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Development of Ultra Low-Cost Air Quality Monitoring with Weather Parameters

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Abstract *:* The increase in population in African continent coupled with poor waste management result into high level of air pollution post danger on people. To be able to create a better awareness magnitude of air pollution need to be quantified. To be able to achieve this goal a low-cost gas, dust and weather monitoring device was developed. The device consists of sensing unit (that comprised of gas sensors, dust sensor and weather sensor), microcontroller, real-time clock, MicroSD card shield and graphical liquid crystal display. For analysis, the data is stored in excel format and can be copied directly from MicroSD card. The device was tested and examined through intensive experimental work. The sample data shown on table and plots obtained from the experiment on field display the performance of device, it is clear that there is a close conformity between the data collected by the developed system and the existing standard systems. The need for extra cost and expensive third-party computer software for interfacing to download data from the logger have been eliminated. The system will be helpful in monitoring and recording of gas emission from dump site and atmospheric parameters.

Keywords: Air pollution, gas sensor, weather parameters, data logger, waste management.

I. INTRODUCTION

Air pollution is increasing across the African continent due to poor waste management and lack of control, and yet there are few actions and steps being taken to improve air quality. It will increase morbidity and mortality, reduce economic productivity, impede human capital formation, and hamper development in the absence of deliberate intervention. African urban populations are among the most vulnerable to dangerous levels of air pollution (Petkova *et al*., 2013; Leman, *et al.*, 2013; WHO, 2018). The lack of action is largely due to a lack of awareness about the dangers of air pollution, as well as a lack of evidence to quantify the scale and magnitude of air pollution in African cities, combined with the resource constraints of setting up and maintaining a monitoring network, as well as expertise to process and analyze data for local interventions (Arun *et al.*,2017; Okure *et al.*, 2022).

To effectively combat air pollution in African cities, city authorities, governments, the private sector, and the general public must begin to recognize air pollution as a priority challenge. This requires data and contextual evidence demonstrating the scope and magnitude of air pollution as well as its effects on urban health. Unfortunately, air pollution in Nigeria and many African cities is under-monitored, owing to the high cost of air quality monitoring devices.

Nigeria, in particular, has less than 19 publicly accessible continuous monitoring installations, equating to one monitoring device for every 10-15 million people. With this in mind, low-cost sensors, rather than more expensive technologies that necessitate trained personnel and high investment costs, may be a viable option for addressing the scarcity of air pollution measurements in Africa, and particularly Nigeria.

II. METHODOLOGY

Figure 1 illustrates a block diagram of a developed gas, dust, and weather parameters monitoring system, which encompasses chemresistor gas sensors, dust sensors, temperature, relative humidity, pressure, and altitude sensors (BME280), wind speed, wind vane, real-time clock, MicroSD card shield, microcontroller, and graphical liquid crystal display (GLCD).

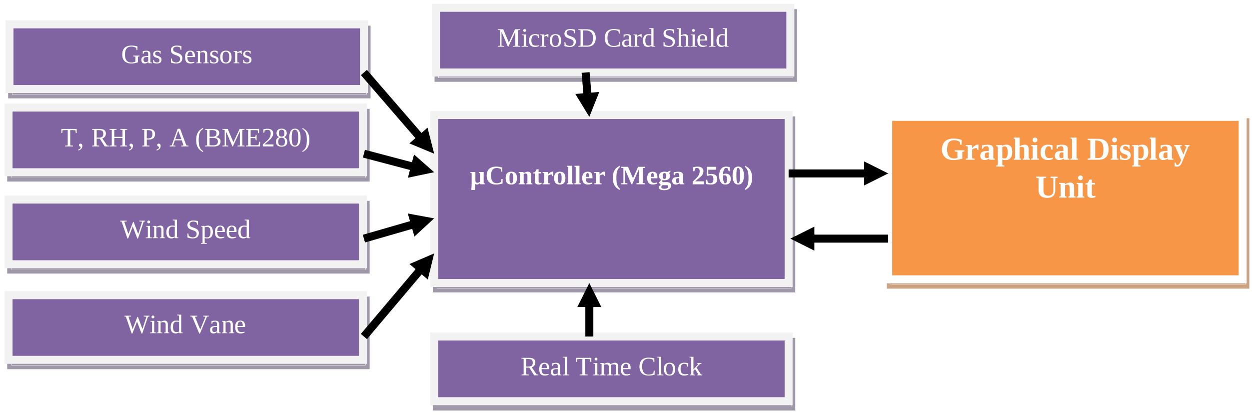

Figure1. The Block Diagram of Gas and Dust Monitoring Device

2.1 SENSORS

i. Chemresistor Gas Sensors

a. General working principle of chemresistor gas sensors

The potentiality of a Gas sensor to detect gases is determined by the capability of the chemiresister to conduct current. Tin Dioxide (SnO_2), an n-type semiconductor with free electrons, is the most commonly used chemiresistor (also called the donor). In most cases, the atmosphere contains more oxygen than combustible gases. The oxygen particles attract the free electrons in SnO_2, pushing them to the SnO2 surface. Because there are no free electrons available, the output current is zero.

When the sensor is placed in an environment containing toxic or combustible gases, the reducing gas reacts with the adsorbed oxygen particles, breaking the chemical bond between oxygen and free electrons and releasing the free electrons. As the free electrons have returned to their original state, they can now conduct current; this conduction will be direct to the number of free electrons available in SnO2, with more free electrons available if the gas is highly toxic.

b. Basic electronics circuit of MQ series (MQ135, MQ4, MQ7)

These sensors are typically available as modules (shown right), which include the gas sensor and a comparator IC. The pin out of the gas sensor module that can be connected to any analog input comprises four terminals (shown in Figure 2).

i. **Vcc** – Power supply
ii. **GND** – Power supply
iii. **Digital output** – This pin gives an output either in logical high or logical low (0 or 1) that means it displays the presence of any toxic or combustible gases near the sensor.
iv. **Analog output** – This pin gives an output continuous in voltage which varies based on the concentration of gas that is applied to the gas sensor.

Because the output of a gas sensor is so small (in mV), an external circuit is required to obtain a digital high low output from the sensor. A comparator (LM393), used as an adjustable potentiometer; resistors and capacitors are found used as sample-and-hold (Shown in Figure 3).

The LM393's purpose is to read the sensor's output, compare it to a reference voltage, and display whether the output is logically high or not. The potentiometer's purpose is to set the required gas threshold value above which the digital output pin should go high.

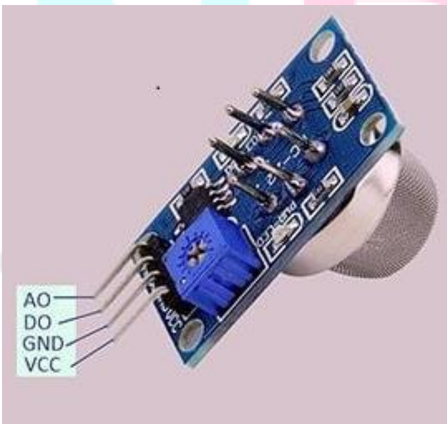

Figure 2. Picture View of Sample of Gas Sensor

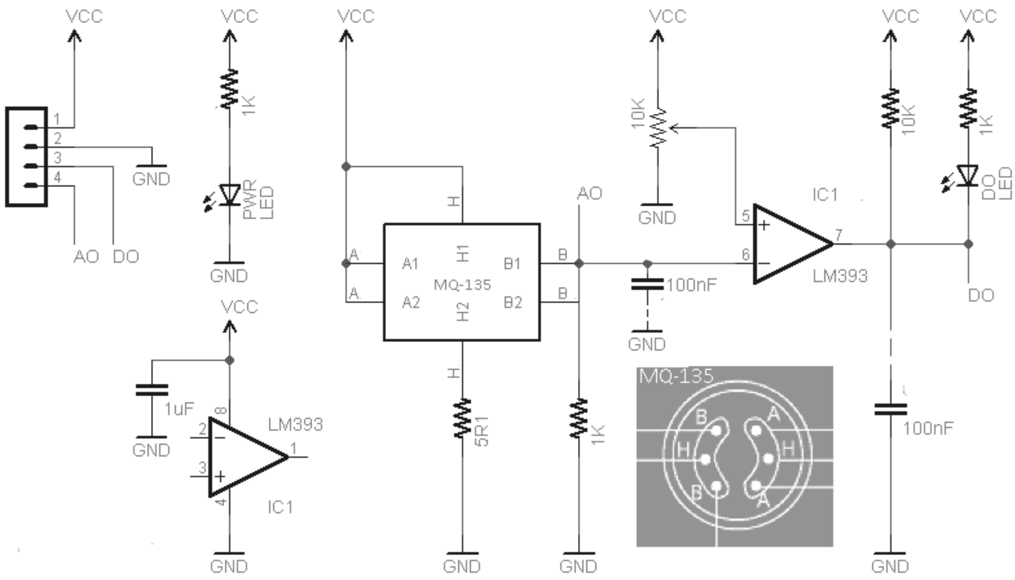

Figure 3. Digital Output Circuit for Gas Sensor Output

2.2 Temperature, Humidity and Pressure Sensor with BME280

The BME280 from Bosch is a precision sensor that is useful in a wide range of areas of application ranging from weather monitoring to gaming controls to altitude measurement where the accuracy of a few feet is required. This sensor is easy to use, pre-calibrated and requires no additional components. It can be powered and connected to a microcontroller immediately. It will begin measuring relative humidity, temperature, barometric pressure, and altitude in no time when the appropriate driving embedded program is used.

a. **Measuring temperature**

Temperatures measured by the BME280 range from -40°C to 85°C. The accuracy is 1.0°C within a temperature range of 0 to 65°C; *outside that range, the accuracy drops to 1.5°C.* Internally, this temperature measurement is used to calibrate the pressure and humidity sensors. *The measured temperature is usually slightly higher than the actual temperature because the sensor self-heats. If this is critical to the research, compare the measured temperature to the exact temperature and, if necessary, apply an offset.*

b. **Measuring humidity**

The BME280 can measure relative humidity from 0 to 100% with a 3% accuracy. The sensor can measure up to 100% humidity over a temperature range of 0 to 60°C, according to the datasheet. However, at extremely high and low temperatures, the maximum measurable humidity decreases. When comparing dry and wet thermometers at temperatures above 60oC, a correct factor can be included.

c. **Measuring pressure**

The BME280 has an absolute accuracy of 1 hPa and can measure pressure between 300Pa and 1100 hPa. Full accuracy is obtained over the temperature range of 0 to 65°C, resulting in an altitude measurement accuracy of about 1 meter. The accuracy drops to 1.7 hPa outside of that range.

d. **Calculating altitude / elevation**

The BME280 is capable of measuring pressure with such precision (low altitude noise of 0.25m) that it can also be used as an altimeter with one-meter accuracy. It can be used to determine both absolute and relative altitude. Absolute altitude is the height above sea level (MSL), whereas relative altitude is the height above ground level (AGL). Because it can directly measure pressure, it can accurately calculate relative altitude. In addition, the SEA LEVEL PRESSURE constant is provided in accordance with sea level pressure at a specific location to obtain an accurate absolute altitude measurement.

2.3 Particles Dust Sensor ZH03B (PM1, PM10 and PM2.5)

The ZH03 Laser Dust sensor module is a common type, small size sensor that detects dust particles in the air using the laser scattering principle, with good selectivity and stability. It is simple to use, with UART and analog outputs. (Ewetumo *et al*,. 2018; Ewetumo *et al*,. 2019; Adong *et al.*, 2022)

2.4 Wind Speed and Wind Vane

a. Wind Speed Sensor

The three Cups type (Plate 3.4) Wind Speed Sensor out Voltage range from 0-5 V. Anemometer that can be measured the wind speed. The external power requirement is 9-24 V and the wiring to Arduino in the same ground with external power's GND. Arduino Program to estimate the wind speed according to output voltage is as follow:

```
int sensorValue = analogRead(A0);
float outvoltage = sensorValue * (5.0 / 1023.0);
Serial.print("outvoltage = ");
Serial.print(outvoltage);
Serial.println("V");
int Level = 6*outvoltage;//The level of wind speed is proportional to the output voltage.
Serial.print("wind speed is ");
```

```
Serial.print(Level);
Serial.println(" level now");
Serial.println();
delay(500);
```

b. Wind Vane

The wind vane consists of a free-run potentiometer with a 358-degree resistance contact and 10 k values. It has a pointer that points to the actual North, and the resistance value is 0 and 10 kΩ. The pointing direction was obtained by determining the number of cardinal points of interest and their equivalent resistance values. The ten kΩ is divided by 16 when designed with 16 cardinal points. Figure xx shows the diagram of the potential resistance circuit that converts the resistance to voltage equivalent, representing the direction in 16 cardinal points, as shown in Table 1.

Table 1. Value of Resistance and Voltage for each Cardinal Point

Cardinal Point	Range of Resistance Value				Equivalent Value in Voltage			
N	9687.5	10000	0	312.5	4.84375	5	0	0.15625
NNE	312.5			937.5	0.15625			0.46875
NE	937.5			1562.5	0.46875			0.78125
NEE	1562.5			2187.5	0.78125			1.09375
E	2187.5			2812.5	1.09375			1.40625
SEE	2812.5			3437.5	1.40625			1.71875
SE	3437.5			4062.5	1.71875			2.03125
SSE	4062.5			4687.5	2.03125			2.34375
S	4687.5			5312.5	2.34375			2.65625
SSW	5312.5			5937.5	2.65625			2.96875
SW	5937.5			6562.5	2.96875			3.28125
SWW	6562.5			7187.5	3.28125			3.59375
W	7187.5			7812.5	3.59375			3.90625
WSW	7812.5			8437.5	3.90625			4.21875
NW	8437.5			9062.5	4.21875			4.53125
NNW	9062.5			9687.5	4.53125			4.84375

III. DATALOGGER AND DISPLAY UNIT

The data logging unit consists of arduino mega 2560 microcontroller, MicroSD card shield, real time clock (RTC) and Display.

3.1 Microcontroller

The microcontroller is small size computer on a single IC containing a processor core, memory, and programmable input-output peripheral. Microcontrollers are designed for stand-alone computer applications, in contrast with microprocessors used for personal computers and other general-purpose applications. Atmega2560 is a low-power, high-performance, CMOS 8-bit microcontroller based on the AVR-enhanced RISC architecture. Atmega2560 provides 256 Kbytes with 8 Kbyte RAM of in-system self-programmable memory with read-while-write capability and 2 Kbyte EPROM. The microcontroller coordinates the instrument's activities, from accepting data from the Senor to processing data to storing and displaying information.

3.2 MicroSD card shield

The MicroSD card shield module was interfaced with a microcontroller using the Serial Peripheral Interface (SPI) protocol standard. The module is designed for dual-voltage power supplies. The interface module can be used with two logic levels, i.e., CMOS at 3.3 volts or TTL at 5 volts.

3.3 Real time clock (RTC)

The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for the leap year(https://how2electronics.com/arduino-ds3231-real-time-clock-temperature/). The clock operates in a 24-hour or 12-hour format with an AM/PM indicator. Two programmable time-of-day alarms and a programmable square-wave output are provided. Address and data are transferred serially through an I2C bidirectional bus (https://embeddedexpert.io/?p=1326).

3.4 Graphical display (liquid crystal display)

The ST7920 display platform enables the use of the ST7920 with Arduino. The 3-wire SPI bus connects the components for information displays. It's a monochrome LCD graphic display. The E, R/W, and RS pins can be connected to any Arduino data port. During SPI communication, it is critical to connect the PSB on the LCD to GND.

IV. Result and Discussion

The device's complete circuit design is assembled on the plastic case shown Figure 4 and Figure 5. During testing, some routing foods (banana, decay bean cooked, sour soup) and urinary were brought to the gas sensors by blowing a fan against it. Each of the gas sensors immediately responds to it to varying degrees. The value of gas sensors increases as the speed of the blow increases.

The temperature, relative humidity, pressure, and altitude were measured using standard equipment at the Meteorology and Climate Science department at the Federal University of Technology in Akure, Nigeria.
The device was installed at the dump site in Igbatoro, Akure, Nigeria, to execute the field test, as depicted in Figure 6. Table 2 shows the sample data obtained from the device. On 1/3/2022, this device was installed in Igbatoro, Akure, at longitude 07.22032o N and latitude 05.24031o E. Table 2 shows the sample data stored at one minute averaging.
Figures 7 and 8 depict the relationship between temperature and relative humidity with potential gases emitted at the dump site. The CH4 and CO levels demonstrate the fluctuation of gases emitted as a function of temperature and relative humidity. After examining the field, the developed device shows excellent detector performance and data logging.

Table 2. Sample Data from Device

Date	Time	Temp (oC)	RH (%)	Pressure (mbar)	Altitude (m)	NH3 (ppm)	CO (ppm)	MQ-CO (ppm)	NO2 (ppm)	CH4 (ppm)	PM1.0 (ppm)	PM2.5 (ppm)	PM10 (ppm)
1/3/2022	11:25:07	27	78	975	322.24	0	0	0.56	0	1.14	0	0	0
1/3/2022	11:26:08	27	77	975	322.07	0	0	0.32	0	0.6	0	0	0
1/3/2022	11:27:08	27	76	975	322.24	0	0	0.23	0	0.4	0	0	0
1/3/2022	11:28:08	27	76	975	322.07	0	0	0.18	0	0.29	0	0	0
1/3/2022	11:29:08	27	76	975	322.24	0	0	0.14	0	0.23	0	0	0
1/3/2022	11:30:10	27	77	975	322.24	0	0	3.26	0	9.08	0	0	0
1/3/2022	11:31:10	27	77	975	322.24	0	0	2.96	0	8.1	0	0	0
1/3/2022	11:32:10	27	77	975	322.24	0	0	2.61	0	6.99	0	0	0
1/3/2022	11:33:09	27	76	975	322.24	0	0	2.44	0	6.44	0	0	0
1/3/2022	11:34:09	27	79	975	322.58	0	0	2.12	0	5.48	0	0	0
1/3/2022	11:35:10	27	79	975	322.41	0	0	2.05	0	5.26	0	0	0
1/3/2022	11:36:09	27	79	975	322.58	0	0	1.92	0	4.86	0	0	0
1/3/2022	11:37:09	27	80	975	322.41	0	0	1.84	0	4.63	0	0	0

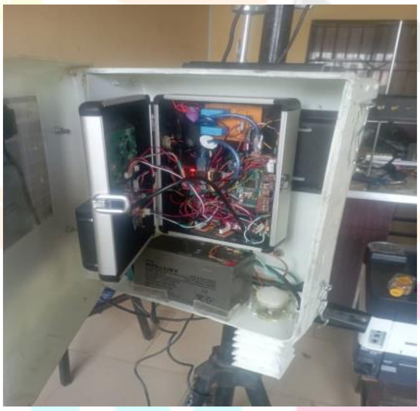

Figure 4: Internal of Constructed Air Pollutant Data Logger unit for data storage with Sensors

Figure 5: Assembling of Constructed Air Pollutant Data Logger unit for data storage for Laboratory Test

Figure 6: Field Installation and Data Collections

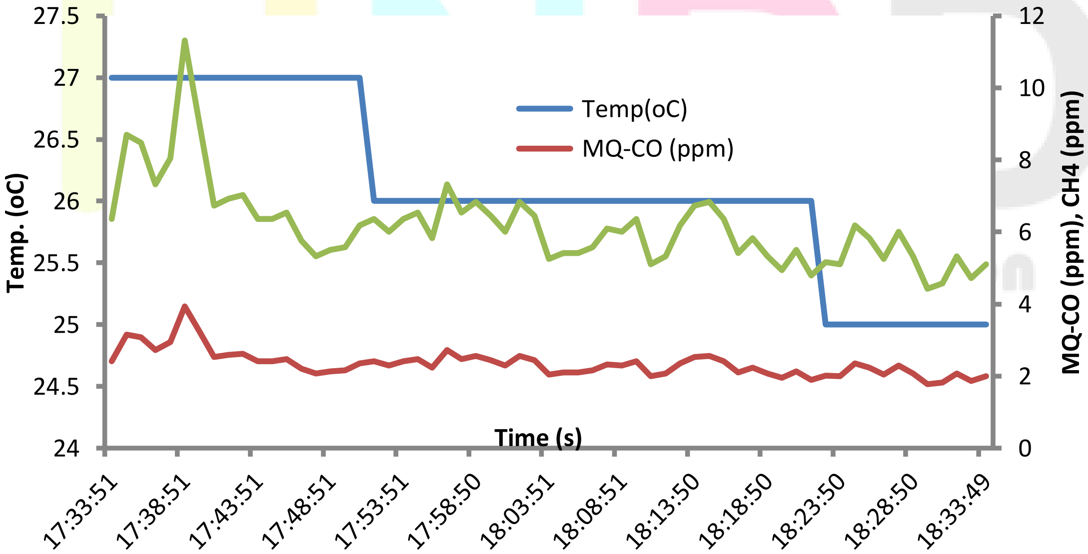

Figure 7. Sample Data Analysis at Igbatoro, Akure, Nigeria (Temp. and Gas Release from Dump Site) on 1/3/2022

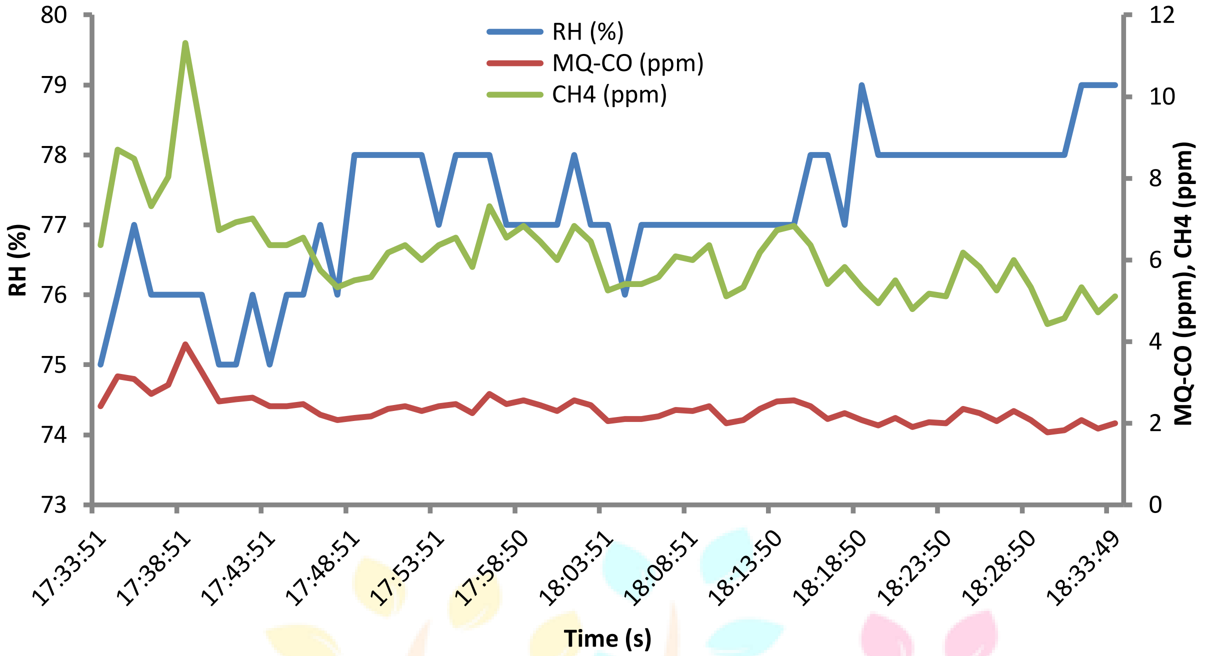

Figure 8. Sample Data Analysis at Igbatoro, Akure, Nigeria (RH and Gas Release from Dump Site) on 1/3/2023.

V. CONCLUSION

This work has successfully developed a low-cost gas, dust, and weather monitoring device. Logged data is saved as comma-separated values that can be analyzed in an Excel sheet. From the tables and plots obtained from experiments during the examination of the device, it is clear evidence that there is a close conformity between the data collected by the developed system and the data collected by the existing, expensive systems. The need for extra cost baud rate and expensive third-party computer software for interfaces to download data from the logger has been eliminated. Compared to imported gas, dust, and weather data logger monitoring devices, the developed device is about 78.3% less expensive. Compared to another commercially available similar monitoring system, the performance proved reliable and flexible, with ease of maintenance. Therefore, the gas, dust, and weather monitoring device is a better choice in terms of cost and maintenance. The developed device is mass-producible, can be installed in major cities, and can be used for long-term measurements and recordings from various atmospheric pollution sensors.

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