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Real-Time Environment Monitoring Embedded System in RMG Factories to Emphasize Awareness About Workers Health Safety

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Abstract

Air quality in an RMG factory must be at a safer level to ensure the good health and well-being of the workers. Safe and healthy environments are targets of Sustainable Development Goals (SDG) 8.8 & 3.9, respectively. So, regular monitoring and monitoring-based initiatives should be taken by the compliance team. To facilitate this monitoring process, ESP8266 mediated dust, humidity, temperature, and carbon monoxide (CO) gas sensors can play an unprecedented role, especially for local RMG manufacturers, as they are not aware enough in most of the cases. In this study, we utilized a dust sensor (GP2Y1010AU0F), a combined humidity-temperature sensor (DHT22), and a CO gas sensor (MQ-7) to determine dust amounts, humidity, temperature, and CO level in three sections of an RMG factory, such as cutting, sewing, and finishing. Particularly, the average dust amount values are approximately 65, 198, and 32 $\mu g/m^3$ in the cutting, sewing, and finishing sections, while the standard value is 20-30 $\mu g/m^3$ for good quality of air as per PM10. According to WHO, this working environment can be labeled as weak, very weak, and moderate for the cutting, sewing, and finishing sections, respectively. Other results are approximately 29°C, 63%, and 86 ppm in the case of humidity, temperature, and CO concentration. However, the solutions may vary as per previous studies on dust sensors, like exhaust fans, water spray, etc. In addition, this study represents the existing poor environmental scenario in Bangladesh garment factories to generate as much awareness as possible. As a part of the process, this study focuses on the utilization of a cost-effective microcontroller system with a ThingSpeak cloud-based application.

Keywords
Internet of things (IoT), RMG, Health safety, Air monitoring, Microcontroller

1. Introduction
The ready-made garment (RMG) sector in Bangladesh contributes 84% of national export earnings to the economy of Bangladesh according to the report of BKMEA, 2024. In pursuing of significant amount of export sales, this country utilizes its advantage of low labor cost and large production capacity, which requires an intensive work environment. Worker's continuous health monitoring in such environment has given a great importance. Garment sections such as

cutting, sewing and finishing section produce a lot of dust in processing. These dust not only effect the human, but also affect the fabric quality. When people inhale in such a condition for 8 hours continuously each day, it damages them internally at a slow rate leading to serious lung infections in future. Additionally, inappropriate temperature and humidity are responsible for human discomfort as well as adverse changes of garment. When loadshedding occurs, there can exist a high level of CO_2 and CO in the floor causing breathing discomfort. Under these circumstances, it is a pressing need to monitor air conditions continuously in terms of dust level, temperature, humidity, and CO level. This concept is to be applied by the local factories in their production floors. For this, the execution must consume minimum cost to install, maintenance, and for cloud-based sharing. So, this study aims to make a real-time monitoring system which encompasses several benefits like affordability, easy operation, and traceability. It is meant to demonstrate working conditions as well as to generate the concern for the workers, and to make a feasible low-cost setup for local manufacturers to persuade them for enjoying long term benefits.

2. Literature Review

Air quality monitoring, including particulate matter (PM), humidity, temperature, CO, etc., is not only a major task in smart crop production (Rajak et al. 2023), prevention of food poisoning (Mahidul Hasan et al. 2021), but also in textile (Sutradhar et al. 2021) and RMG sector , where workers are exposed to dust in apparel floor and fly fibers in knitting and weaving (Pranta et al. 2025). According to WHO, recommended annual average value for PM2.5 and PM10 are 10 & 20 $\mu g/m^3$, whereas 25 & 50 $\mu g/m^3$ for 24 h average. Prolonged exposure more than that creates respiratory diseases such as cough, byssinosis, phlegm, blood with phlegm, and, bronchitis, cardiopulmonary diseases, and eye problems (Khan et al. 2024); (Subramaniam et al. 2024); (Xing et al. 2016).

Several embedded systems have been utilized till now, such as ESP32, Raspberry Pi 5, ESP8266, etc. In the case of indoor application, Taştan experimented with an IoT system using ESP8266-12E with few sensors, like PMS7003 for dust monitoring, MH-Z19A for CO_2 concentration, and AHT10 for temperature/humidity (Taştan 2022). However, Yildiz and Sucuoglu employed a system for outdoor monitoring with the combination of GP2Y10, MQ-7, gravity ENS160 for volatile organic compounds, and DHT11, where Raspberry Pi 5 was the microcontroller. They approached IoT along with the idea to merge machine learning (Yildiz and Sucuoglu 2025).

Gomathy et al. studied with an IoT-based cotton dust monitoring system to transfer data at a greater distance by using GP2Y1010AU0F optical dust sensor (Gomathy et al. 2023). A comparative analysis among three sensors (Sharp GP2Y1010AU0F, Shinyei PPD42NS, and Honeywell HPMA115S0-XXX) was conducted by Sivanesan et al., for monitoring dust levels in the textile industry, placing inside mask to measure cotton dust, establishing an IoT-based cotton dust monitoring system that provides real-time data through mobile devices (Sivanesan et al. 2025). Anupriya et al. developed an AI based sustainable system to monitor air quality through dust sensors and by crossing a threshold limit, AI algorithm changes solar powered fan speed and suction power for dust collection (V et al. 2025).

Devi et al. designed an IoT-based dual sensor, DHT11 sensor for measuring temperature and moisture content, and IR sensor for continuous conveyor belt monitoring, integrated with ESP32 microcontroller in a yarn spinning mill. They used heater and cooling fan to control humidity and temperature respectively in a controlled manner (Kalavathi Devi et al. 2022). Balasundaram et al. used different sensors attached to the dyeing machine to measure temperature, humidity, and gas emissions. This IoT-enabled technology collected and analyzed the data to optimize toxic chemicals being used (Balasundaram et al. 2023).

Nahid and Khan constructed a system with Arduino Uno R3 as microcontroller, MQ-8 and MQ-9 as gas sensors that measure toxic gases such as carbon monoxide, methane, hydrogen, and LPG, and LM35 as temperature sensor. The real-time data was uploaded to the ThingSpeak cloud-based platform to be easily accessed with mobile phone application. This study suggested that their system can be used in the textile and garment industry as well as mines where toxic chemicals are exposed (Nahid and Khan 2021). Mobin Hossain et al. developed a system with Arduino UNO as a microcontroller, MQ 6, MQ 7, and MQ 8 as gas sensors, and MQ 135 as air quality sensor. For wireless data transmission, an HC-05 (Bluetooth Module) was employed, which allowed real-time data monitoring through a mobile app (MobinHossain et al. 2022).

This study has proposed a novel combination of three sensors, such as GP2Y1010AU0F, DHT22, and MQ-7 system with ESP8266 NodeMCU. This has been considered only for the workers' safety and monitoring of environmental conditions in RMG factories in Bangladesh. Basically, this highlights an affordable IoT-based microcontroller system, from which data were collected from ESP8266-ThingSpeak-GitHub dashboard through internet. This will lead proper air monitoring and will make easier to take necessary precautions based on daily, weekly, or monthly reports. Eventually, this will serve greatly in the case of reporting sustainability measures related to the working conditions to fulfill certain SDGs.

3. Methodology
3.1. IoT Based Monitoring System
The proposed monitoring system, including temperature, humidity, carbon monoxide, and dust sensors in Table 1, is designed using a modular IoT architecture. Figure 1 presents the schematic of the entire system.

Form the Table 1(a) the Sharp GP2Y1010AU0F was selected as a low-cost optical particulate matter sensor that has been systematically characterized in laboratory and real-world environments, demonstrating acceptable sensitivity and linearity for indoor dust monitoring. Prior studies report that this sensor, while inexpensive and compact, provides reliable trends in PM concentration for research applications (Agrawal et al. 2024; Bučar et al. 2020; Kuula et al. 2020; Wang et al. 2015).

Table 1. Chosen sensors for the system

SI	Sensors	Model	Specifications	Ref
a	Dust Concentration	Sharp GP2Y1010 AU0F	Sensitivity: 0.5V per 0.1 mg/m³ Output at no dust: 0.9V Supply voltage: 5±0.5V	(Sharp Corporation 2006)
b	Temperature-Humidity	DHT22	Temperature range: -40~80 °C Humidity range: 0–100% RH Power supply: 3.3-6V	(Aosong Electronics 2015)
c	CO Concentration	MQ-7	CO range: 10~10000 ppm 10~500 ppm 20~2000 ppm Sensing Resistance: 2KΩ-20KΩ Sensitivity: Rs (air)/Rs (100 ppm CO) ≥ 5 Operating humidity < 95% RH Input voltage: 5±0.1V	(Henan Hanwei Electronics 2006; Thingbits Electronics; Zhengzhou Winsen Electronics Technology Co. 2014)

The DHT22 digital temperature-humidity sensor; Table 1(b) was selected due to its low cost and documented suitability for indoor environmental monitoring, where several studies have used it in Arduino-based or IoT data-logging systems and reported adequate accuracy for research-grade trend analysis (Pereira and Ramos 2022; Siswoyo 2025). Also for Table 1(c) ; the MQ-7 metal-oxide gas sensor was chosen as a low-cost carbon monoxide detector that has been successfully integrated in household and safety monitoring prototypes, demonstrating consistent response to CO levels in practical conditions (Sales-Lérida et al. 2021).These sensors provide an economical yet reliable basis for continuous monitoring of thermal comfort and gaseous air quality parameters (Rathnayake et al. 2024).

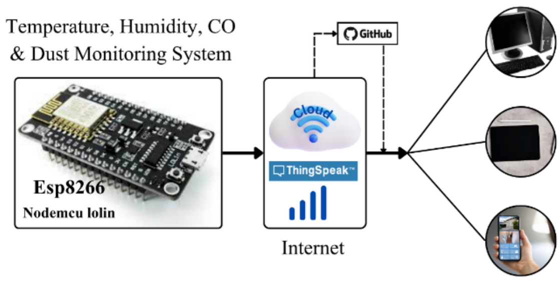


Figure 1. Schematic of the proposed system.

The core sensing and data acquisition are handled by an Esp8266 NodeMCU microcontroller, which interfaces with three sensors: DHT22 for temperature and humidity, MQ-7 for CO detection, and Sharp GP2Y1010AU0F for dust concentration. These components are connected through appropriate voltage divider, passive components, and dedicated wiring for stability and accurate signal conversion (Figure 4).

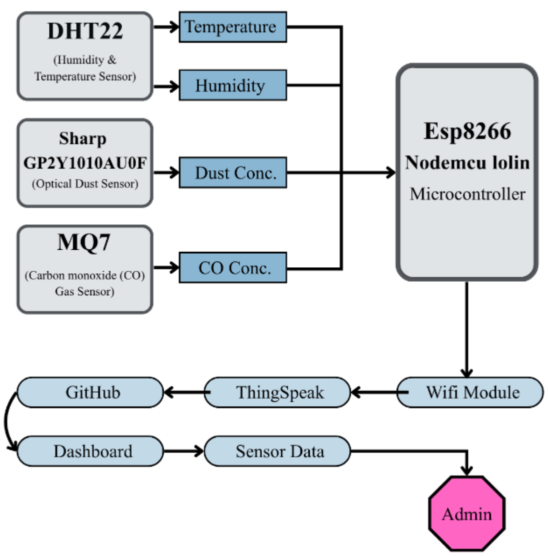


Figure 2. Block diagram of the proposed system.

The block diagram in Figure 2 illustrates the logical flow of sensor data. Environmental readings are gathered, and transmitted after calibration via Wi-Fi to the ThingSpeak cloud platform for remote monitoring and analytics. Integration with GitHub supports linkage with ThingSpeak and collaborative data management for the data visualization.

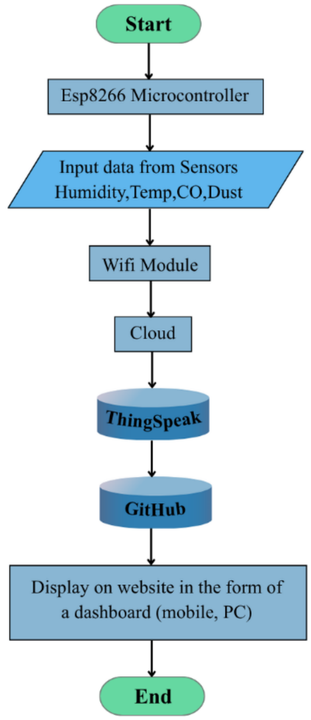


Figure 3. Flowchart of the proposed system.

The system operation is explained in Figure 3, which displays the flowchart outlining key steps: initialization, sensor data input, transmission over Wi-Fi, cloud storage, and real-time dashboard presentation on mobile and desktop devices. The microcontroller initiates data acquisition cycles after calibration, transmits sensor readings securely, and enables users to visualize and analyze environmental parameters from anywhere through the online dashboard.

Figure 4 provides the detailed circuit schematic used in developing the system. Careful attention was given while selecting components and designing the wiring to ensure signal stability and to minimize electrical noise. Voltage divider circuit were implemented to safely interface the analog output of the dust sensor with the digital pin of the NodeMCU, while capacitors and resistors were strategically placed to support both accurate sensing and reliable data transmission.

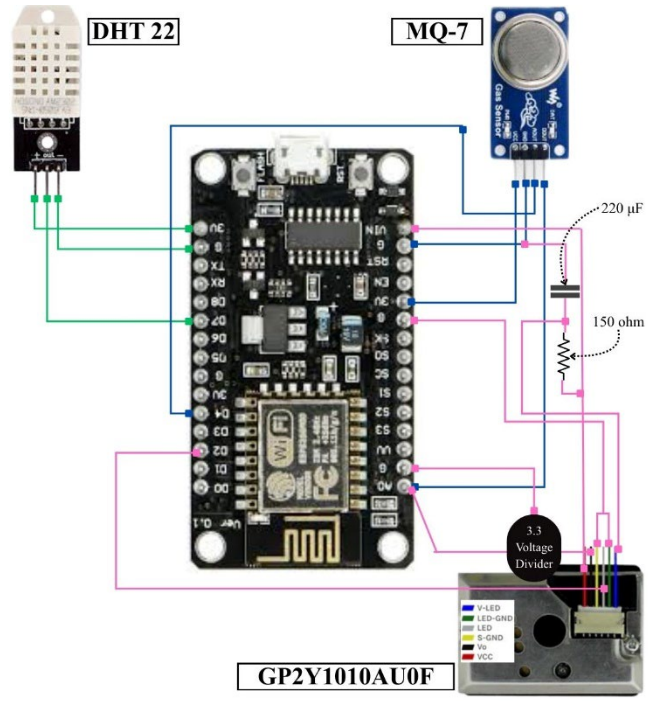


Figure 4. Circuit diagram of the prototype.

This practical hardware configuration underpins the overall system, creating a robust platform for real-time atmospheric monitoring. In the case of the dust sensor, VIN was selected for powering, whereas DHT22 and MQ-7 were given electricity from 3.3V source separately. For digital output, D2, D4, and D7 were chosen for the dust, MQ-7, and DHT22 sensors respectively. To get analog output from dust and MQ-7 sensors, only A0 was the option. Extra devices were needed, like 3.3V divider, 150 Ω resistor, and 220 µF for the dust sensor. Those components are summarized in Table 2.

Table 2. All components in the proposed system

SI	Components	Purpose	Parts
1	ESP8266	Microcontroller	Controlling Unit
2	GP2Y1010AU0F	Optical Dust Sensor	Sensors
3	DHT22	Temperature-Humidity	
4	MQ-7	CO level	
5	AMS1117	3.3V Divider	Accessories
6	150 Ω Resistor	For LED	
7	220 µF Capacitor	Smooth Voltage	
8	Wires	For Connection	
9	Breadboard	Circuit Development	

3.2. Implementation

The whole system module is demonstrated in Figure 5. The system including DHT22, MQ-7, and Sharp GP2Y1010AUOF sensors read data continuously to give information about temperature, relative humidity percentage, CO concentration, and dust concentration.

The chosen place for data acquisition was a RMG factory in Gazipur, Bangladesh serving as a real-time environment. The setup was placed in three sections, such as cutting, sewing, and finishing. This study has been conducted for several days. The duration has been approximately 3-4 hours each day from about 10 am to 3 pm excluding the lunch time. Real-time data was being monitored onsite and online simultaneously through ThingSpeak as well as GitHub.

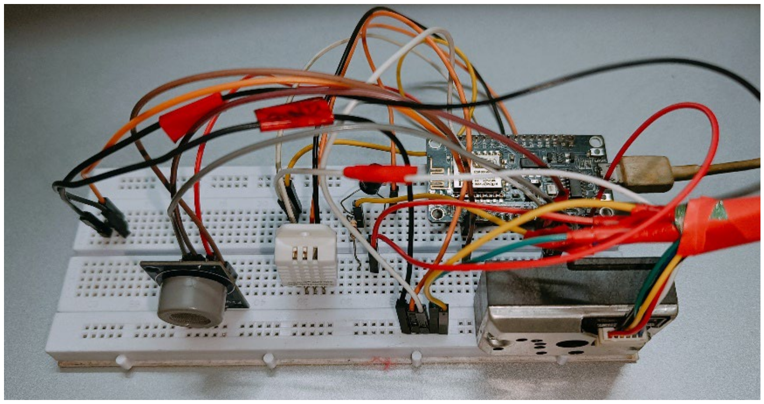


Figure 5. The proposed microcontroller system.

4. Experimental Results

4.1 Monitoring Data on ThingSpeak

Collected data from the sensors was stored in ThingSpeak, which is a familiar cloud platform (Figure 6). For this, a channel was created with 5 fields, such as Dust, AQI, Temp, Humidity, and CO PPM. After connecting with a laptop, data started to come and those data were visible in the form of graphs as fixed.

GitHub was utilized optionally to demonstrate the data in well-defined dashboard structure. That's why ThingSpeak was connected to GitHub link to receive data. Then data were visualized in a predefined way having three tabs, such as Home, Graphs, and Table. Home provided information to check at a glance, table included data from 5 fields with recent 20 data and graph gave illustrations of the fields. Hence, air monitoring dashboard readily serve its purpose by providing concise as well as detail information (Figure 7).

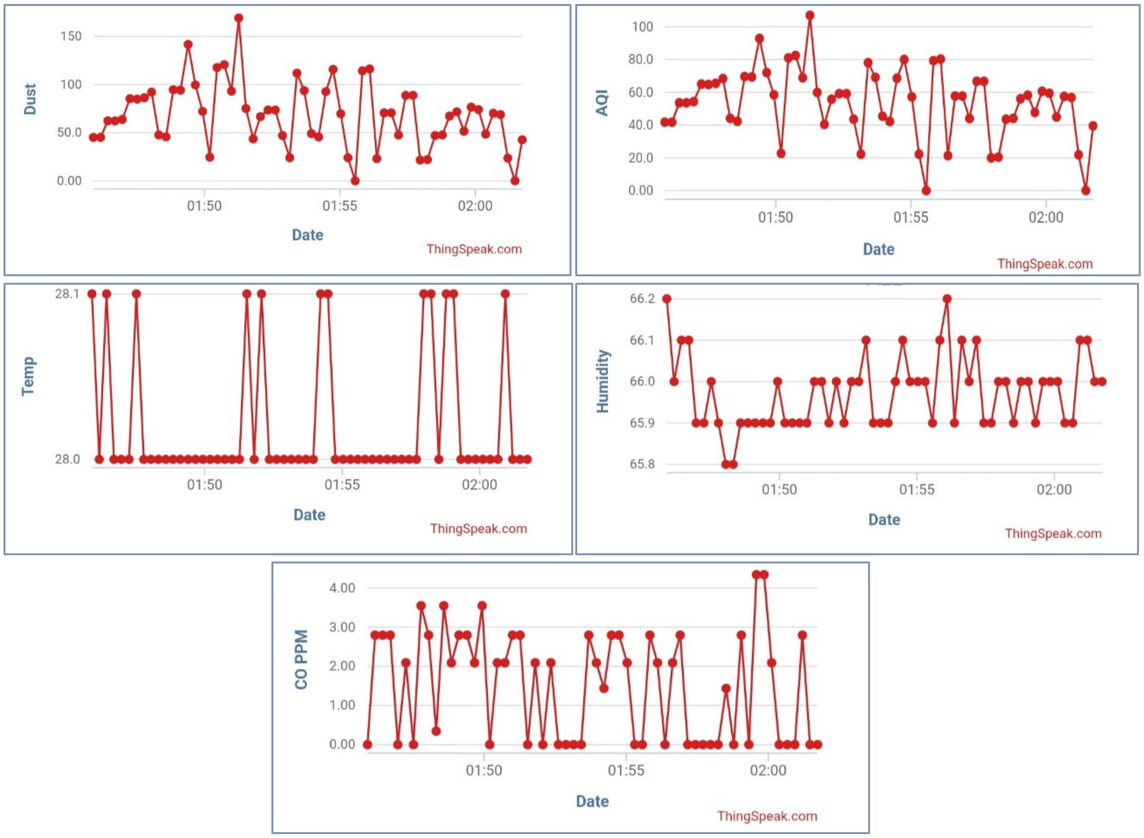
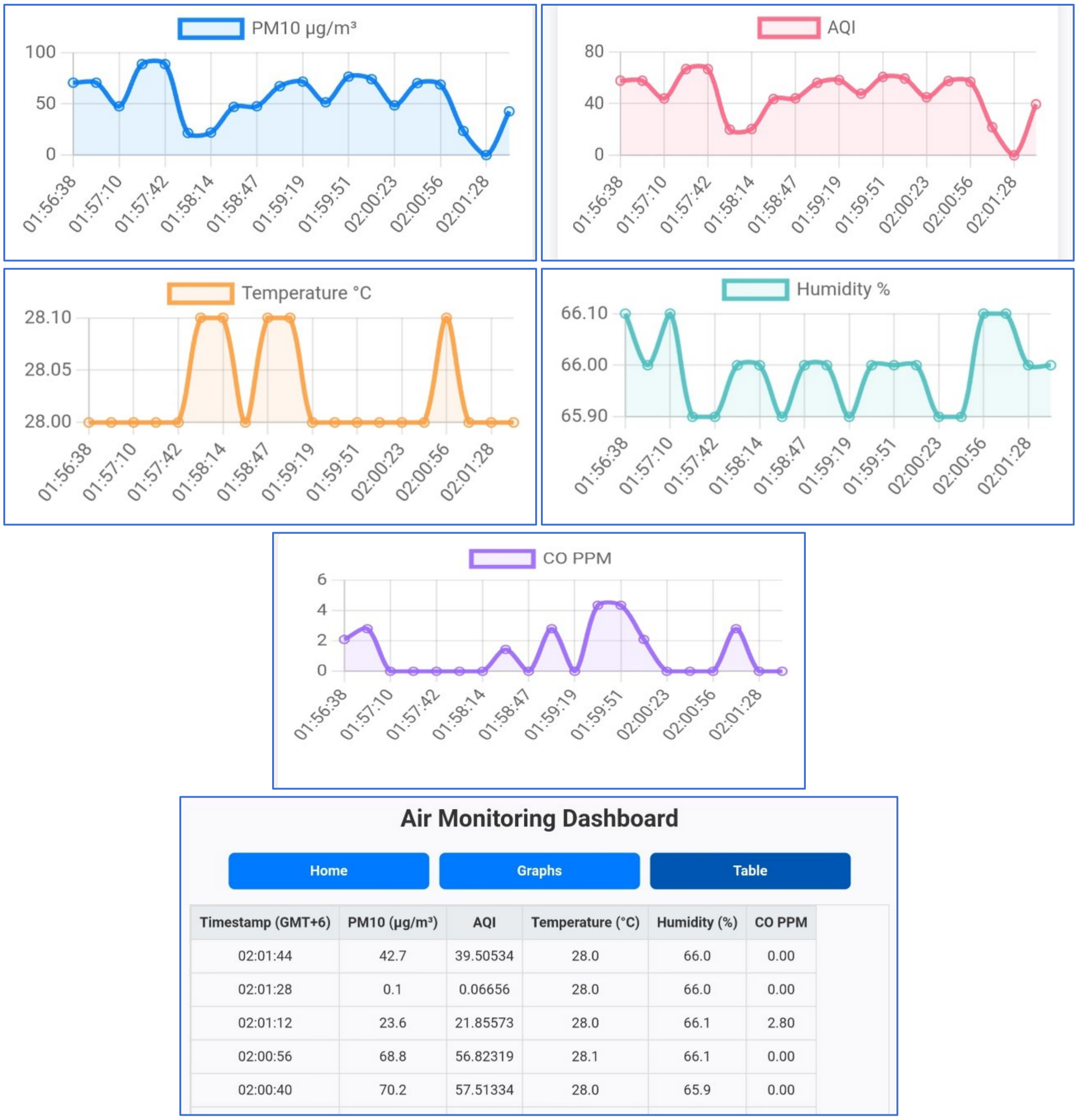


Figure 6. Data monitoring through ThingSpeak



Timestamp (GMT+6)	PM10 (µg/m³)	AQI	Temperature (°C)	Humidity (%)	CO PPM
02:01:44	42.7	39.50534	28.0	66.0	0.00
02:01:28	0.1	0.06656	28.0	66.0	0.00
02:01:12	23.6	21.85573	28.0	66.1	2.80
02:00:56	68.8	56.82319	28.1	66.1	0.00
02:00:40	70.2	57.51334	28.0	65.9	0.00

Figure 7. Air monitoring dashboard on GitHub

4.2 Data Calibration, Filtration & Mean Calculation

Calibrated data given by the sensors required filtration which included excluding data. For example, data below 10 µg/m^3 and above 300 µg/m^3 were removed from the readings of sensor data. Similarly, the initial unstable data for 3-5 minutes were also not considered. Finally, we got individual data which helped to get average data (equation 1) from the sensors. Figure 8 displays actual amount of dust in µg/m^3 for the sewing section of the factory.

$$Average = \frac{x1 + x2 + \cdots + xn}{n} \qquad (1)$$

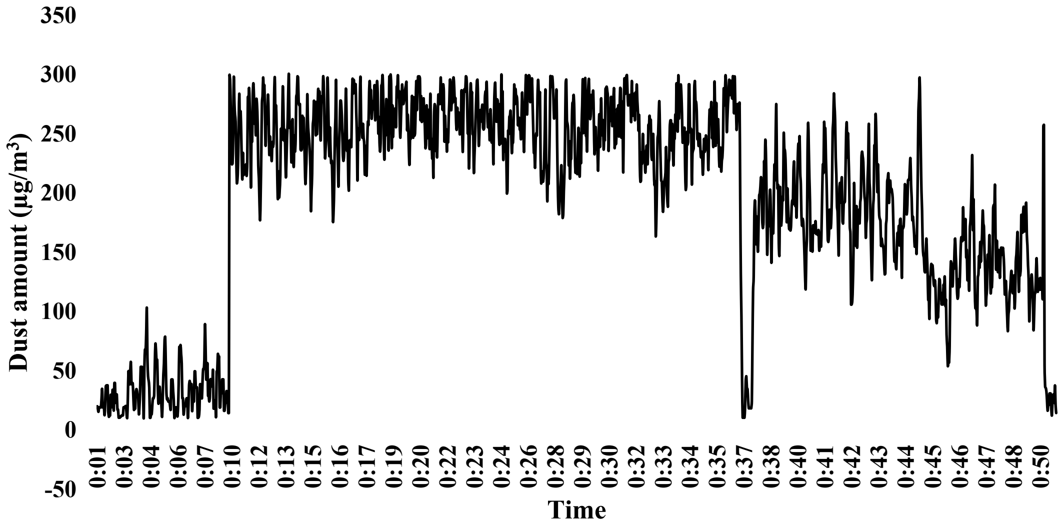


Figure 8. Raw dust concentration (µg/m^3) in sewing section

4.3 Project Analysis

Data from the sensors were uploaded to the cloud platform through internet after a period of each 15 sec. Cloud platform data was linked to the GitHub with a dashboard which was published online. Anyone could access the webpage and could monitor the real-time environmental conditions of the factory.

Dust concentration was given priority as it might cause severe side effects. Hence, data from the sensor was collected separately from cutting, sewing, and finishing section. In Figures 9, 10, and 11 representative data are demonstrated in the form of histogram. In cutting section, moderate level of dust was found throughout the experiment. For example, majority of the values were between 11 & 79. This value was influenced by handling, spreading, and cutting of fabric generating dust. From the findings, dust sensor gave 2 major categories of values in sewing section. One was between 10.3 & 45.3 and the other one was between 220.3 & 290.3. The first one can be regarded as okay while the other one was showing worst condition of the section. Maximum value was recorded in the section indicating dust presence owing to sewing machine, sewing thread, sewing operation, and handling of cut panels, semi-finished products. Suppose, operating overlock sewing machine for a long time can produce a lot of dust as it trims fabric. Unlike the sections mentioned above, finishing section's dust values were comparatively lower. For instance, majority of the values were between 10.8 & 38.16. This can be attributed to less dust causing activities like thread removing, ironing, folding, packing, etc.

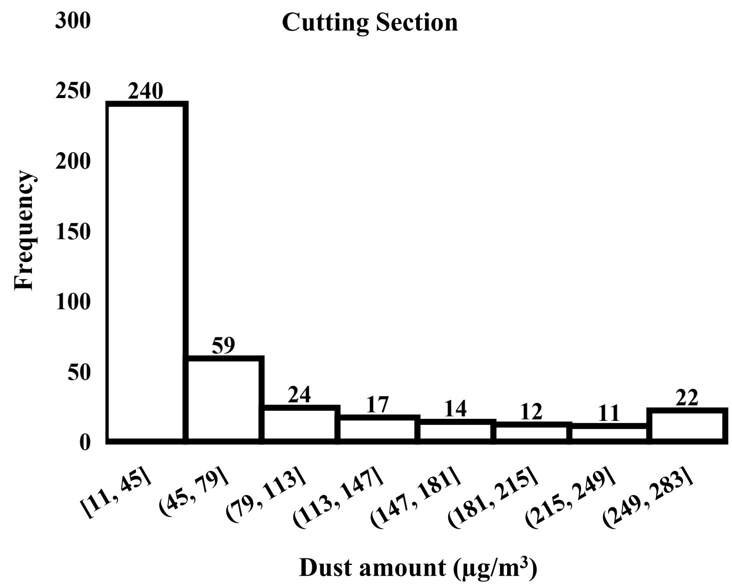


Figure 9. Dust concentration (µg/m^3) in cutting section

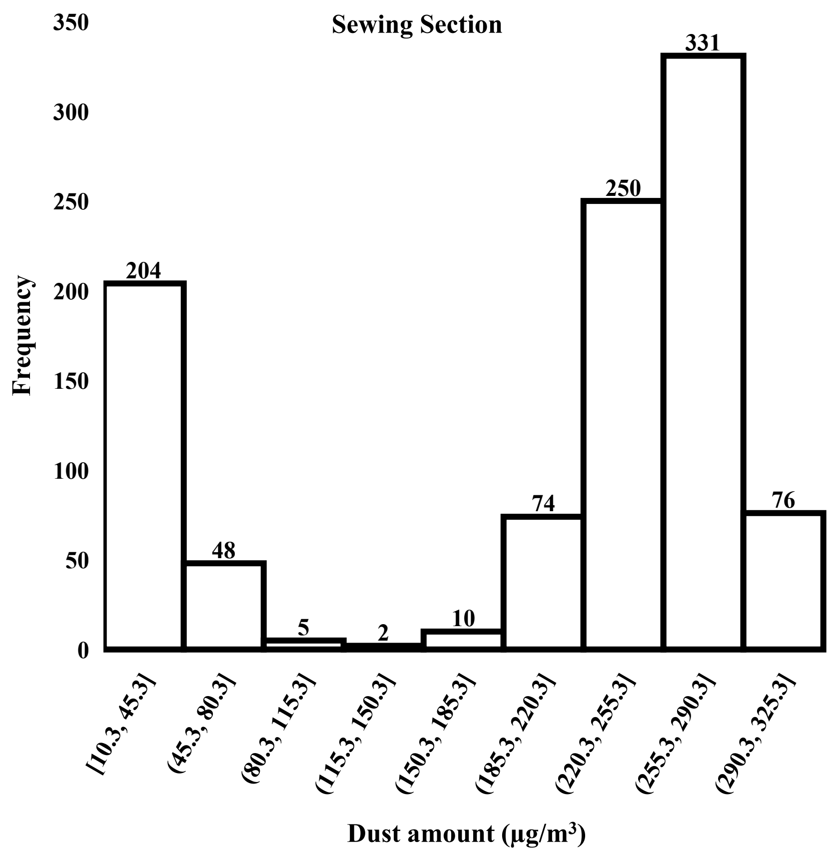


Figure 10. Dust concentration (µg/m^3) in sewing section

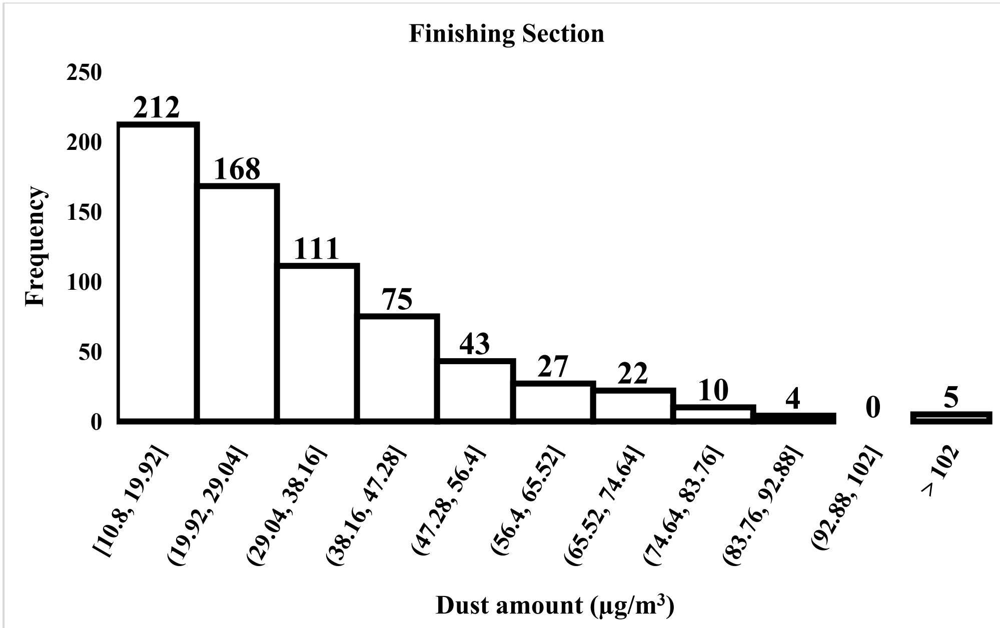


Figure 11. Dust concentration (µg/m^3) in finishing section

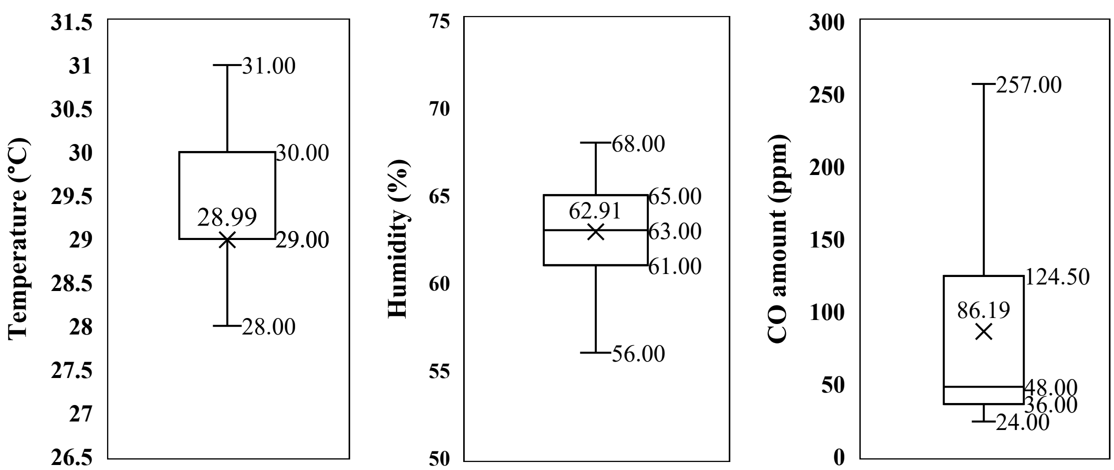


Figure 12. Temperature, Humidity (%), and CO amount (ppm) in different sections

In Figure 12, the results from DHT22 and MQ-7 sensors are summarized and illustrated through box and whisker. In the case of temperature, the value was consistent having a mean of 28.99 with a minimum fluctuation between 28°C to 31°C. Similarly, the average percentage of humidity was 62.91 within the range between 61% to 63%. However, carbon monoxide level was found to be unstable where data were lower initially. With frequent spike of the values, the sensor got an average of 86.19 ppm which is above the safe limit. Hence, prolonged working in these conditions may feel discomfort initially as well as severe health issues in the long run.

5. Recommendation and Future Works

In this experiment, data was read only for several days creating a need for working with big data. So, this idea needs to be experimented for longer periods to check its accuracy level. Also, this was done with cheap sensors without making a prototype of the proposed system. Technically, ESP8266 doesn't have compatibility with dust sensor as it generates analog output upto 5V. So, 3.3V divider was mandatory for the safety of the microcontroller. Again, Sharp GP2Y1010AUOF has not the capability to detect the size of a dust particle, which was considered PM10 overall. This necessitates the application of a capable dust sensor.

So, future initiatives can be utilizing the following things to get better results:
- Better sensors in terms of detecting PM 2.5 or PM 10 accurately
- Well-fitted prototype with a PCB design
- Operating the system for a longer period of time
- Employing ESP32 to overcome compatibility issues
- Combining more sensors for establishing inter-related matrices
- Proper crosschecking and validation

6. Conclusion

The study essentially mentions the prevailing environmental conditions of an RMG factory considering the major three sections. To delve into it, an embedded system based on ESP8266 with three sensors to monitor the environment has been a great asset towards developing a real-time dashboard. From the study, average dust amount was found in the sewing section with the value of 198 $\mu g/m^3$, which symbolized excess dust level. In this circumstance, long time exposure can yield respiratory problems of the workers. However, dust was reported to be less in the cutting and finishing sections comparatively labeled as moderate to safe level of dust respectively. In addition, temperature and humidity were consistent as regular values. Meanwhile CO concentration was inconsistent with an average of 86 ppm, which needed special attention from the compliance department.

Most importantly, this study indicates the overall environmental conditions prevailing in RMG factories. And, the parameters are not aligned with the recommendations of World Health Organization (WHO) and Occupational Safety and Health Administration (OSHA) given in Table 3. Majority of the local factories are supposed to follow the same trend. As a result, people working there are not safe for which proper measures should be taken by the authority (Table 3).

Table 3. Comparison between the study and the standards

Sections	Dust ($\mu g/m^3$)	Temperature (°C)	Humidity (%)	CO (ppm)
Cutting	65 (avg)	28.99 (avg)	62.91 (avg)	86.19 (avg)
Sewing	198 (avg)			
Finishing	32 (avg)			
Recommended	PM10 < 45 (24-hour avg) (WHO)	20-24 (OSHA)	20-60 (OSHA)	<10 (8-hours avg) (WHO)

However, anyone can gather information about dust amount, temperature, humidity, and CO level if he/she has internet access. As a result, this has the potential to monitor local factories in Bangladesh from the factory end and the buyer end. This can not only push towards sustainability but also towards the safety of workers in a great extent. Also, this system is affordable as well as easy to use. To conclude, this study implemented cloud-based monitoring for not only knowing the conditions but also showing concern for the people who are relentlessly working and undergoing untold and unseen health damage in RMG factories.

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Biographies

Mst Mim Khatun is a recent BSc graduate in textile engineering (Apparel), achieving a perfect CGPA of 4.00 out of 4.00 from Atish Dipankar University of Science and Technology (ADUST), Dhaka, Bangladesh. She has been awarded the prestigious “Chancellor Gold Medal” for securing the top position in her department. Currently, she serves as a laboratory assistant in the department of textile engineering at ADUST. In this role, she guides students in practical sessions, maintains lab equipment. Also, she assists in apparel and textile experiments. Along with her regular duties, she has been engaged in several review works in the textile field.

Saiful Islam is a BSc holder in textile engineering from Bangladesh University of Textiles (BUTEX), Dhaka, Bangladesh. Presently he is doing his MSc in Textile Engineering from the same institution. He has also served as a part-time lecturer in the department of apparel engineering at Bangladesh University of Textiles. At the same time, he is serving as a lecturer in the department of textile engineering at Atish Dipankar University of Science & Technology. As an academic person, he has been engaging himself in taking classes along with mentoring students as well as doing research and review works. His research interests include IoT in textile sector, functional finishes in textiles, recycling and circularity in textiles, etc. For this, he has been learning about IoT systems, python and machine learning to cope up with the modern research area.

Md. Fyzul Hasan is a distinguished mechanical engineer who earned his BSc in Mechanical Engineering from Ahsanullah University of Science and Technology (AUST) with the prestigious Dean’s Award for exceptional academic performance. He currently serves as a lecturer in the department of textile engineering at Atish Dipankar University of Science and Technology (ADUST), Dhaka, Bangladesh, where he delivers courses on textile machinery, mechanics, and production engineering while mentoring students in practical and research activities. Simultaneously, he is pursuing an MSc in Mechanical Engineering at the Military Institute of Science and Technology (MIST) to further enhance his expertise. He is passionate about advanced manufacturing and sustainable engineering solutions.

Esmail Hossain Emon is serving as a lecturer in the department of textile engineering at Atish Dipankar University of Science & Technology, Dhaka, Bangladesh. He has also served as a part-time lecturer in the department of wet process engineering at Bangladesh University of Textiles (BUTEX). He took his BSc in Textile Engineering from Bangladesh University of Textiles with the prestigious Dean’s Award for his academic excellence. Presently he is doing his MSc in Textile Engineering from the same institution. He has assisted several students in their final year project works. Simultaneously, he is passionate about research works, like sustainability in wet processing, nanoparticles integrated functional textiles, and IoT applications in textiles.

Shihab Molla is a recent graduate in Textile Engineering (Apparel), achieving a CGPA of 3.70 out of 4.00 from Atish Dipankar University of Science and Technology (ADUST), Dhaka. He has been engaging himself in extracurricular activities along with his studies from his childhood. He and his team were awarded the champion of Inter department debate competition carrying victory to the department of textile engineering as the best speaker. Currently, he serves as a tourist guide showing his excellence in communication. In this role, he guides tourists from receiving them to facilitating their travelling in Bangladesh.

Mohammad Noor Nabi is an assistant professor and chairman of the department of textile Engineering at Atish Dipankar University of Science & Technology (ADUST) in Bangladesh. He is recognized in the textile field who has been awarded the "Research & Development Fellowship" by the Ministry of Science and Technology, Bangladesh, multiple times. Also, he conducted applied research in garment manufacturing, which includes a study on lean waste in the apparel industry. On behalf of the department of textile engineering, he has been playing an active role in enhancing industry-academia collaboration. His last contribution was the university's MoU with Zee Fashion Ltd.

Dr. Shaikh Md. Mominul Alam is a reputed textile researcher and academic, serving as professor and head of the textile machinery design & maintenance department at Bangladesh University of Textiles (BUTEX). He has contributed significantly in functional textiles, textile composites, and nanofiber research. He has published several works on topics such as IoT-based quality control, nano-hybrids, and sustainable textile processing. His contribution has earned national recognition, including repeated research-fellowship awards (e.g., from the Ministry of Science and Technology). He is also associated with Atish Dipankar University of Science & Technology (ADUST) as an advisor in the department of textile engineering.