five wireless sensors modules for measuring the levels of light, temperature, gas, vibration, noise and humidity. All these subsystems and parts were placed in workshop in different locations.

To test and validate the system design, the ambient working environment was changed, different cases were introduced including creating harmful conditions and unacceptable limits of light, vibration, noise, gas and temperature, as well as, acceptable conditions were created. As temperature and gas pollution source, the XU-192 gas based burner was used. Mini Lathe and drilling machines were used as vibration and noise sources. In all created cases, the wireless sensor modules detected all changes in ambient environment, transmitted data to main control unit successfully. The main control unit with control algorithm received the transmitted data, process it successfully with correct decision taken, that was transmitted to right wireless relay interface module for activating and deactivating the final control element. to ensure the acceptable quality of industrial manufacturing factory’s environment, while the ambient environment indicators’ values was not within the acceptable limits, even if one environment indicator was not within the acceptable limits, the main control unit kept displaying indicators’ values, and notifying using red light and soft or loud sound depending on indicator’s value, in addition activating sucking fanes, as well as, sending notification to supervisor. When the acceptable conditions are achieved, the system switches off all alarms and displays green light.

**CONCLUSIONS**

Theoretical and hardware designs, as well as, physical development of real-time smart industrial environment monitoring and assessing system is presented and successfully tested. The overall system consists of three main subsystems: wireless sensor nodes, main control unit, and wireless final control circuit for activating and deactivating the actuators to achieve desired optimal levels of industrial environment norms.

The optimal, acceptable and dangerous levels and limits of most of the parameters were identified and experimentally tested.

The mathematical expressions, used to map and calculate the equivalent sensors’ reading to the pollutant measuring level and unit are presented e.g. equivalent sound level value in dB, dust density in air in microg/m3units. The continuously and in real time acquired data by all sensor modules, are wirelessly broadcasted to main control unit, that programmed with specially designed control algorithm, to perform data processing and analysis to take smart adjusting actions and notifying decisions based on, readings from sensor modules and reference identified critical conditions limits and their set points, including; notifying both workers and supervisors, using soft and hard sound and light alarm notifications, displaying results on LCDs and, wirelessly send taken decision to final control element/actuators to implement.

**REFERENCES**


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