Gas Detection for Biogas System Using Internet-of-Things(IoT)

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Abstract

Global warming remains one of the most detrimental by-products of industrialization. Fossil fuels contribute to the majority of greenhouse gases emitted but remain a popular option for the generation of energy. An easy fix for this conundrum is to utilize other forms of fuel for energy generation which burns cleaner and renewable as opposed to fossil fuels. The aforementioned solution would be to use biomethane generated from waste products which burn cleaner and comes from a renewable source. In this paper, an IoT based biogas monitoring system for biogas reactors is proposed. An ESP-32 microcontroller system is deployed and tested to detect the presence of gas production. A dashboard plotting the data obtained from sensors is designed to help user monitor parameters. Data obtained is automatically uploaded to a Google Spreadsheet for data.

Keywords: Sensors; Biogas monitoring; Microcontroller; IoT

1. Introduction

Fossil fuels have been lambasted for being one of the main contributors of global warming. The burning of fossil fuels releases harmful chemicals into the atmosphere such as carbon dioxide and nitrogen oxides into the atmosphere. Carbon dioxide contributes to the greenhouse effect in which the heat from the sun is trapped in the atmosphere. Since the mid-19th century, the United States alone were responsible for a whopping 29% of carbon dioxide emissions by humans or 328,000,000 metric tons of carbon dioxide [1]. With the increase in temperature comes the melting of the glaciers which results in an increase in sea levels. The world population continues to grow every year, and with that the demand for energy also continues to grow. In big countries such as China, it was estimated that the population in 2021 was 1.43 billion and 543.98 million in 1950 [2]. The increase in population also contributes to the increase in urbanization of a country. With the increase in urbanization comes the increase in energy demand as well. China’s energy consumption in 2003 reached 1678 million tonnes coal equivalent (or MTCE) where coal consumption took up 67% of the total consumption, oil taking up 23% and hydroelectricity and natural gas being 7% and 3%, respectively [3]. This shows that the burning of fossil fuels remains one of the preferred fuels for energy generation.

With the continuous use of fossil fuels, comes the detriment of the environment and eventual depletion of this fuel source as fossil fuels are not renewable. A promising solution for this is to use biogas as an alternative to fossil fuels. The decomposition of waste products such as animal manure and food wastes through anaerobic digestion of different microorganisms creates biogas as one of the end products of the decomposition process [4]. All that is required by the average household to create their own biogas is an affordable way to monitor the biogas production.

IoT helps connect previously unconnected and dumb physical devices while simultaneously giving them the intelligence to act on a command or situation. It is likely that the integration of IoT technology and other industries can change the mode of economic development, achieve green growth and low-carbon economy [5]. IoT technology has been widely used in environment protection, industry monitoring, food tracing source, logistic trading and other fields [6]. In this paper, a system that utilizes IoT to monitor components in a biogas reactor will be presented.

2. Methodology and Experimental Setup

2.1. *Materials*

Biogas samples were obtained by mixing animal manure and food waste in a blender and then adding inoculum to the solution. Desiccant beads were included in the biogas chamber to remove moisture.

2.2. *Apparatus and Equipment*

The microcontroller used for the data acquisition device is an ESP-32. An MQ-4 semiconductor sensor was used for the detection of methane. An MQ-135 sensor was used to detect the presence of carbon dioxide in the air while a DHT-11 sensor is used for detecting the presence of temperature and humidity. A soldering set was used to create a circuit board for the data acquisition device. IFTTT protocol was used to constantly update a Google Sheets file with the data obtained from the sensors.

2.3. *Prototype Setup*

The basic idea of the system is to monitor the biogas generated in the biogas reactor and update the remote database. The microcontroller collects data from the sensors and then sends it to the Blynk mobile application and Google spreadsheets via IFTTT. Fig. 1 shows the overall architecture of the system proposed while Fig. 2 shows the system flowchart. The reactor contains a mixture of inoculum, food waste and rabbit dung. Biogas produced in the reactor travels from the reactor to a mason jar containing the sensors of the data acquisition device.

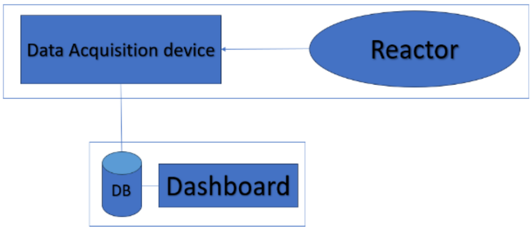


Fig. 1 Overall System Architecture

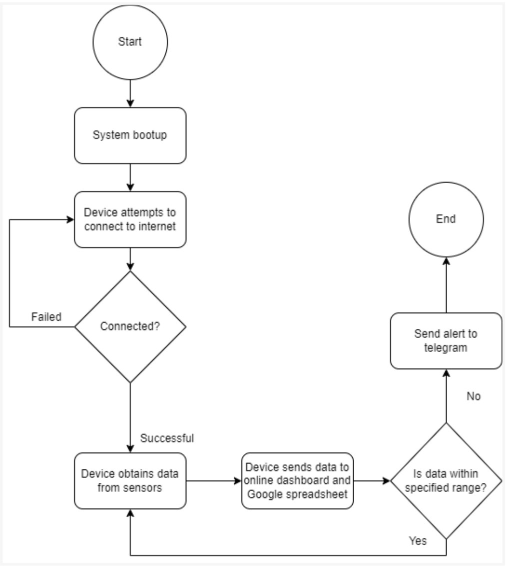


Fig. 2 System Flowchart

The data acquisition device is placed together with the biogas reactor. The device measures the methane gas as well as carbon dioxide produced by the biogas reactor and then uploads the data to Blynk's database and a Google spreadsheet via IFTTT. The data can then be viewed on Blynk's dashboard. The data acquisition device requires an active internet connection to send data. A Telegram bot was created to receive alerts from the device if the data is out of the specified range.

2.3.1 Preheating Process

The MQ-4 and MQ-135 sensors require initial preheating before the sensors provide stable readings. The datasheet advises that the sensors be given a 24-hour period to preheat. The sensors were found to provide stable readings after 12-hours from the start of power on. The subsequent use of the sensors requires roughly 10-minutes of preheating.

2.3.2 Sensor Calibration Process

The MQ-4 and MQ-135 sensors require calibration. After the sensors were preheated and readings stabilized, data from a reference sensor was used to assist in the calibration process. Both readings were compared and the difference in data was compensated for in the code written for the ESP-32 microcontroller.

2.3.3 Data Acquisition Device fabrication

The data acquisition device consists of an MQ-4 sensor to detect methane, MQ-135 sensor to detect carbon dioxide, and DHT-11 to detect temperature including humidity. The microcontroller used for the device is an ESP-32. Fig. 3 shows the circuit diagram of the device.

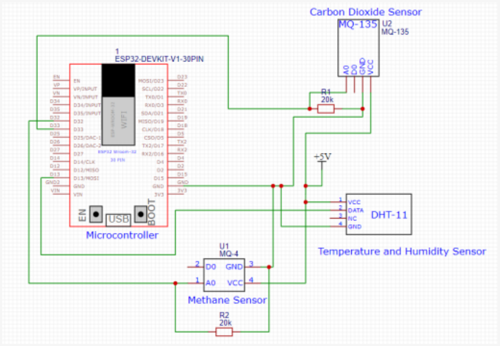


Fig. 3 Data Acquisition Device Circuit Diagram

2.3.4 Blynk Dashboard and IFTTT

A dashboard was designed to show the data obtained by the device. The dashboard displays the data in the form of a graph and the value at an instance on a gauge. The data is provided in PPM (Parts Per Million) over time. Fig. 4 shows the dashboard as viewed on a computer and Fig. 5 shows the dashboard on the mobile application.

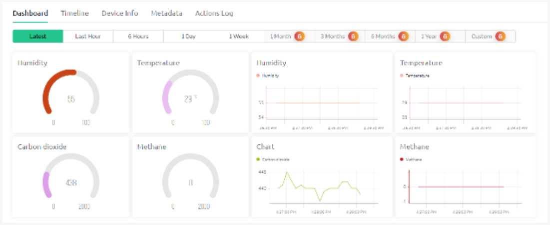
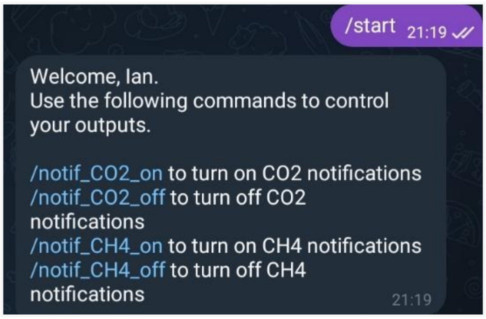


Fig. 4 The dashboard on the computer

Fig. 5 The dashboard on the mobile application

2.3.5 Telegram Alert Function

A Telegram message bot was created to receive alerts from the device in an event where a specific condition has been met (Fig. 6). An example of this would be when the methane or carbon dioxide levels drop below a certain level or when methane is detected. When the methane or carbon dioxide levels drop from a high concentration to a lower concentration, it may signify that a leak is present in the chamber and allows the user to perform data-driven decision making.



/start 21:19

Welcome, Ian.
Use the following commands to control your outputs.

/notif_CO2_on to turn on CO2 notifications
/notif_CO2_off to turn off CO2 notifications
/notif_CH4_on to turn on CH4 notifications
/notif_CH4_off to turn off CH4 notifications
21:19

Fig. 6 Telegram Alert Function

2.3.6 Test Setup

The first prototype was built and tested as shown in Fig. 7. From the labels in Fig. 7, one represents the reference sensor, two represents the biogas reactor containing food waste and animal manure, three represents the sensors in a mason jar, and four represents the microcontroller.

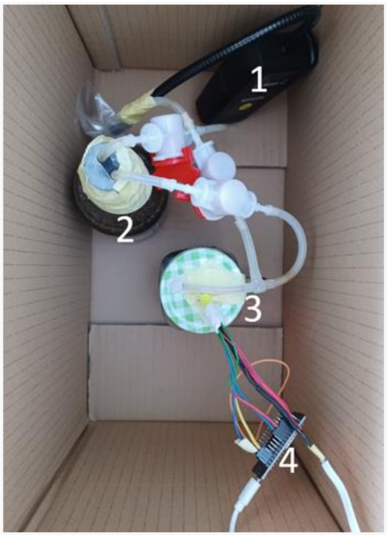


Fig. 7 Prototype test setup

3. Result and Discussion

3.1. *Data Acquisition Device*

In determining the sensor's accuracy, the sensor readings of the MQ-4 and MQ-135 were compared to a secondary set of data obtained in clean air and in biogas. The DHT-11 sensor data was compared with another measuring device that measures temperature and humidity.

Fig. 8 shows results of the MQ-4 sensor in clean air. The sensor readings fluctuate slightly when compared to the secondary set of data due to noise. Fig. 9 shows the results of the MQ-135 sensor in clean air. The data shows a similar trend when compared to the secondary set of data in clean air. Fig. 10 and Fig. 11 shows the comparison between the data obtained by the DHT-11 sensor and the reference measuring device. It was found that the temperature data from the DHT-11 sensor deviated about two degrees Celsius while the humidity data was found to deviate about three percent. As the data of the MQ-4 and MQ-135 fluctuates drastically, a tabulation of data was created for comparison (Table 1).

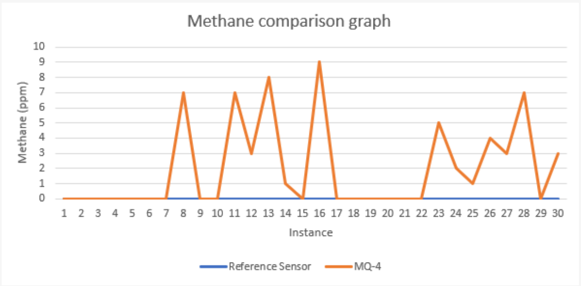


Fig. 8 Methane comparison graph

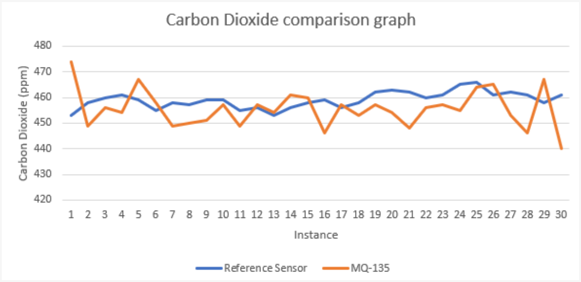


Fig. 9 Carbon dioxide comparison graph

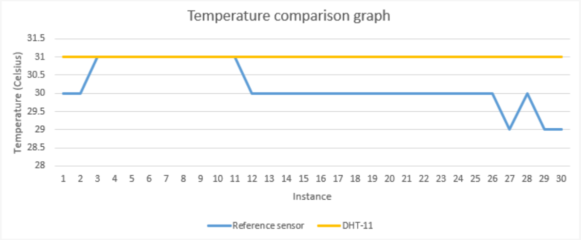


Fig. 10 Temperature comparison graph

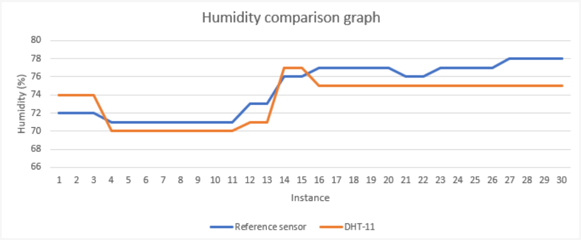


Fig. 11 Humidity comparison graph

Table 1 Sensor Data in Clean Air

No.	***Sensor Data***			
	MQ-4	***MQ-135***	***Reference (methane)***	***Reference (carbon dioxide)***
1	*0*	*474*	*0*	*453*
2	*0*	*449*	*0*	*458*
3	*0*	*456*	*0*	*460*
4	*0*	*454*	*0*	*461*
5	*0*	*467*	*0*	*459*
6	*0*	*458*	*0*	*455*
7	*0*	*449*	*0*	*458*
8	*7*	*450*	*0*	*457*
9	*0*	*451*	*0*	*459*
10	*0*	*457*	*0*	*459*
11	*7*	*449*	*0*	*455*

No.	Sensor Data			
	MQ-4	MQ-135	Reference (methane)	Reference (carbon dioxide)
12	3	457	0	456
13	8	454	0	453
14	1	461	0	456
15	0	460	0	458
16	9	446	0	459
17	0	457	0	456
18	0	453	0	458
19	0	457	0	462
20	0	454	0	463
21	0	448	0	462
22	0	456	0	460
23	5	457	0	461
24	2	455	0	465
25	1	464	0	466
26	4	465	0	461
27	3	453	0	462
28	7	446	0	461
29	0	467	0	458
30	3	440	0	461
31	4	465	0	463

Fig. 12 shows the results of the MQ-4 sensor in biogas. It was observed that the MQ-4 sensor provided near similar readings compared to the reference sensor until near the end where a leak was likely the cause of the large deviation. Fig. 13 shows the MQ-135 sensor in biogas. The percentage of error was calculated using Eq. (1).

$$Percent\ error = \frac{Act - Meas}{Act} \times 100\% \qquad (1)$$

Where;

Act= Actual reading
Meas= Measured reading

It was discovered that the MQ-4 sensor had an error of less than 6% and was deemed accurate. It was discovered that in higher carbon dioxide concentration, the MQ-135 becomes less sensitive and thus has a 41% error. However, the MQ-135 did detect the presence of carbon dioxide and is deemed acceptable. The data for Fig. 12 and Fig. 13 were tabulated in Table 2. The readings from the DHT-11 were affected by the heat generated by the MQ-4 and MQ-135. Due to the reference sensor being placed in a separate compartment, the data of the DHT-11 and reference sensor was different and was thus omitted.

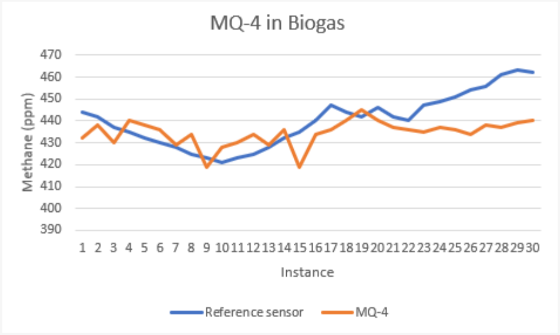


Fig. 12 Comparison Between MQ-4 and Reference in Biogas

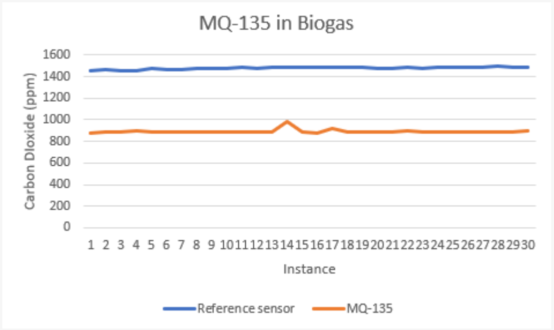


Fig. 13 Comparison Between MQ-135 and Reference in Biogas

Table 2 Sensor Data in Biogas

No.	Sensor Data					
	MQ-4	MQ-135	Ref. (CH_4)	Ref. (CO_2)	%error (CH_4)	%error (CO_2)
1	432	881	444	1451	2.703	39.283
2	438	882	442	1462	0.905	39.672
3	430	887	437	1459	1.602	39.205
4	440	897	435	1452	1.149	38.223
5	438	885	432	1471	1.389	39.837
6	436	884	430	1466	1.395	39.700
7	429	883	428	1468	0.234	39.850
8	434	885	425	1476	2.118	40.041
9	419	892	423	1473	0.946	39.443

No.	**Sensor Data**					
	MQ-4	***MQ-135***	***Ref. (CH_4)***	***Ref. (CO_2)***	***%error (CH_4)***	***%error (CO_2)***
10	428	890	421	1479	1.663	39.824
11	430	884	423	1482	1.655	40.351
12	434	886	425	1479	2.118	40.095
13	429	888	428	1485	0.234	40.202
14	436	980	432	1482	0.926	33.873
15	419	890	435	1488	3.678	40.188
16	434	877	440	1485	1.364	40.943
17	436	922	447	1484	2.461	37.871
18	440	890	444	1487	0.901	40.148
19	445	885	442	1482	0.679	40.283
20	440	887	446	1475	1.345	39.864
21	437	889	442	1479	1.131	39.892
22	436	895	440	1484	0.909	39.690
23	435	892	447	1479	2.685	39.689
24	437	889	449	1485	2.673	40.135
25	436	889	451	1484	3.326	40.094
26	434	890	454	1490	4.405	40.268
27	438	892	456	1487	3.947	40.013
28	437	890	461	1493	5.206	40.388
29	439	892	463	1491	5.184	40.174
30	440	902	462	1486	4.762	39.300

**To save space methane and carbon dioxide has been abbreviated to CH_4 and CO_2 respectively.*

3.2. *Power Consumption*

The current draw of the sensors including the ESP-32 were pulled from the data sheet. The power consumption was calculated using Eq. (2).

$$\text{Power} = \text{Current} \times \text{Voltage} \qquad (2)$$

Table 3 shows that the estimated power consumption of the device totals up to 2.702W. Although the power was calculated using the maximum rated current draw from the component’s respective datasheet, the actual power consumption of the device could potentially be higher due to energy loss in the form of heat.

Table 3 Power Consumption

Component	***Current draw (mA)***	***Power (W)***
MQ-4	*150*	*0.75*
MQ-135	*150*	*0.75*
DHT-11	*0.3*	*0.0015*
ESP-32	*240*	*1.2*
Total	***540.3***	***2.7015***

3.3. *Project Cost Analysis*

The project cost analysis breakdown is shown in Table 4. Some of the components of the project such as the wires and soldering iron were not taken into account for as the cost is negligible due to only using a small amount.

Table 4 Cost Breakdown

Part name	***Individual Price (MYR)***	***Quantity***	***Total (MYR)***
ESP-32	*15.00*	*1*	*15.00*
MQ-4	*5.20*	*1*	*5.20*
MQ-135	*6.50*	*1*	*6.50*
DHT-11	*4.90*	*1*	*4.90*
PCB	*1.00*	*1*	*1.00*
Mason Jar	*10.00*	*1*	*10.00*
Total			***42.60***

4. Conclusion

The design proposed in this paper is a scalable solution to monitor the production of methane and carbon dioxide within the biogas which are important parameters to determine the efficiency of the biogas reactor. The proposed design was tested and was deemed capable in detecting the presence of biogas and carbon dioxide in the biogas reactor.

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