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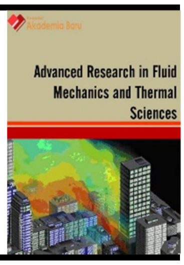

Preliminary Study on Designing and Development of a Synthesis Gas Analyser in the Process of Gasification

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ABSTRACT

Malaysia has a great development in biomass industry. The industry needs to use synthesis gas analyser for monitoring gas composition in the process of gasification. Since there is no local production of such analyser, it is commonly imported from oversea for a very high price. Furthermore, analysers in the market are not easily customized which ends up with the industry having to buy separate analysers to measure several types of gas. Therefore, this study focuses on developing a portable synthesis gas analyser for biomass gasification that suits the local industry's application which is low cost, at the same time, maintaining its accuracy and reliability. The analyser is integrated with a monitoring system using the Internet of Things (IoT) concept. The developed analyser uses Raspberry Pi microcomputer as the core element in its electronic design along with several other necessary hardware components. The analyser is capable of measuring methane (CH_4), carbon monoxide (CO), hydrogen (H_2), and carbon dioxide (CO_2). It also includes a web server for displaying its measurement in a local network and the internet for monitoring purpose. Selected sensors used in the analyser shows positive response toward respective gas in a sensor validation experiment. Thus, the sensors can be used for further development of the analyser. Case building, addition of the web server's features, and accuracy and reliability experiment will be conducted in future development of the analyser. Therefore, this study shows the possibility of developing a portable synthesis gas analyser. Furthermore, the analyser may offer a cheaper yet reliable alternative for gasification process monitoring to the local biomass industry in the future.

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1. Introduction

As among the leading nation in oil palm production and having an active agricultural activity, Malaysia has plenty of biomass resources. These resources can be converted into alternative energy or eco-products. Biomass industry uses synthesis gas analyser for monitoring gas composition in the gasification process. However, since there is no local production of such analyser, it is normally imported from other countries for an excessive cost between RM 23,000.00 to RM 132,000.00 per unit. This causes local biomass industry to spend a great amount of money for this purpose. Furthermore, gas analysers in the market are not easy to be customized which sometimes causes the industry buying several analysers for measuring different types of gases which is worth unnecessary. Thus, this study focuses on designing and fabricating synthesis gas analyser for biomass gasification application with the following objectives; to study and investigate functionality of various sensors used to make a synthesis gas analyser which suits the local biomass industry application, to design and fabricate a portable and cost-effective synthesis gas analyser system with a web server, and to assess performance of the system by validating its measured parameters. Research and experiment setup of fluidized bed gasifier by Suksuwan *et al.,* [1] and Suksuwan *et al.,* [2] have given a bigger picture on biomass gasification process. Product gas of the process are hydrogen (H_2), oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), and methane (CH_4). For this early stage of development, only four out of five gases were selected based on the availability of gas sensors in the market. Based on these gases, a synthesis gas analyser was developed. Since there is no past research in making a synthesis gas analyser using low-cost electronic components such as Raspberry Pi and MQ gas sensor, air quality monitoring system researches were used as the closest reference to this study as it involves similar hardware components. Several design using Arduino microcontrollers was studied such as wireless sensor network system for monitoring indoor air quality developed by Abraham and Li [3], air quality monitoring system proposed by Ali *et al.,* [4], micro-controller based temperature monitoring system implemented by Tayab and Yuen [5], and system for measuring air quality of vehicles using Internet of Things (IoT) implemented by Rushikesh and Sivappagari [6]. Their designs work best with their applications but is inefficient to support the analyser's features. Wireless self-powered air quality measuring device using Redboard which is a copy of Arduino designed by Reilly *et al.,* [7] is also unsuitable in this application for the same reason. Smartphone-based air quality measurement system developed by Hasenfratz *et al.,* [8], Oletic and Bilas [9] are unsuitable for the analyser's application due to limited number of sensors that can be installed. Based on many designs studied, the best is using Raspberry Pi microcomputer because it supports the most features as compared to the others. Thus, electronic components of the analyser was designed based on several previous works such as smart environmental monitoring system proposed by Ibrahim *et al.,* [10], environmental monitoring system developed by Deshmukh and Shinde [11], smart gas detection system developed by Ilie and Vaccaro [12], pervasive monitoring of carbon monoxide (CO) and methane (CH_4) using air quality prediction by Karamchandani *et al.,* [13], air quality monitoring system based on IoT using Raspberry Pi proposed by Kumar and Jasuja [14], IoT based low cost air pollution monitoring system developed by Parmar *et al.,* [15], and smart environmental monitoring through IoT using Raspberry Pi proposed by Patil [16]. Combining their designs with some adjustment suits best for the analyser's application. In addition, Wi-Fi is used in the system for data transmission as it is the widely used technology today for Internet access [17]. This study has a potential to provide a cheaper alternative to produce a gas analyser which can be customized and made for local biomass industry applications. It will save the industry's money from buying imported gas analyser and from buying multiple gas analyser to fulfil required gas measurement. Moreover, it may encourage local development of analyser required by local industry. With large scale production of the analyser, it can contribute in potential new jobs to the people and boost the local economy especially in the biomass industry.

2. Methodology

2.1 Internet of Things Approach

The unique feature is integration of the gas analyser with a monitoring system using Internet of Things (IoT) approach. Instead of only one usage of the analyser, it can also be a monitoring system. Moreover, by applying the concept of the IoT, the system can be monitored on any smartphones, tablet, or personal computer from anywhere around the world provided there is internet connection. Figure 1 shows the system's integration concept.

Fig. 1. The system's integration concept

2.2 Hardware Design

As shown in Figure 2 (a), a Raspberry Pi 3 Model B microcomputer is used as the core electronic design of the analyser. It retrieves reading from the sensors used, convert the reading into percentage (%) value, and display it on a 20 x 4 LCD screen and a web server. The LCD screen is used to display reading directly on the device itself while a web server is employed to display the reading online which is accessible from the internet via any smartphone, tablet, or personal computer. The LCD screen was connected to the General-Purpose Input Output (GPIO) port of the Raspberry Pi. A portable Wi-Fi modem is utilized to allow connection of the web server to the internet. The modem supports virtual server to do port forwarding for global connectivity or access from the Internet. The modem also comes with a signal indicator for user's reference to the signal's strength at the current location of the system. Furthermore, the modem can support a consistent and solid Wi-Fi signal within ten-foot radius. The Raspberry Pi communicates with the modem via Wi-Fi. The modem has an internal battery. However, for long time usage, the modem is connected to a USB port of the Raspberry Pi via a USB cable for charging purpose. A 10 kmAh power bank is to supply power to the system. The power bank supplies 5 volt with 2.1 ampere. When fully charged, it can support the system running up to five hours. The power bank also has a build in power level light to indicate its remaining power level. The power bank was connected to 5 volt micro USB port of the Raspberry Pi via a USB cable. Four gas sensors used in the system are MQ-4 for measuring level of methane (CH_4), MQ-7 for measuring level of carbon monoxide (CO), MQ-8 for measuring level of hydrogen (H_2) and MG811 for measuring level of Carbon Dioxide (CO_2). The sensors send readings via a logic level converter and an analogue-to-digital converter (MCP3008) to GPIO port of the Raspberry Pi. The logic level converter lowers output voltage of the sensors from 5V to 3.3V which is the supported input voltage of GPIO port of the Raspberry Pi. Since output reading of the sensors is in analogue and GPIO port of the Raspberry Pi only reads in digital, an analogue-to-digital converter was used to convert output voltage of the sensors from analogue to digital before connecting it to GPIO port of the Raspberry Pi. Figure 2 (b) shows schematic diagram of the electronics components. Two more gas sensors, MG811 (CO_2) and ME2-O2-Φ20 (O_2) will be added to the schematic diagram in future development.

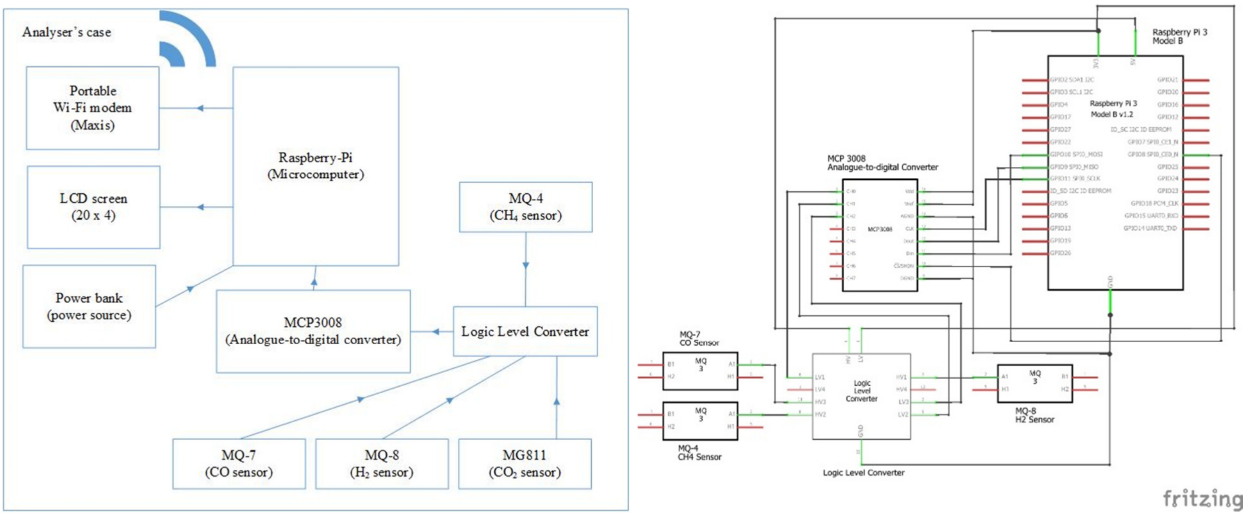

Fig. 2. Synthesis gas analyser (a) Block diagram and (b) Schematic diagram

Figure 3 shows a proposed design of the analyser's case. The inner part of the case is divided into three levels. The upper level is where all the sensors will be placed, and it also will be the place where gas be measured flow in and out of the analyser. The inhale tube will be connected to a fluid pump and another tube will connect the pump to a chamber where all the sensors are placed. The exhale tube will be connected to the other end of the chamber. The LCD screen will also be placed on this level to display reading of the measured gas. The middle level houses the electronic components. Since the power bank and portable Wi-Fi modem are stand alone and replaceable part, it is placed at the lower level separated from the electronic components for easy replacement, if required.

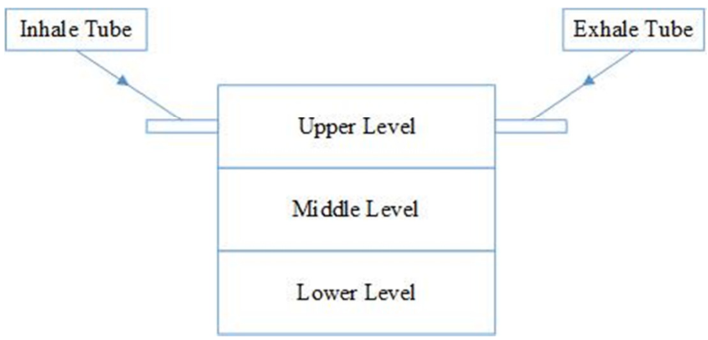

Fig. 3. The analyser's proposed case design

2.3 Software Design

Upon starting, the analyser measures the gas concentration of CH_4, CO, and H_2. The concentration measurement is in parts per-million (ppm). Then, the reading was converted into percentage (%) value. The percentage value was displayed on the LCD screen and the web server. Figure 4 shows the flow of the main program where it loops by itself on average of five seconds which means the analyser's readings is updated every five seconds. The web server was made to ease user access to the monitoring system which can be opened in any browser on any smartphones, tablet, or personal computer at a distance. The web server is Python based and hosted from Raspberry Pi. Web pages in the web server was designed using hypertext markup language (HTML) and cascading style sheets (CSS) while programmed in Python.

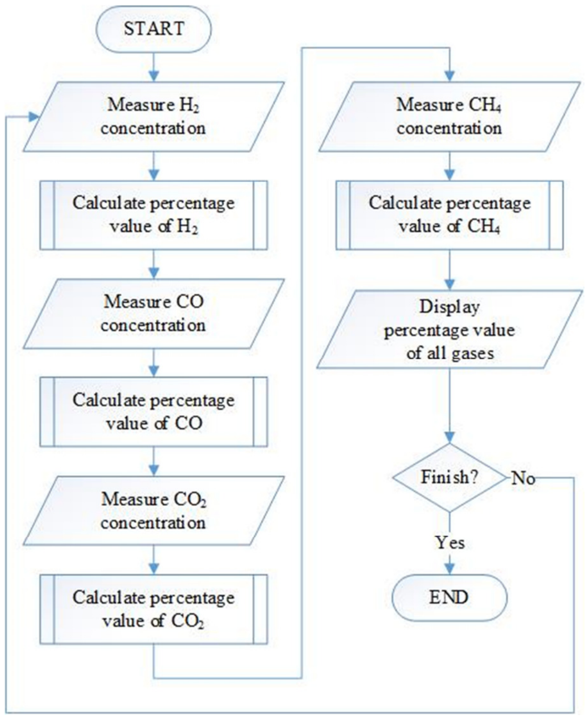

Fig. 4. Flowchart of the system's main program

In term of accessibility, the web server can be accessed locally via the Wi-Fi modem and globally via the internet. For local access, the system does not require telecommunication's data (internet) subscription, while for global access, a telecommunication's data (internet) subscription is necessary. To access locally, device used must be connected to the system's Wi-Fi modem (SYNAL) and use http://192.168.1.203:8080 as URL at the browser. While for global access, simply use http://synal.duckdns.org:8080 as URL at the browser directly. However, for both cases, the system must be on to access its monitoring system. For security measures, the system's Wi-Fi modem must be turned on manually by pressing it's ON button. Then, the modem required password to allow internet connection which protects it from an unintended access from the internet as shown in Figure 5 (a). Other than that, the system's Wi-Fi is also password-protected as shown in Figure 5 (b). Both modem's and Wi-Fi's password are different from one another for extra security measures. The modem's password is intended for authorise use to extend accessibility of the system to the Internet. While the Wi-Fi's password is intended for users to access the system locally.

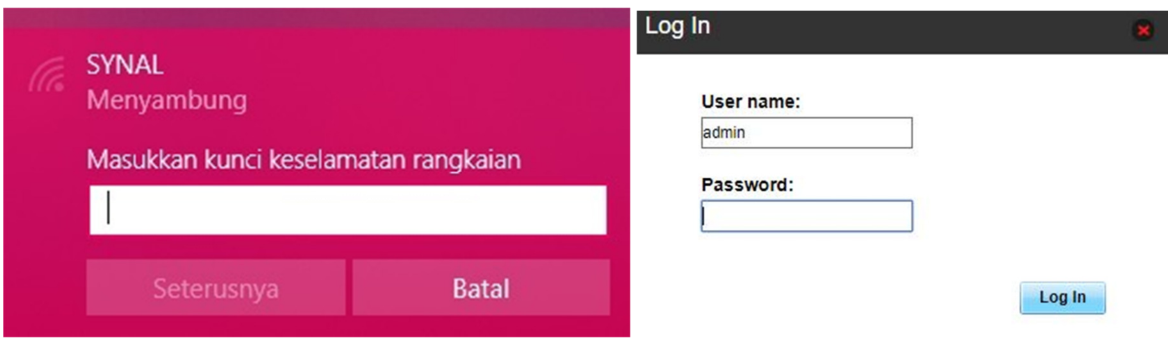

Fig. 5. (a) Wi-Fi and (b) modem login popup

Several pages were made on the web server to ease user monitoring. The first page when a user enter the system's URL was as shown in Figure 6 (a). SYNAL is short for syngas analyser which is the system's name. The syngas button will redirect to a monitoring page. Other than that, an ON and OFF button for the system's online database was included. Google Firebase, an online open source database was used as shown in Figure 6 (b). The database can be used for future development of an app for the system. An ON and OFF button for recording the system's measurement was also included. However, the recording feature was only for the developer's use as for the time being.

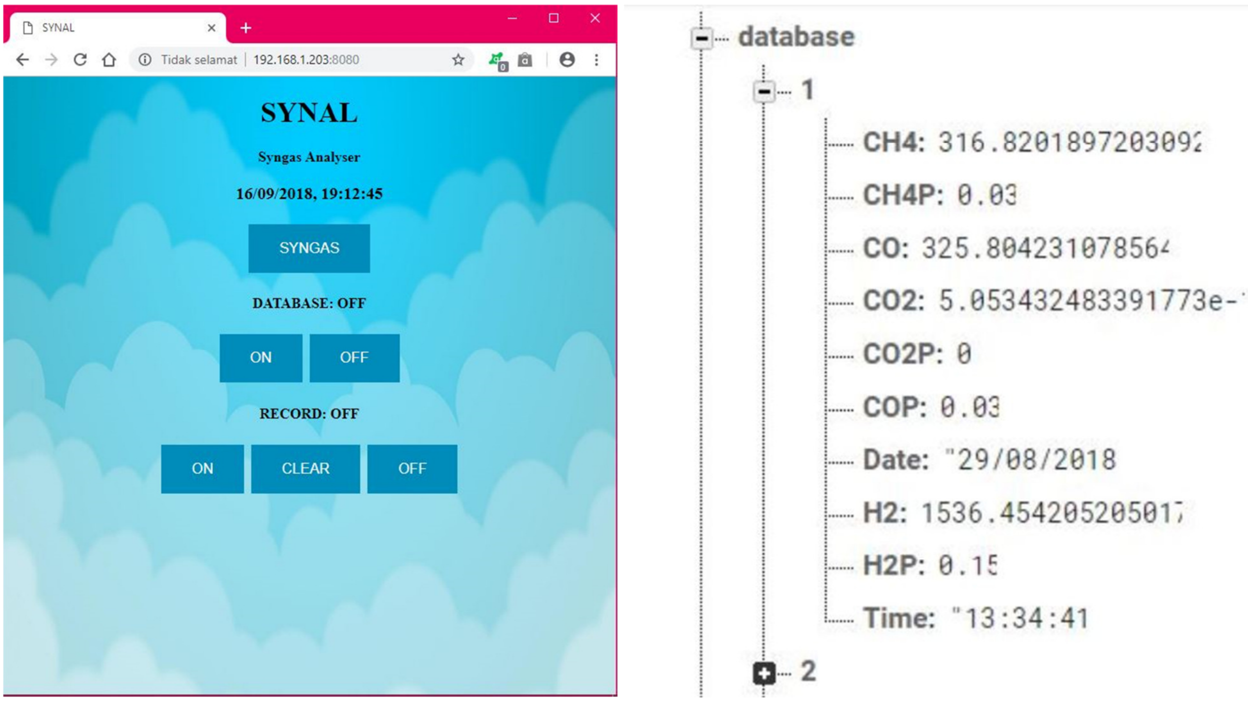

Fig. 6. (a) Main page and (b) database

As the syngas button was pressed on the main page, it redirects the user to a monitoring page in percentage value as shown in Figure 7 (a). Upon pressing the PPM button on navigation bar of the percentage monitoring page, it redirects user to a monitoring page in parts-per-million (ppm) value as shown in Figure 7 (b). The analyser button brings the user back to the main page. On the top left of both pages is an auto refresh checkbox which allow user to auto refresh the pages every ten seconds with updated readings to ease user monitoring. On the lower end of both pages is the system's status bar for the user to monitor the system itself. More advance features of the page will be continued in future development.

2.4. Experiment on the Sensors

According to the sensor's datasheet, the sensors produce reading in parts-per-million (ppm). The reading was converted into percentage (%) using Equation (1) to suit its application as a gas analyser. To validate functionality of the sensors, a sensor validation experiment was conducted in a laboratory with setup as shown in Figure 8. All the sensors are placed in a container. Then, gas supplied by Linde Gas Company with fixed and known percentage of gases was channelled into the container using a connecting tube. The gas used has composition of CH_4 (10%), CO (35%), H_2 (30%), and CO_2 (25%). To validate the sensors as working, reading from the sensors should have an increase in value when the gas was channelled into the container. The sensor's reading was recorded in the Raspberry Pi. Accuracy and reliability experiment on the sensors will be conducted in the future.

$$Gas\ concentration\ (\%) = \frac{Gas\ concentration\ (ppm)}{10{,}000} \quad (1)$$

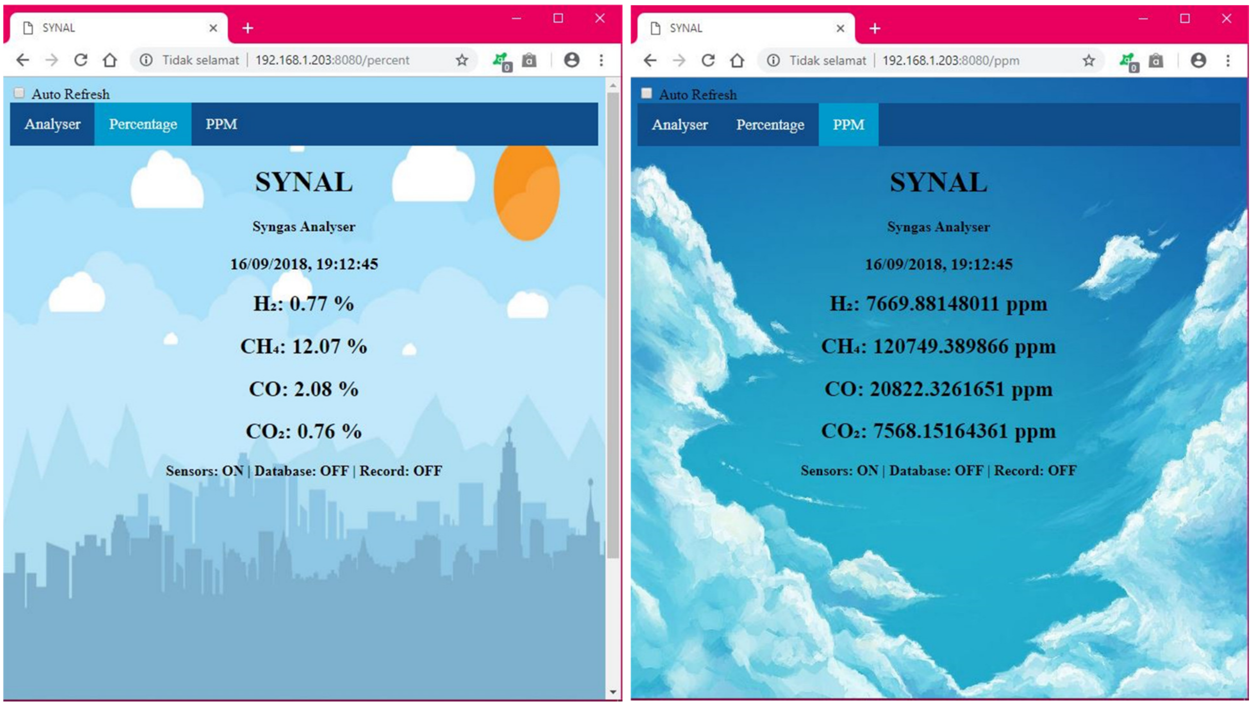

Fig. 7. Measurement page in (a) percentage and (b) ppm

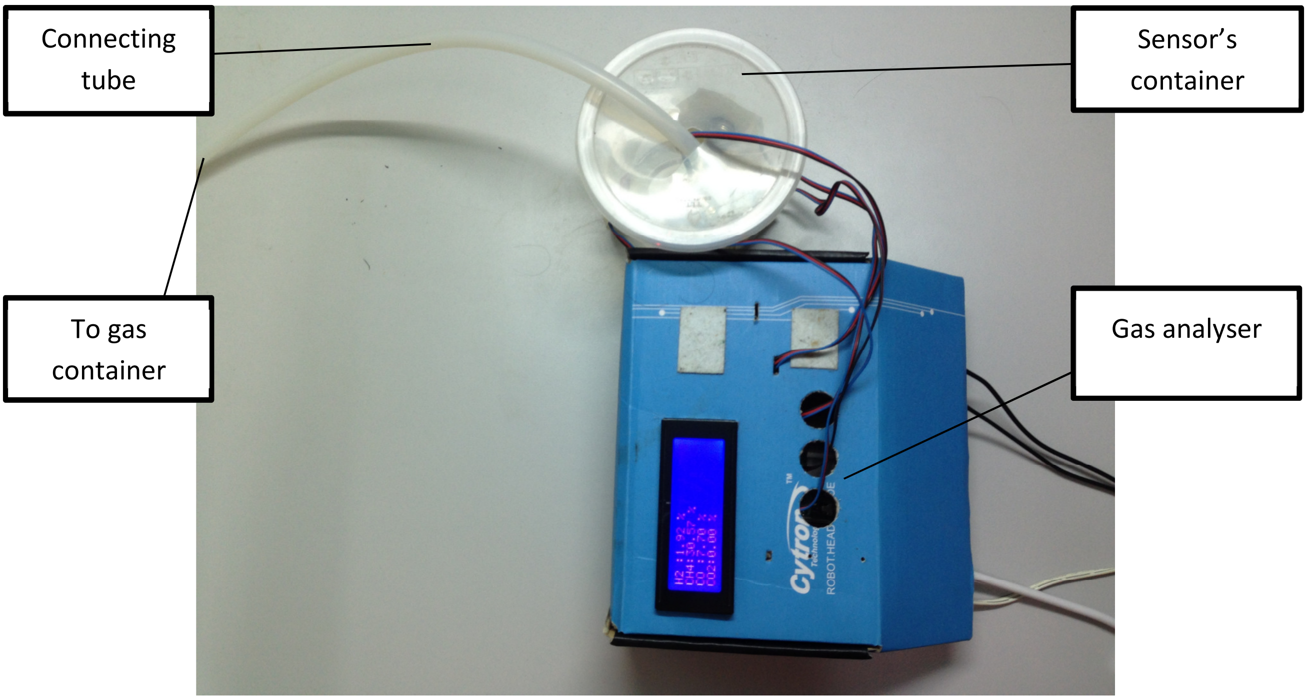

Fig. 8. Experimental setup for sensor validation

3. Results

In the validation experiment, the gas from Linde Company was used. The gas has a composition of 10% CH_4, 35% CO, 30% H_2, and 25% CO_2. Therefore, the sensors were expected to have increased reading, which is close to the gas composition during the experiment. The recorded readings were extracted from the Raspberry Pi and plotted onto a graph as shown in Figure 9. The graph shows readings obtained from the validation experiment of MQ-4 sensor (CH_4), MQ-7 sensor (CO), MQ-8 sensor (H_2), and MG811 sensor (CO_2). Reading of MQ-4 sensor fluctuates and appears to be unstable. However, lower points of the fluctuated reading are quite accurate. Reading of MQ-7 and MG811 sensor also fluctuates and appears to be unstable. However, upper points of the fluctuated reading are quite accurate. While reading of MQ-8 sensor are quite stable with reading slightly lower than the gas composition value. Further adjustment may be required for sensors with fluctuated reading. Thus, the sensors were verified and can be used in the analyser system as they can detect the present of respective gases well. Furthermore, the system runs smoothly throughout the experiment without having a crash. Thus, the system is stable.

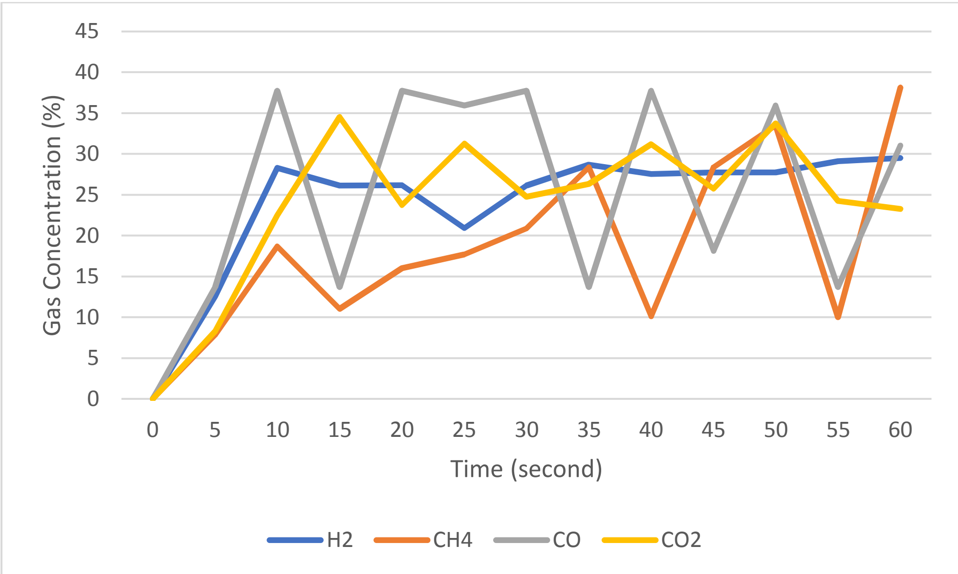

Fig. 9. Result of sensors validation experiment

4. Conclusions

The analyser's electronic components were successfully integrated together, and a global web server was successfully hosted to display measured gas readings including an online database. The system proved to be stable without having a crash when running its program. The sensors were verified in a validation experiment. Thus, the sensors can be used for the analyser. From this study, it is possible to develop further the analyser and will be enhanced. In the future development, effort will be focuses on obtaining a stable and accurate reading from the sensors, design and building a suitable case to house the system as a portable device and run a comprehensive test on the system.

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