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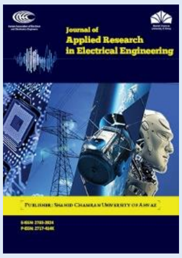

Research Article

RTWSM: Real-Time Ad Hoc Wireless Sensor System Monitoring of Local Air Particle Pollution

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Abstract: The ever-increasing threat of air pollution as a serious health hazard throughout the world requires measuring prior to devising a structured solution. Air quality monitoring systems measure the amount of particulate matter such as particles and hazardous gases in the air. Information is required on the quality of air monitoring and dust detection system in order to make managerial decisions to improve environmental conditions and prevent and treat diseases caused by dust. The present study aims to develop a simple, highly sensitive, and economical monitoring system for the determination of air particulate. In this paper, we develop a real-time ad hoc wireless airborne particle monitoring system using the IEEE 802.15.4 low power sensor network technology called RTWSM, featuring a low-cost sensor node for mass production. Its dynamic features of high scalability and ad hoc architecture enable the design to provide significantly more useful information under all environments, including indoor or outdoor monitoring applications. The performance of the proposed monitoring sensor system is evaluated in environmental and industrial occupation debates to monitor the PM2.5 particle data. The results confirm that the proposed experimental setup works well for local air pollution monitoring and could be extended to automation industrial applications.

Keywords: Wireless sensor networks, air particle monitoring, PM 2.5, experimental setup, IEEE 802.15.4.

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1. INTRODUCTION

Nowadays, wireless sensor networks (WSNs) and the Internet of Things (IoT) are mature enough to be employed in extreme environmental condition monitoring and controlling applications such as harsh weather condition monitoring [1-3]. The wireless sensor networks consist of some small, low-power, and low-cost sensor nodes that communicate together wirelessly to transmit the collected and processed data from the environment [4]. WSNs have ad hoc architecture with the potential of the easy deployment of hundreds to thousands of sensors to cover the monitoring areas, which makes them a suitable solution for air pollution monitoring applications in difficult-to-access environments.

According to the World Health Organization (WHO), air pollution is one of the most important human health risks that should be considered in modern smart city systems. Some of the air quality parameters that should be measured are carbon dioxide, methane, dust particles, ozone, nitrogen dioxide, sulfur dioxide, and hydrogen sulfide [5]. These items are not concentrated in normal conditions, but in many cases, the air is out of normal conditions, and some parameters of air pollution are increased dramatically. One of these cases is dust storms in which the size of particulate matter increased heavily. The correct prediction of dust storms is difficult in many cases.

The technology of air pollution monitoring systems is not advanced and widespread enough to allow globally predicting air quality at a country level. Consequently, there is an essential need for local air quality monitoring in different places of cities such as parks, hospitals, and schools. Monitoring systems measure the concentration of air pollutants that can be analyzed and interpreted. Then, the information is used for decision-making in different applications. For example, analyzing the data from the monitoring system allows more accurate geographical assessments, such as where the air quality is better and where it is weaker or in which areas the condition is improving and where is getting worse. The information is utilized to understand how pollution increases by traffic or industrial activities. By analyzing the relationship between meteorology and air quality, it can be predicted whether the weather conditions cause contamination [6]. Low air quality may increase short-term health problems, such as fatigue and nausea, as well as chronic respiratory disease, heart disease, and lung cancer. Governments can take advantage of the monitoring system data from WSNs to make the right planning and decisions. Also in emergency situations, they can take useful actions such as sending relief teams, and people can use the information to manage their everyday activities [7, 8].

The sensor networks have enough potentials to meet the requirements of air pollution monitoring applications. Furthermore, clustering schemes are used in sensor networks to geographically gather local data for monitoring applications [9]. This paper presents the design and implementation of WSNs for monitoring the status of air parameters.

The remainder of the paper is organized as follows: the related works are described and discussed in Section 2. The hardware architecture and designing issues are explained in Section 3. Section 4 presents the experimental results. Finally, conclusions are made in Section 5 along with suggestions for future works.

2. RELATED WORKS

This section describes the applications of WSNs for air pollution monitoring schemes. The results as to the development of a WSN to monitor air quality in smart city programs are described in [5]. It is implemented to test the system in two cities to compare the concentration of CO_2 with airborne particles. The preliminary results indicate that the developed wireless system may be used as a low-cost tool to monitor air pollution. In [6], a new type of outdoor air quality monitoring system is studied and preliminarily practiced and has proven certain feasibility and applicability. The experimental results show that the prediction model has strong applicability and high accuracy in the period prediction of pollution weather. It is established that air pollution in the city is mainly caused by the manufacturing industry. In [7], the authors focus on using WSN for air pollution mapping and tackle the optimization problem of sensor deployment using the integer linear programming model. An appropriate coverage formulation based on an interpolation formula that is adapted to the characteristics of air pollution sensing is developed. Two deployment models are derived for air pollution mapping using integer linear programming while ensuring the connectivity of the network and taking into account the sensing error of nodes. A real-time cognitive WSN system is presented in [8] for carbon dioxide monitoring in a complex indoor environment. Moreover, the system coexists with minimum interference with other systems in the monitoring area. A prototype is designed to show the enhanced real-time data transmission. Experiments are conducted to validate and support the development of the system for real-time monitoring and alerting. In [10], the paper describes the application of WSNs and IoT for monitoring the main pollutants that determine Santander City's air quality in Spain by analyzing how event-based sampling techniques can address efficient communication between nodes and a reduction in each node's power consumption. To meet the requirements of data acquisition from mobile pollution sources and unfixed data acquisition points in an atmospheric particle monitoring system, a real-time monitoring system is designed in [11] for atmospheric particles such as PM2.5 based on a single-chip microcomputer, an ET-iLink open cloud platform, and an Android operating system. A distributed real-time monitoring system for atmospheric particles has been designed, implemented, and tested in [12]. The proposed system consists of a front-end data wireless acquisition network, an embedded web server system, a central server, and remote monitoring terminals. In this study, the PM1.0, PM2.5, and PM10 particle data were successfully collected, transmitted, and checked by the monitoring system.

The primary contribution of [13] is to design a low-power ZigBee sensor network and inter-node data reception control framework to be used in real-time acquisition and communication of data concerning air pollutant levels from volatile organic compounds (VOCs). The design is based on the ATmega16 microcontroller and the Atmel RF230 ZigBee module, which are used to effectively process communication data with low power consumption. Indoor air quality and energy conservation can be achieved by integrating the VOC monitoring system proposed. A system for monitoring and forecasting urban air pollution is presented in [14]. The system uses low-cost air-quality monitoring motes that are equipped with an array of gaseous and meteorological sensors. The research in [15] focuses on a network of low-cost and autonomic wireless sensors, aiming at a finer spatiotemporal granularity of sensing. The main contribution is to design integer linear programming models that compute sensor deployments capturing both the coverage of pollution under time-varying weather conditions and the connectivity of the infrastructure. The work in [16] describes the design and evaluation of a low-cost participatory sensing system called Haze Watch that uses a combination of portable mobile sensor units, smartphones, cloud computing, and mobile apps to measure, model, and personalize air pollution information for individuals. In [17], a method is presented for data reduction through a dynamic sub-sampling of the measured variable, data fusion from several sensors for the same variable, and data scaling taking into account the ranges of the variables. The reduction of data is implemented to save energy, reduce the transmission time, keep the channel available, and save storage space. A WSN is examined in [18] for distribution in underground coal mines. During the mining operation, the dust that is created is currently measured with manual and laboratory samples. But, with the proposed system, the status of these particles is visible at any moment. A trial version of the wireless air sensor network system is presented in [19] for monitoring and predicting air quality in the 3D area. The system distributes 200 PM2.5 sensors in two-dimensional space and measures a PM2.5 parameter at different altitudes using an unmanned airplane with a similar sensor. In [20], a collaborative system is proposed that is composed of a WSN and an air robot that is used to monitor frost in vineyards. In this way, farmers can promote their farms and crops in their own style from a completely new perspective. Design and implementation of a complete WSN platform are presented in [21], which can use a wide range of IoT applications for long-term environmental monitoring. In [22], a method is proposed for gas concentration detection based on the WSN and laser technologies. In [23], airborne particles are measured in urban environments using WSN and the frequency of their changes is analyzed. In [24], a WN is used to monitor air pollution. In [25], a WSN is implemented in a poultry farm to monitor temperature, humidity, and air quality.

3. HARDWARE ARCHITECTURE

This section introduces the structure of the implemented WSN for air pollution monitoring. The implemented network can measure airborne particles, and then each node sends the results to the sink through other relay nodes on the route to the central station. This method uses simple, small, and inexpensive nodes to implement the network. The experimental setup has two parts: measuring the particulate matter and forming the network. These two parts are introduced separately, and the hardware is examined in detail.

3.1. Sensing the Airborne Particles

The HK-A5 sensor is used to measure airborne particulates in micrograms per cubic meter and transmit it to a controller through a serial port. The PM2.5 dust sensor is a solid particulate concentration sensor that is used to obtain suspended particles in a unit volume with dimensions of 0.3 to 10 microns. Fig. 1 shows the sensor structure diagram.

The PM2.5 sensor uses the theory of laser dispersion, that is, the dispersion of laser radiation into airborne particles so that the scattered light is collected at a particular angle to obtain the dispersion intensity in comparison with the time curve. After collecting data by a microprocessor, the sensor calculates the amount of particulate matter using the relationship between time domain and frequency range by Fourier transform and then, through a series of complex algorithms. The sensor has a small fan that samples the air and measures the amount of particulate matter according to the rules of light distribution. The sensor function is such that it sends a 32-byte packet per second. The power supply required for the sensor has the following specifications. The voltage ripple should be less than 100mV. The power supply voltage stability should be 4.95 ~ 5.05V. The power supply should be more than 1W (5V, 200mA). The upper and lower electric voltage surge needs to be less than 50% of the system power supply voltage. The serial port profile is configured as follows: a port baud rate of 9600 bit/s, none parity bit, one stop bit. The packet length is fixed at 32 bytes.

3.2. Sensor Node and Protocols for Forming the Network

To measure the amount of particulate matter in the air by the WSN, IEEE802.15.4 is considered as the MAC protocol and the sensor boards are designed to support the ZigBee protocol [27]. The IEEE 802.15.4 standard for short communications in low power sensor networks is designed to be used in the frequency bands of 868 MHz, 915 MHz, and 2.45 GHz and is supported by many scientific and commercial sensor nodes. Data transfer rates are 20, 4, and 250 kbs. The sensor boards operate at 2.4 GHz frequency and have low power consumption. The ATMEGA128L microcontroller from ATMEL Company has been used as the processing unit [28]. ATMEGA128L can be programmed by the TinyOS operating system. The sensor boards provide network and analog and digital IOs, I2C, SPI, and UART interfaces, which can be connected to external side devices and different sensor boards. The CC2420 radio is used as the transmitter/receiver in the sensor boards for wireless communication. The CC2420 radio has a data rate of 250 kbs and operates on a 2400-2485.5 MHz frequency band. Additionally, this antenna is resistant to RF interference and has an automatic data security system. The range of the radio in ideally nominative mode is suited for an open environment of 75-100 meters and in a closed environment of 20 to 30 meters. Fig. 2 shows the designed sensor board. The nesC language is used to program sensor boards. This language is, in fact, the same as language C, which has added new language features for creating and using components, as well as creating a kind of parallel processing. The codes written in nesC language are made by the TinyOS operating system and are installed on the sensor boards.

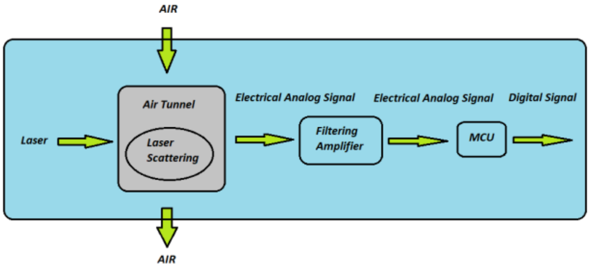


Fig. 1: The sensor structure block diagram [26].

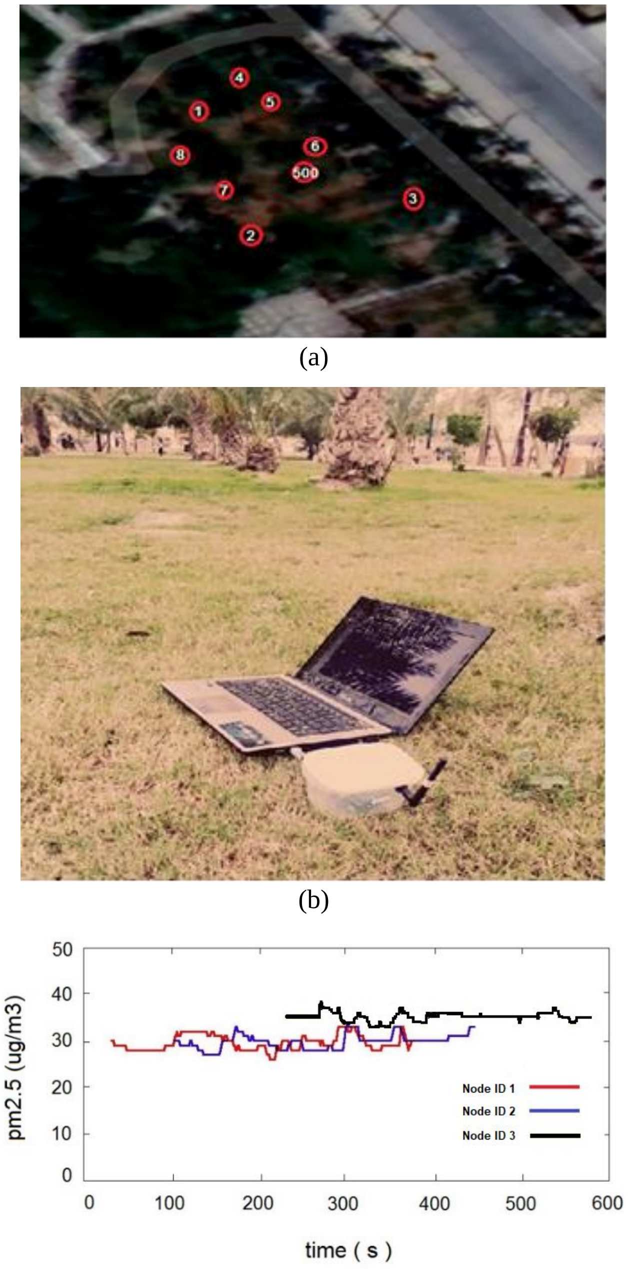
4. EXPERIMENTAL RESULTS

The results of using the WSN to measure dust and airborne particles are provided in this section. Particulate matter graphs are presented for different case studies.

4.1. The RTWSM in the Park

In this case, the real-time ad hoc wireless sensor system monitoring (RTWSM) is employed to monitor the air particulate matter in the Petrochemical Park of Mahshahr City. Nine nodes are used to cover the park area as shown in Fig. 3a. The nodes with identification numbers of 1 to 3

Fig. 2: The designed sensor board.

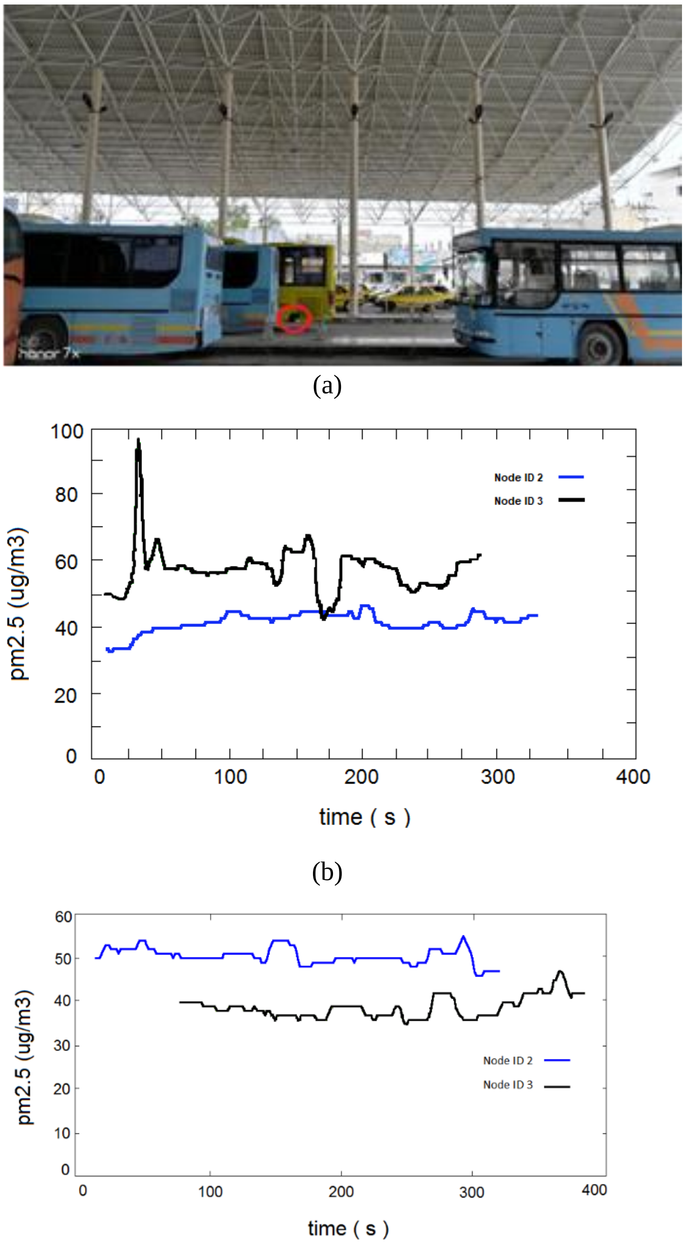


(a)

(b)

(c)

Fig. 3: The RTWSM in the park, (a) The location of the nodes in the park, (b) The location of the base station, (c) The concentration of the measured PM2.5 in the park.



(a)

(b)

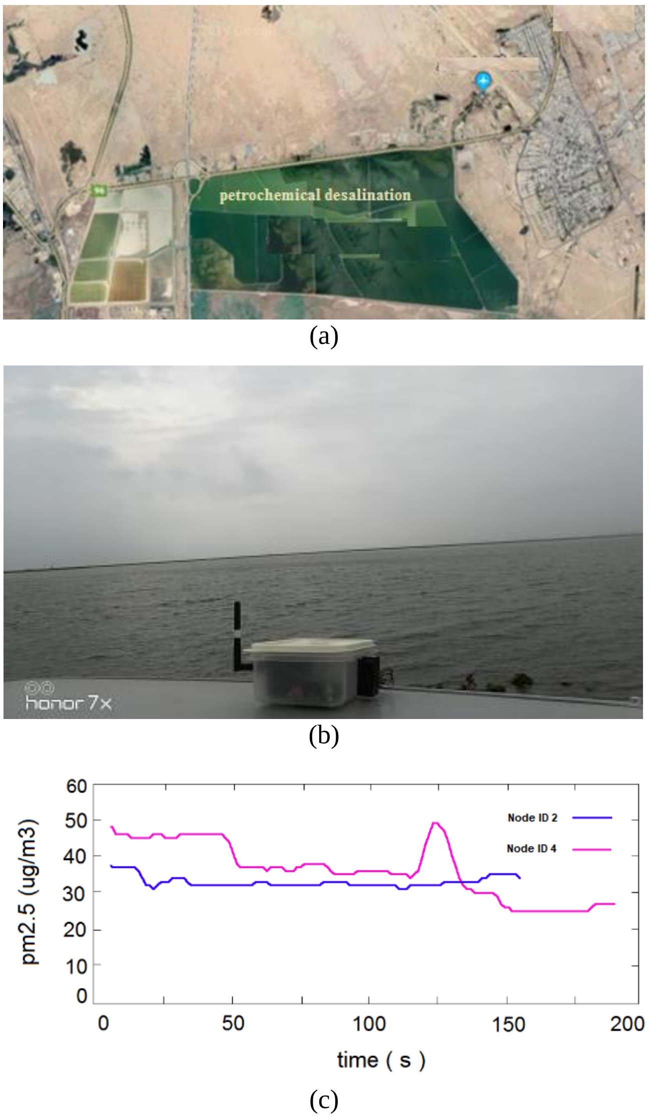
(c)

Fig. 4: The RTWSM in the city center, (a) The RTWSM in the taxi and bus station, (b) The concentration of the measured PM2.5 in taxi and bus station, (c) The Concentration of the measured PM2.5 in the central square of the city.

measure air particulate matter using dust sensors and nodes with numbers 4 to 8 acting as relays. Node number 500 is the central station that is connected to a laptop to capture and analyze data as shown in Fig. 3b. The results of measuring the air particulate matter by node numbers 1 to 3 are displayed in Fig. 3c. The graphs show that the airborne particle fluctuates between 25 and 40 µg/m^3.

4.2. The RTWSM in the City Center

The RTWSM is used to measure particulate matter in the city center in two different places: the central square of the city and the indoor taxi and bus stations that are close to each other. The purpose of this case study is to examine the status of particulate matter in the city center, which is mainly traffic-intensive, and to investigate the effect of the indoor station on the city air pollution. However, it is important to note that the ceiling of the station has a high altitude and the air flows from four sides. Meanwhile, the weather at the time of the experiment was rainy and windy. Fig. 4a shows the taxi and bus stations in which RTWSM is installed for condition monitoring. In the network, two nodes with identification numbers 2 and 3 are used to measure the particulate matter, and a node is used as a relay to the central station. As shown in Fig. 4b, the graphs fluctuate between 40 to 60 µg/m^3 and the graphs reach the 100 µg/m^3 point when the buses get close to the sensor nodes.



(a)

(b)

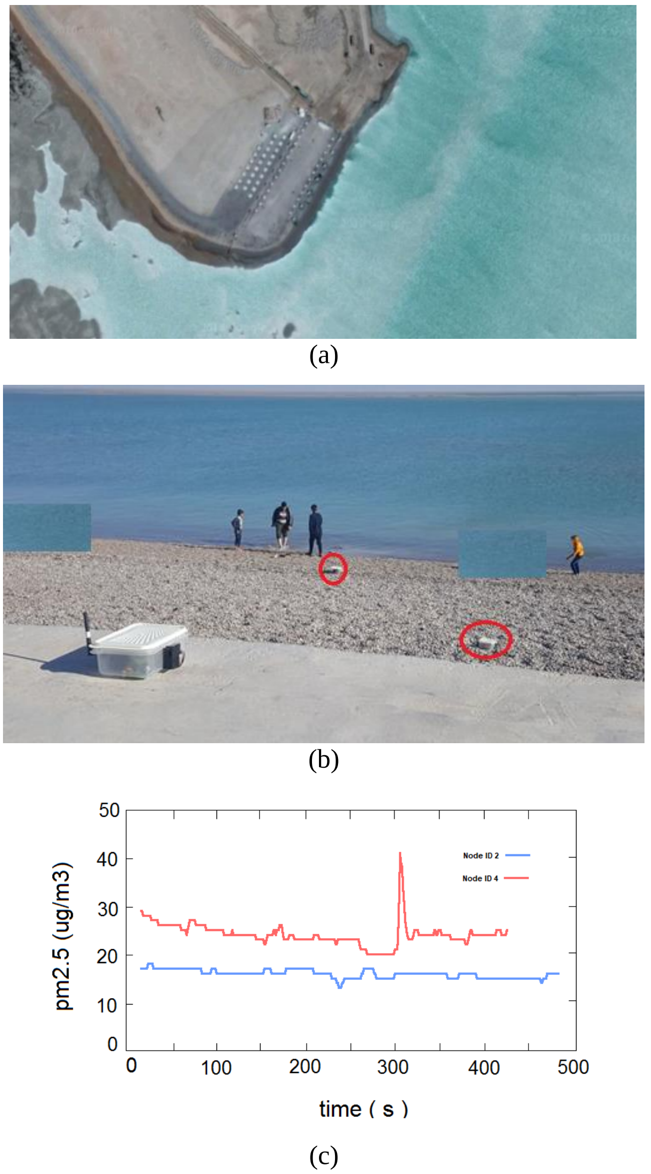
(c)

Fig. 5: The RTWSM in the petrochemical desalination ponds, (a) The location of petrochemical desalination, (b). The sensor node in petrochemical desalination, (c) The concentration of the measured PM2.5 in petrochemical desalination ponds.

Fig. 4c shows the concentration of PM2.5 in the central square of the city where there is usually traffic around the square. As was mentioned above, it was rainy and winding during the experiment. Comparing Fig. 4b with Fig. 4c, it is concluded that in spite of the distance between the taxi and bus station and the central square of the city, the suspended particles in the taxi and bus station is greater than those in the central square due to being surrounded indoor.

4.3. The RTWSM for Measuring the Particulate Matter in Petrochemical Desalination Ponds (Salt Lake)

Fig. 5a shows the location of petrochemical desalination ponds between Mahshahr and Sarbandar cities. They are closer to Mahshahr. The lands around these ponds are also used as an amusement park for the public. The RTWSM was used to measure particulate matter in the area on the same day that the WSN was conducted in the central square of the city and the taxi and bus station. The graphs show that the difference is small, and this slight difference indicates that the particulate matter around the salt lake is lower than that in the city center. Fig. 5b shows the RTWSM wireless sensor node in the desalination ponds of Mahshahr petrochemical plants. Fig. 5c displays the particulate matter graph in these ponds.



(a)

(b)

(c)

Fig. 6: The RTWSM in the recreational sea coast port, (a) The location of the coast of the port, (b) The location of the distributed nodes, (c) The concentration of the measured PM2.5 in the coast of the port.

4.4. The RTWSM for Measuring the Particulate Matter in the Recreational Sea Coast Port

The RTWSM was configured on days after rain with a clear sky and clear air. The RTWSM was employed on the same day that the sensor network was configured around petrochemicals. The airspace between this beach and the petrochemicals is about three kilometers. Fig. 6a shows the location of the distributed nodes. Fig. 6b shows the dust graphs of the two nodes that measure the dust.

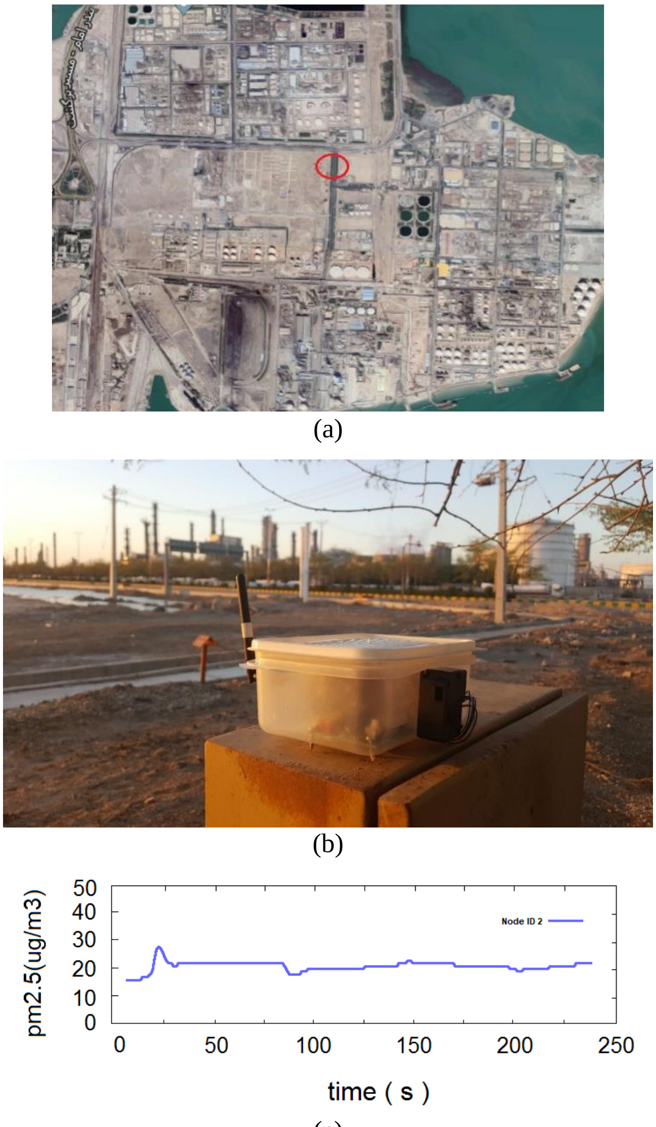


Fig. 7: The RTWSM for measuring particulate matter in the industrial petrochemical zone, (a) The location of the sensor node installed between Imam Petrochemical Complex and Razi Petrochemical Complex and the special economic zone, (b) The sensor node installed in the site, (c) The concentration of measured PM2.5 between Imam Petrochemical Complex and Razi Petrochemical Complex.

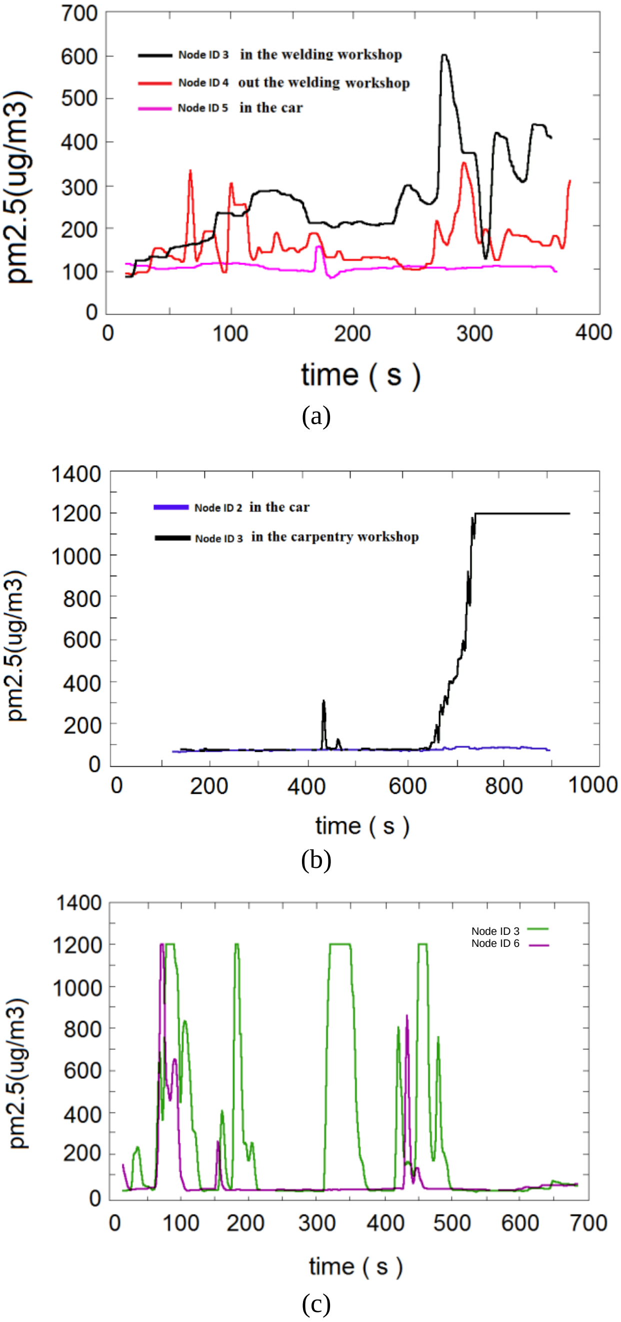


Fig. 8: The RTWSM for investigation of particulate matter in the industries, The concentration of PM2.5 at (a) the welding workshop, (b) the carpentry workshop, and (c) the stonework.

4.5. The RTWSM for Measuring the Particulate Matter in an Industrial Petrochemical Zone

Fig. 7a shows the location of the node installed between Imam Petrochemical Complex and Razi Petrochemical Complex and the special economic zone with a red mark. Fig. 7b displays the node installed on the site and Fig. 7c depicts the airborne particle graphs. This chart is for the days after rain with a clear sky and clear air.

4.6. Investigation of Particulate Matter in the Industries

Some occupations in the construction industry are examined in this section for the amount of particulate matter and the relative duration that the people involved in these occupations contact with dust and smoke – occupations like welding, carpentry, and stonework that all are linked to dirt or smoke. The welding industry produces suspended particles due to the use of cutting machines. It also produces smoke due to the use of welding devices. Due to the volume of welding, smoke is produced. Fig. 8a shows dust and smoke charts in a welding workshop. As shown in Fig. 8a, in this experiment, the smoke rate reached 600 µg/m^3. According to people working in the workshop, this test was not carried out at the peak of the work. In cases where more welding is performed, the smoke also increases.

Woodworking also emits particles into the air due to the use of cutting machines. The RTWSM sensor node was installed at a carpentry workshop. Fig. 8b displays dust graphs at the carpentry workshop. The graph shows that the largest amount measured by the dust sensor is 1200 μg/m^3, and this is the highest amount that this network can measure.

Comparing the charts of the welding workshop and the carpentry workshop, it is clear that the amount of dust in the carpentry is greater during cutting. But, the duration of exposure to this smoke and dust is longer in welding because the welder always has to either weld or cut, but the carpenter takes a while to work with a nail and a hammer and a glue that does not produce a lot of dust .

The WSN, in this section, was implemented along with the mosaic workers. Tessellation and stonework are jobs that at times need cutting rocks to adjust their size, and this creates intense dust and the person who makes the cuts is close to the dust and cannot get away from it at work .Now, if the cutting is done in an open space, the dust will disappear a few moments after cutting, but if the cutting is done in a closed space, this dust will last longer with the workers in this part of the construction industry. Here, we also tried to place the sensor in the same place where the person was. Fig. 8c shows the dust graphs during cutting. It is clear that in certain parts that are repeated frequently, the graphs reach their highest value, 1200 μg/m^3, indicating the working time with a stone cutting machine.

4.7. Comparison of Experiments

For comparison, Table 1 presents the results of experiments in different locations where RTWSM was installed. As is evident, the measured PM2.5 varies in different places. The lowest airborne particles were measured in the industrial petrochemical area because this experiment was for the days after rain with a clear sky and clear air. The highest measured airborne particles were found in the industry.

5. CONCLUSION

An ad hoc sensor network was developed in this paper for real-time wireless monitoring of air particulate matter called RTWSM. The RTWSM was employed in dusty days, clean days, and after a foggy day in different parts of the city such as recreational and coastal parks and industrial areas including petrochemicals, as well as the building occupations that drains dust; and the related graphs were provided. The experiments show that the RTWSM, a low-cost tool for monitoring particulate matter, is scalable and can be used in the environmental debate and in the industrial occupations debate to monitor air particulate matter. Finally, it is proposed to study the application of a new platform with a wider range for meteorological debate in future work. Furthermore, research is proposed to be conducted on preparing a network for installation in industrial environments and communicating with controllers by supporting analog 4-20 mA signals as a measure of air pollution.

Table 1: Comparison of experiments

Location of RTWSM	PM2.5 Measured (μg/m^3)
Park	between 25 and 40
City Centre	between 30 and 100
Petrochemical Desalination Ponds	between 20 and 50
Recreational Sea Coast Port	between 15 and 42
Industrial Petrochemicals Zone	between 15 and 30
Industries (welding workshop, carpentry workshop, stonework)	between 30 and 1200

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Reza Ghanavati: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Roles/Writing - original draft. **Yousef Seifi Kavian**: Conceptualization, Methodology, Project administration, Supervision, Writing - review & editing. **Abdolnabi Kosarian**: Conceptualization, Conceptualization, Conceptualization.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy has been completely observed by the authors.

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