Indonesian Journal of Electrical Engineering and Computer Science
Vol. 32, No. 1, October 2023, pp. 545~554
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v32.i1.pp545-554

Low-cost mobile air quality monitoring based on internet of things for factory area

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Article Info

Article history:

Received Jul 11, 2022
Revised Jul 10, 2023
Accepted Jul 18, 2023

Keywords:

Ambient air quality
Factory area
Internet of things
Low cost
Mobile monitoring

ABSTRACT

The most significant effect of industrialization is air pollution. Air pollution monitoring has become an important requirement in affected areas. With the advancement of electronic sensor technology and the internet of things (IoT), there are plenty of remote ambient air quality monitoring systems have been developed by measuring the levels of major air pollutants such as Sulfur Dioxide, (SO2), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Ozone (O3), and particulate matter (PM). However, other hazardous gases such as Hydrogen Sulfide (H2S), Carbon Monoxide (CO), and Ammonia (NH3) also have the potential to appear in factory areas, especially factory areas located in rural areas. Therefore, this study proposes a low-cost mobile ambient air quality monitoring system by measuring CO, H2S, and NH3 gas levels that are easy to implement. The proposed system has been tested in factory areas and rural areas where factory pollutants can be mixed with agricultural pollutants. The test results show that the proposed system can detect CO, H2S, and NH3 gas levels. The levels of CO, H2S, and NH3 gases at the test site were still at a safe level. A mobile remote monitoring scheme by utilizing Thinger.io as an IoT platform also works very well.

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1. INTRODUCTION

Air is an important component for the existence of biological life on earth [1]. Good air quality which is characterized by the composition of life-supporting gases such as adequate and proportional oxygen, and minimal levels of gases that are harmful to life, will support a good quality of life so that individuals living in the environment have good physical and psychological health and fitness as well as higher life expectancy [2]. As human civilization advances, air quality is getting worse due to deforestation, mining, urbanization, and the conversion of the natural biological environment [3]. The reduction in air quality is further exacerbated as the human civilization entering the industrialization era [4]. As for today, the advancement of a civilization is marked by the industrialization of the civilization. Although industrialization has tremendous economic and cultural impact, industrialization also has a negative impact, especially on the environment, including air pollution which also harms the living life around it [5].

Air emissions resulting from factory activities in industrial areas are categorized as pollutants because they contain hazardous substances such as particulate matter and harmful gases [6], [7]. These particulates and harmful gases can cause health problems in the human respiratory system such as asthma to lung cancer, in addition to heart diseases and stroke can also be caused by industrial air pollution [8], [9]. The diminished health quality of human resources in industrial areas can reduce industrial productivity and increase the cost of health services to reduce profits from operating the industry [10], [11]. Besides being harmful to human health, air pollution from factories can also pollute the environment, especially the plants and trees around the factory [12]. So, if there is an agricultural area around the factory, air pollution from factories can reduce the yields of the agricultural products [13].

To control air pollution due to factory activities in industrial areas, it is necessary to implement ambient air quality monitoring (AQM) in the factory area and its surroundings to obtain information on the levels of harmful gases in the specified area [14]. With the maturity of electronic sensor technology and the several other studies have solved the problem of monitoring using internet of things (IoT), AQM Ambient remotely and mobile can be implemented easily [15], [16]. With an open-source scheme, electronic sensor devices that are quite reliable and devices with IoT technology can now be obtained easily and at an affordable cost [17], [18]. There have been many kinds of research and articles that have developed low-cost ambient air quality monitoring systems in industrial areas using IoT technology [19]. however, the types of pollutants in these past studies were only limited to the types of air pollutants listed in the typical major ambient air pollutant according to air pollution mitigation guideline standards such as Sulfur Dioxide, (SO2), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Ozone (O3), and Particulate Matter (PM) [20]. Meanwhile, other harmful gases have the potential to appear in the factory area, such as hydrogen sulfide (H2S), and ammonia (NH3) [21]. Hydrogen sulfide can emerge from rayon textile factories and can form other pollutants such as SO2 [22], [23]. Ammonia can appears as a result of industrial processes and can form other air pollutants such as ammonium sulfate [24], [25].

The purpose of this research is to design a low-cost remote air quality monitoring device using IoT technology. Air quality monitoring is carried out by monitoring the levels of harmful gases that do not categorize as major air pollutants, which include CO, H2S, and NH3. The measurement data is then transmitted using the IoT technology scheme. The hardware and software materials in the design of this proposed device use low-cost and open-source materials so that AQM can be implemented easily by anyone. Therefore, the results of this study are to determine the levels of CO, H2S, and NH3, in the factory area using a low-cost and reliable ambient air quality monitoring device that is easy to implement so that the rural communities around the factory can easily implement the mobile ambient AQM proposed in this study.

2. METHOD

The study location for testing the proposed device is located at Politeknik Enjinering Indorama, Jatiluhur District of Purwakarta Regency in West Java Province, Indonesia (Latitude: -6.554492277351455, Longitude: 107.41877034284663). Politeknik Enjinering Indorama is a polytechnic campus located in the rural area of Jatiluhur District and the industrial area of PT Indorama. Politeknik Enjinering Indorama is about 300 meters from the coal power plant owned by PT Indorama and about 350 meters from PT Indorama Polychem Indonesia (IPCI) which is a chemical factory with products including PET (Polyethylene Terephthalate), polyester fiber, and filament. The distance in Google Maps is shown in Figures 1 and 2. Coal power plants and chemical factories are known as potential sources of air pollutants including carbon monoxide (CO) hydrogen sulfide (H_2S), and ammonia (NH_3) [20], [21], [24], [25]. With these situations, Politeknik Enjinering Indorama is designated as the location for remote testing of air quality monitoring prototypes in industrial areas using IoT technology.

Figure 1. Distance of sensor system from coal power plant based on Google Maps

Figure 2. Distance of sensor system from PT Indorama Polychem Indonesia (IPCI) based on Google Maps

2.1. System design and architecture

The general concept of the working principle of the proposed device is to detect CO, H_2S, and NH_3 gas levels at a predetermined place. The sensor reading data is displayed on the on-site monitor device and then sent to the server via the internet using a Wi-Fi module device. The data stored on the server can then be accessed by mobile devices. Figure 3 shows a flow diagram of the working principle of the proposed device by referring to a low-cost air quality sensor/monitoring framework introduced by Morawska *et al.* [19]. In the framework, there are sections such as Sensors, Monitor, Deployment, and Data. The sensor part requires a device that can detect air gas levels The data obtained is then processed on the main processing device of the sensor-monitor system where data processing can be in the form of data selection or data assessment The temporary processing results are displayed on the monitor device and sent to the server at the deployment stage via a wireless internet communication device. The system can also be divided into measurement stations, servers, and mobile (user).

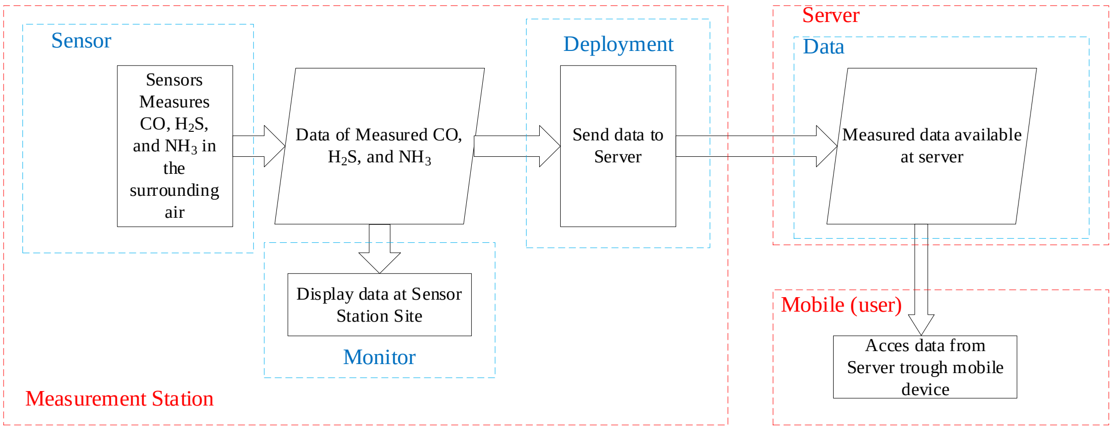

Figure 3. The framework of low-cost AQM

This section discusses the hardware needed to implement the conceptualized system architecture. Referring to this research objective, the selected materials used in the development of the proposed system are low-cost materials. The measurement station uses Arduino UNO [26] with ATMega328P microcontroller-based as the main processing device. The MQ136 sensor is used to measure H_2S gas level, the NH_3 gas sensor uses the TGS2602, and the CO gas sensor uses the MQ7 sensor. In the Measurement Station, a 16x4 LCD is applied as a real-time display of CO, H2S, and NH3 levels on-site, three LEDs as warning indicators for each gas, and a buzzer to provide a hazard warning if the gas level has entered a dangerous level. Wireless internet communication at the measurement station can be done using the NodeMCU ESP8266 module [27] so that the measurement station can connect to the Wi-Fi network. The server used in the design of this proposed device uses Thinger.io's cloud platform IoT which is open source. By using Thinger.io, data can be accessed using an android mobile device so that ambient AQM can be done on a mobile basis. The hardware and software diagram of the proposed system is shown in Figure 4.

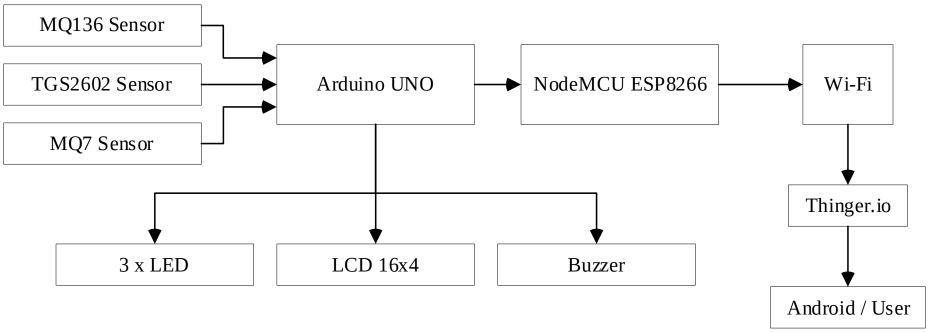

Figure 4. Hardware and software block diagram of proposed mobile ambient AQM

2.2. Materials and Implementation

The MQ7 sensor [28] which is used to detect the presence of CO gas (carbon monoxide), is formed by 3 2OAl ceramics, a thin layer of SnO2, electrodes, and heaters which are combined in a crust made of plastic and stainless. In this sensor, there is a sensor resistance value (R_S) which can change when it detects gas, and also a heater that is used as a sensor cleaner from outside air contamination. This sensor requires a heating voltage (power heater) of 5V, load resistance (RL), and the sensor output is connected to the ADC pin (analog to digital value converter) so that the output can be displayed in the form of a digital signal. When it is turned on for the first time, the sensor needs a warm-up time, which according to the datasheet is about 90 seconds.

MQ136 gas sensor [29] has a high sensitivity to SO2, can also be used to detect other vapors containing Sulfur such as H_2S. This sensor requires an input voltage of 5V. In this sensor, there is a sensor resistance value (R_s) which can change when exposed to the gas, and also a heater that is used to clean the sensor room from outside air contamination. This sensor requires a simple circuit with load resistance (R_L) and requires a power heater of 5V. The sensor output is in the form of analog data.

TGS 2602 gas sensor [30] is a gas sensor to determine the level of gases outside the room such as ammonia (NH_3). This sensor has an internal heater and requires a heating voltage. Where to operate it requires a separate additional circuit. This internal heater is used to heat the sensor surface. When the sensor temperature is evenly distributed over the entire surface, the reading becomes more stable. TGS 2602 requires a heating current of only 56 mA. The sensor requires two voltage inputs, they are the heating voltage (V_H) and the circuit voltage (V_C). The heating voltage (V_H) is applied to integrated heating to maintain circuit voltage elements, while (V_C) applied to allow measurement of the voltage (Vout) across the load resistor (RL) should be selected to optimize the alarm threshold value, keeping the power consumption (PS) of the semiconductor below the 15 mW limit. Power consumption (PS) will be at the highest when the value of R_S is equal to R_L on gas exposure. A summary of the specifications of the gas sensors used is shown in Table 1.

Table 1. Specification of gas sensors

Parameter	Sensor		
	MQ7	MQ136	TGS2602
Heater voltage (V_H)	5.0±0.1V	5.0V±0.1V	5.0±0.2V
Circuit voltage (V_C)	5.0±0.1V	5V	5.0±0.2V
Heater vurrent (I_H)	70±5mA	180 mA	56±5mA
Heater power consumption (P_H)	350mW	≤900 mW	280mW
Load resistance (R_L)	Adjustable	Adjustable	Adjustable
Heater resistance (R_H)	approx 33Ω±5%	29Ω±3Ω	approx 59Ω
Sensor resistance (R_S)	2kΩ ~ 20kΩ	30KΩ-200KΩ	10kΩ ~ 100kΩ

Thinger.io is used as the IoT platform of this proposed system. The IoT platform makes it easy for systems that have been created to implement IoT, especially in data management and data visualization by providing APIs [31]. Thinger.io is an open-source and free IoT platform. There are two main structures of Thinger.io, namely the back-end (server) and the front-end which are web-based so that they can be accessed by computers and mobile devices. The web-based front-end of Thinger.io can display data in a user-friendly manner and can be easily customized using open-source widgets. Almost all smart devices available in the market can implement Thinger.io as their IoT platform including Arduino and NodeMCU ESP8266. In this proposed system, NodeMCU ESP8266 will be used as a client because it is part of the data deployment of the measurement station. Thus, data from the sensors is sent via serial communication by Arduino UNO to the

NodeMCU ESP8266 which is then sent by the NodeMCU to the Thinger.io server via wireless internet. NodeMCU ESP8266 programming can use the Arduino Integrated Development Environment (IDE) making it easier to implement NodeMCU ESP8266 as an IoT device on the Thinger.io IoT platform. Figure 5 shows the implementation of the platform and system.

The hardware design of the measurement system is shown in the fritzing diagram in Figure 6. The description of the figure is as follows:
1 = Arduino UNO
2 = NodeMCU ESP 8266
3 = Potentiometer
4 = 16x4 Liquid Crystal Display
5 = MQ136, TGS2602, and MQ7 Gas sensors
6 = Buzzer
7 = LED

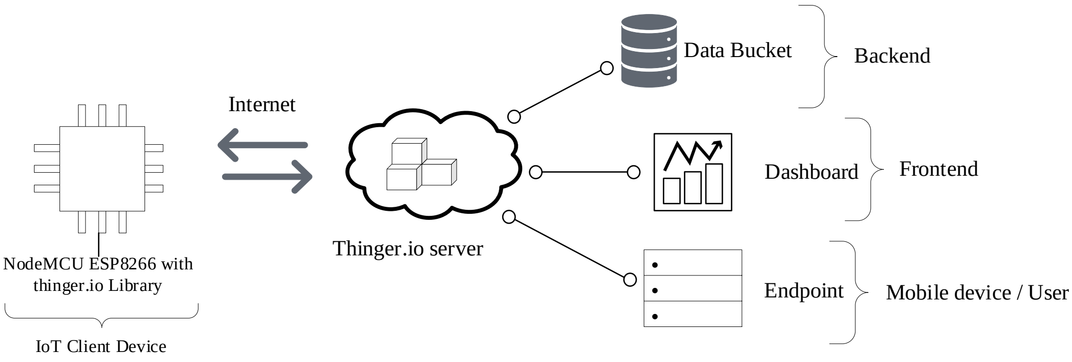

Figure 5. Implementation of Thinger.io as IoT platform on the proposed system

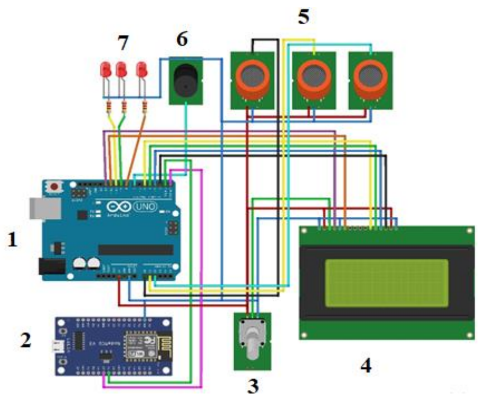

Figure 6. Hardware configuration of measurement system

The measurement of gas molecules in the air in this proposed system uses parts per million (ppm) units. To get the unit value of the reading of each gas sensor CO, H_2S, and NH_3 in ppm units can be obtained from the comparison of sensor resistance R_S and sensor resistance in fresh air R_0. In fresh air, the ratio $R_s/R_o = 1$. The value of R_s of each sensor can be acquired from:

$$R_s = \frac{V_c \times R_L}{V_{RL}} - R_L \quad (1)$$

In (1), V_C and R_L can be obtained from the datasheet, but we must find the value of the load voltage V_{RL}. By testing the ADC output from the sensor, V_{RL} can be obtained using (3):

$$V_{RL} = ADC_{val} * \frac{V_c}{ADC_{scale}} \quad (2)$$

where ADC_{val} is the ADC value of the sensor output, V_c is the sensor input voltage, and ADC_{scale} is the ADC scale of the Arduino UNO (with its maximum value is 1023). By using the ratio curve of R_s/R_0 and ppm provided by the datasheet of each sensor, the equation of ppm can be obtained for each sensor so that the ppm value of the readings of each sensor can be obtained. From the test results of gas levels in ppm for each sensor, the equation for MQ7 sensor for sensing CO level, MQ136 sensor for sensing H_2S level, and TGS2602 sensor for sensing NH_3 are as shown in (3)-(5).

$$ppm_{CO} = 97.2\left(\frac{R_s}{R_0}\right)^{-1.35} \tag{3}$$

$$ppm_{H_2S} = 39.9\left(\frac{R_s}{R_0}\right)^{-3.33} \tag{4}$$

$$ppm_{NH_3} = 0.948\left(\frac{R_s}{R_0}\right)^{-0.436} \tag{5}$$

3. RESULTS AND DISCUSSION

The measurement station or sensor station which was built according to the previously discussed system architecture design is shown in Figure 7. From Figure 7 it can be seen that the measurement station is a wooden box enclosure with sensors, LCD, led lights, and buzzer on the outer surface of the box. Before the sensor is used, the sensor is turned on and left stand by for about an hour so that the sensor stabilizes first. Sensor the results of sensor readings from measurement stations during daytime and night-time respectively are shown i006 Figures 8 and 9.

Figure 7. Measurement station of proposed system

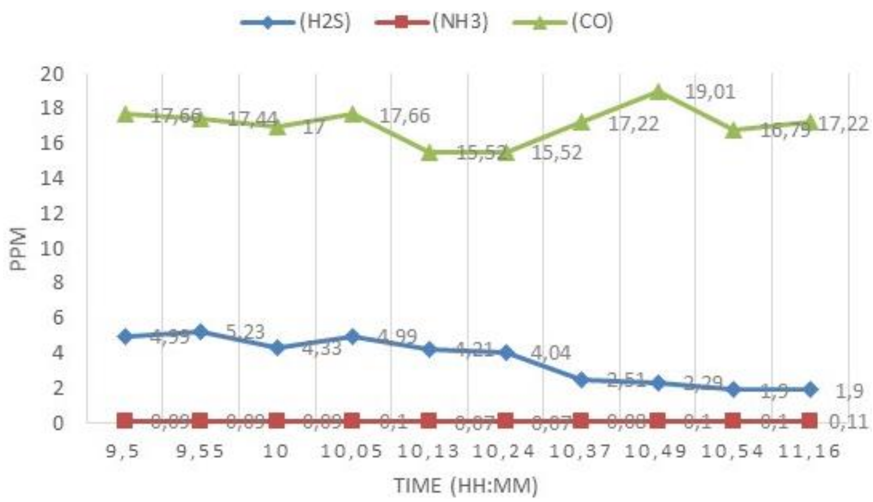

Figure 8. Daytime sensors measurement results

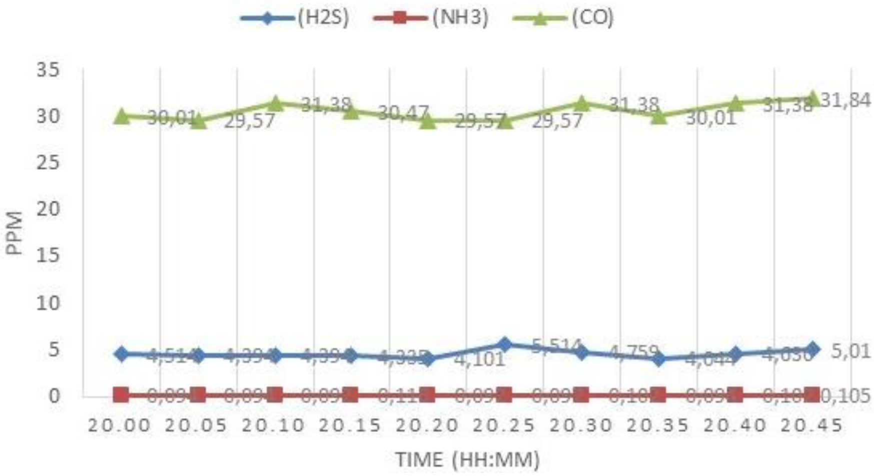

Figure 9. Night-time sensors measurement results

Referring to the Recommended Exposure Limit (REL) by the National Institute for Occupational Safety and Health (NIOSH), the safe limit value of CO, H_2S, and NH_3 gases each are 35 ppm, 10 ppm, and 25 ppm [32]. From the readings of the sensors, it can be seen that the CO, H_2S, and NH_3 are still detected in the environment around chemical factory plant and coal power plant, but is still within the safe threshold. The level of CO gas is higher at night, while NH_3, has a concentration level that tends to be the same both day and night. H_2S level tends to decrease as the time is close to noon. To see the implementation of IoT that can function as a monitoring and control system [33], a dashboard designed using the Thinger.io platform can be seen in Figure 10. to access the dashboard, simply go to the Thinger.io website then login and select the dashboard from the IoT system that has been created.

Figure 10. Dashboard appearance of the proposed iot based mobile ambient air quality monitoring

The dashboard display of the ambient air quality monitoring system that has been created using the Thinger.io platform has a display that is quite informative and quite responsive and quite easy to access. Setting up the dashboard on the Thinger.io platform is quite easy to do and the aesthetics of the display can be improved by adding plugins for free. The mobile view of the dashboard that has been created is shown in Figure 11. dashboards on mobile devices also have the same responsiveness, accessibility, and user-friendly as well as desktop dashboards.

The total cost of this proposed system is Rp. 1.066.00,00 or less than US$100. This amount can be categorized as low-cost for an IoT-based remote monitoring device system [19]. Details of the costs of building the proposed system are shown in Table 2.

Figure 11. Mobile dashboard appearance of the proposed IoT based mobile ambient AQM

Table 2. Bill of material of the proposed IoT based remote ambient air quality monitoring system

Item	Price (IDR)
Arduino UNO R3 Rev 3.0	130.000,00
NodeMCU ESP8266	40.000,00
Enclosure Box	130.000,00
MQ7 Sensor	23.000,00
MQ136 Sensor	400.000,00
TGS2602	210.000,00
LEDs, Buzzer, Cables and Accesories	73.000,00
LCD 16x4	60.000,00
Total	1.066.000,00

4. CONCLUSION

We have researched a building a monitoring system for ambient air quality in the factory area remotely using IoT technology. Monitoring of ambient air quality is carried out by monitoring the levels of harmful gases, are CO, H2S, and NH3 which is a non-major air pollutant but still has the potential to appear in the factory area. For the implementation of IoT, the IoT platform Thinger.io is used in the proposed system. By going through the calibration and heating stages of the sensors, the proposed system can detect CO, H2S, and NH3 in the factory area which is about 300 meters from the coal power plant owned by PT. Indorama and is about 350 meters from the poly chemical factory, PT. Indorama Polychem Indonesia. The detected level of CO, H2S, and NH3 is still within safe limits both during the day and at night. The ambient air quality monitoring system that has been created using the Thinger.io platform has a display that is quite informative and quite responsive and quite easy to access. With a cost of less than US$100, the proposed IoT-based ambient air quality monitoring system is a low-cost, reliable, and easy implement monitoring system.

ACKNOWLEDGEMENTS

Thanks are conveyed to the Telkom University for support this publication, Indorama Engineering Polytechnic which have provided support in the form of access to facilities and data for this research.

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