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# A SMART REAL-TIME MONITORING SYSTEM FOR UPGRADING BIOGAS AND BIOMETHANE

# SISTEMA INTELIGENTE DE MEDIÇÃO EM TEMPO REAL DE BIOGÁS E UPGRADE DE BIOMETANO

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## Abstract

Anaerobic digestion contributes significantly to the generation of biomethane, which is a renewable energy source. Effective management in a bioreactor requires monitoring its internal digesting levels in order to have a prompt response, which will ensure production and prevent any process problems. Currently, there is a dearth of affordable and accurate instruments for small-scale or research-scale biomethane production system measurement. The goal of this research was to develop a device that could track the components of biogas mixture and its production in real time. Initially, the Arduino Uno microcontroller was used to develop this, and later, the open-source ESP32-LoRa was used to

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measure and control, in real time, the production of reactors installed in remote areas. The device includes a brushless motor-driven compound mixing rotor and a network of connected sensors that are periodically checked via remote communication and data archiving. In order to enhance the biomethane generated, it also features a gas filter system. Within the framework of a circular economy, this device's low cost and reproducibility make it suitable for measuring and controlling biogas production from remote reactors autonomously in real time.
**Keywords:** ESP32-LoRa. MQ gas sensors in bioreactors. IoT system for biogas monitoring.

**Resumo**

A produção de biometano por digestão anaeróbica constitui uma importante contribuição para as energias renováveis. Para garantir a produção e evitar possíveis falhas no processo, o controle eficaz em um biorreator requer o monitoramento de suas grandezas internas de digestão de forma a ter rápida resposta. Atualmente se tem carência de dispositivos baratos e confiáveis que possam ser aplicados na medição de biometano em sistemas de produção, seja para pesquisa ou em pequena escala. Este estudo buscou construir um dispositivo para monitorar em tempo real a produção de biogás e os componentes de sua mistura. Este foi desenvolvido inicialmente com o microcontrolador Arduino Uno e posteriormente com ESP32-LoRa de código aberto. O dispositivo tem um sistema de sensores associados e um rotor de mistura dos compósitos, acionado por um motor brushless, que são autuados regularmente, com comunicação e armazenamento dos dados via remota. Também possui um sistema de filtro de gases para dar um upgrade do biometano produzido. Por seu baixo custo e sua replicabilidade, este dispositivo pode ser aplicado para medir e controlar de forma autónoma e em tempo real, a produção de biogás de reatores instalados em áreas remotas, no contexto de economia circular.
**Palavras-chave:** ESP32-LoRa. Sensores de gases MQ em biorreatores. Sistema IoT para monitoramento de biogás.

## 1. INTRODUCTION

Anaerobic digestion (AD) is a biochemical process that reduces organic materials into biogas by mineralizing them. It is mediated by many kinds of syntrophic microorganisms belonging to the Bacteria and Archaea domains (Amaral; Steinmetz; Kunz, 2022). AD has long been used to treat an array of pollutants, including industrial wastewater, livestock manure, organic components of municipal solid waste, and sludge from municipal sewage systems (Grosser; Neczaj, 2018; De la Rubia *et al.,* 2018; Cardoso *et al.,* 2022). Biomethane has two potential uses: it can be compressed for use as biofuel and utilized on-site as a fuel to provide thermal and electrical energy, or it can be turned into renewable natural gas by eliminating carbon dioxide and other impurities (EPA, 2024, Renewable Fuel Standard Program).

Since methane is the primary component of biogas and affects its energy capacity, the rate at which it is produced defines the performance of an anaerobic bioreactor. Methane production rate is dependent on various operating factors, including feed quality and rate, temperature, alkalinity, solids retention time, and hydraulic and solids retention time (Ibro *et al*., 2024; Ding *et al*., 2023; Liu, *et al*., 2022, Sahoo, *et al*., 2023, Nagao *et al.,* 2012).

Understanding the biogas flow rate and methane content is necessary for the proper operation and control of anaerobic digesters (Ghofrani-Isfahani *et al*., 2020). The pace of methane generation is typically tracked in order to optimize methods to prevent disruptions and control the process (Polag *et al.,* 2015; Lara *et al.,* 2015). Measuring instruments for gas analysis are readily available on the market, such as mass spectrometers (Safi, Arnold, Rennick, 2024), infrared spectroscopes (Yacovitch *et al*., 2014), and gas chromatography (Krause *et al.,* 2018). However, because of their high cost and the logistical requirements of operation, these instruments are frequently unsuitable for use in remote areas (Yang *et al.,* 2019).

The physical processes involved in the conversion of inputs into outputs must be measured in order to investigate and analyze biodigestion and the reactions that take place. As a result, when a physical quantity is measured with a sensor, the stimulation of the measure results in the generation of an electrical output signal (Ida, 2020; Fericean, 2019).

This paper introduces a robustly sensitive methane measurement system based on the ESP32-LoRa platform. The ESP32 has built-in Wi-Fi and Bluetooth interfaces that simplify connection and communication with other devices or networks and that can track real-time biomethane content in remote places. One of this device's advantages is that it is inexpensive and lightweight (Hercog *et al*., 2023). Waste is effectively reused to generate methane for specific purposes, minimizing environmental impacts on the soil and the overall environment by lowering methane emissions. This promotes economic benefits and enhances community well-being.

## 2. MATERIAL AND METHODS

### 2.1 Arduino-Uno Platform

A gas detector mod. DG-500 with a USB interface was used to measure the amounts of CO, hydrogen sulfide gas, and methane produced by experimental bioreactors. These samples served as calibration parameters for the first measuring device, which was previously constructed using an Arduino Uno platform in conjunction with pH450C and sensors: MPX5050; DS18D20, MQ4, MQ8, and MQ136. The Arduino IDE environment was used for programming, and C/C++ was the language used. As a result, the control system was made up of a number of sensors that monitored the pH, temperature (ºC), pressure (KPa), and gas concentrations (ppm) created by anaerobic decomposition in an experimental reactor. Following the introduction of the biogas samples, the gadget was configured to automatically measure these values.

### 2.2 Quantities and sensors

The glass electrode that powers the analog pH450c sensor is sensitive to hydrogen ions ($H^+$). In essence, the analog output produced by this sensor is proportionate to the concentration of H+ ions in the solution, which is correlated with the pH value, and indicates the degree of acidity or alkalinity. With a measurement range of 0 to 50 kPa, the MPX5050 pressure sensor is designed to function on the basis of capacitive deformation. The temperature sensor DS18B20 is a digital device that uses a single data wire for communication and operates on the one-wire protocol. Temperature is converted into digital values with great precision and a 9- to 12-bit resolution. A source provided power to this sensor (3.0V to 5.5V).

Sensors from the MQ series were installed for gas measurements. MQ-136 (hydrogen sulfide), MQ-8 (carbon dioxide), and MQ-4 (methane), each with a distinct measurement range. These sensors' working principle is based on how electrical resistance changes in response to a certain gas's presence. To guarantee accurate readings, these sensors need to be calibrated first.

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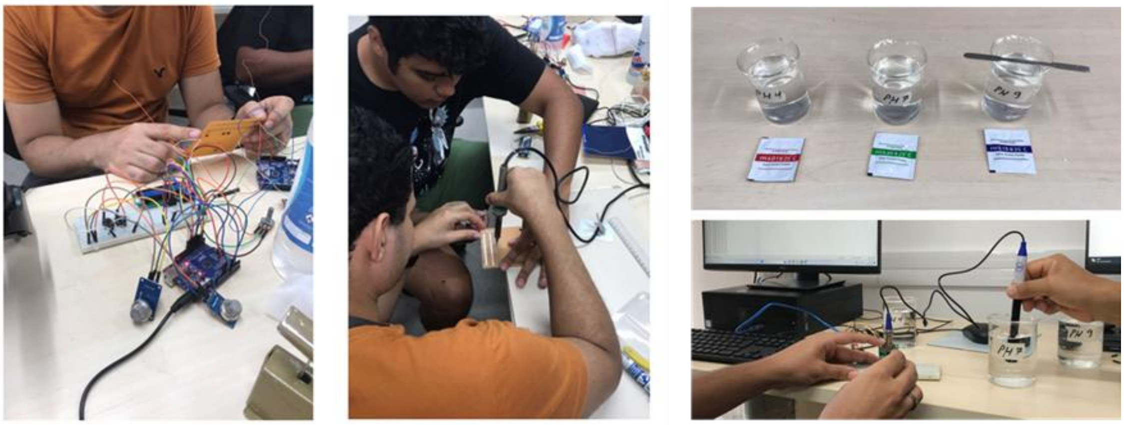
These sensors' analog response is proportionate to the gas concentration that is sensed, which makes it easier to integrate them with microcontrollers (Figure 1).

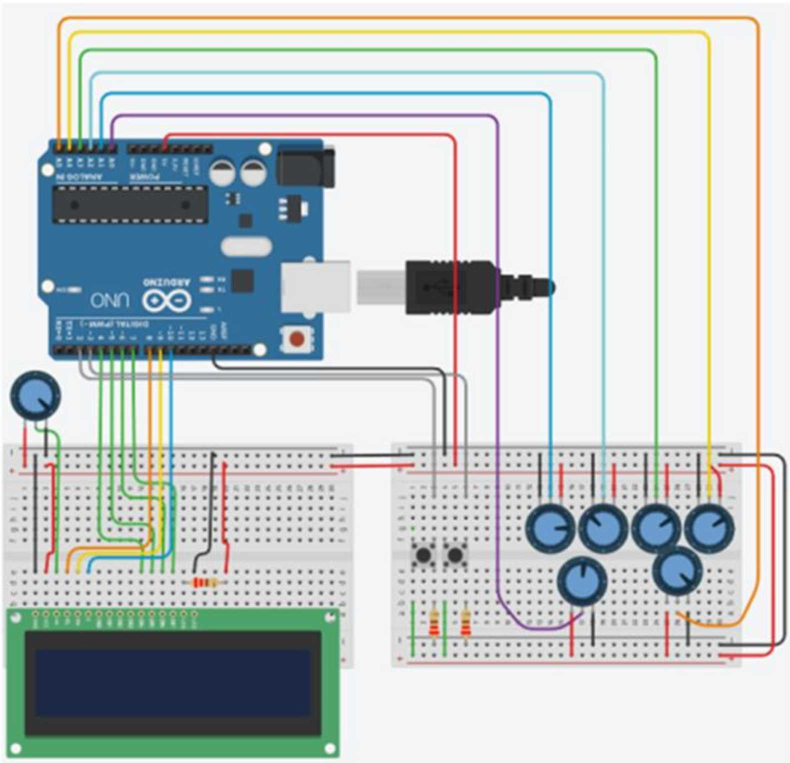
**Figure 1.** Arduino platform with sensors installed for gas monitoring



**Source:** The authors, 2024

To make integration with the microcontroller easier, measurements were taken using an alphanumeric component or a 16x2 LCD display with 32-character display capability that included an HD44780 controller. A 12 volt, 3 amp AC/DC source that transformed grid alternating current (AC) into direct current (DC) and included voltage regulation circuit to guarantee a steady output powered the entire system (Figure 2).

**Figure 2.** Circuit Simulation design made by tinkercad Platform (https://www.tinkercad.com)



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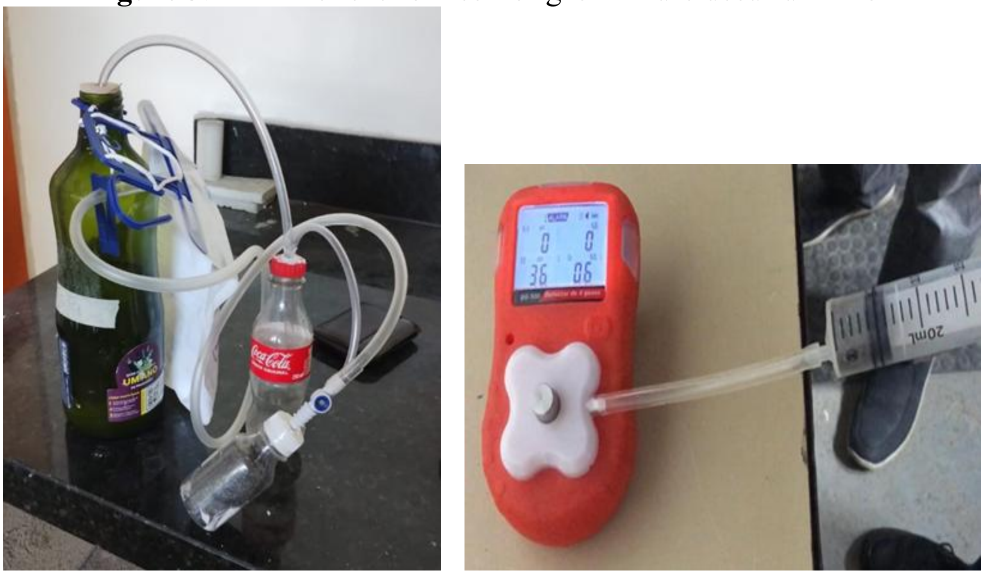
## 2.3 Biogas upgrade

The direct exposure of MQ sensors to the corrosive effects of contaminants like hydrogen sulfide was one of the constraints of using these sensors. As a result, experiments on moisture retention and desulfurization were done in the gas combination. The alkaline reaction of biogas fractions with sodium hydroxide was the first test, which was conducted in accordance with VUT (2012) Angelidaki *et al.,* (2018) and Nezamabadi, Yousefi and Saraei (2022) (Figure 3). To assess the $H_2S$ filtering power, the biogas samples were injected into a medium containing sodium hydroxide solution and then quantified.

**Figure 3.** Alkaline reaction test for gas mixture desulfurization



**Source:** The authors, 2024

A dry reaction between hydrogen sulfide and iron oxide generated by a steel sponge was the second test, as reported by Magomnang and Villanueva, (2015); Riyadi, Kristiano and Priadi (2018) (Figure 4). The samples' $H_2S$ content was measured after they underwent filtration.

**Figure 4.** Dry reaction of hydrogen sulfide with iron oxide

**Source:** The authors, 2024

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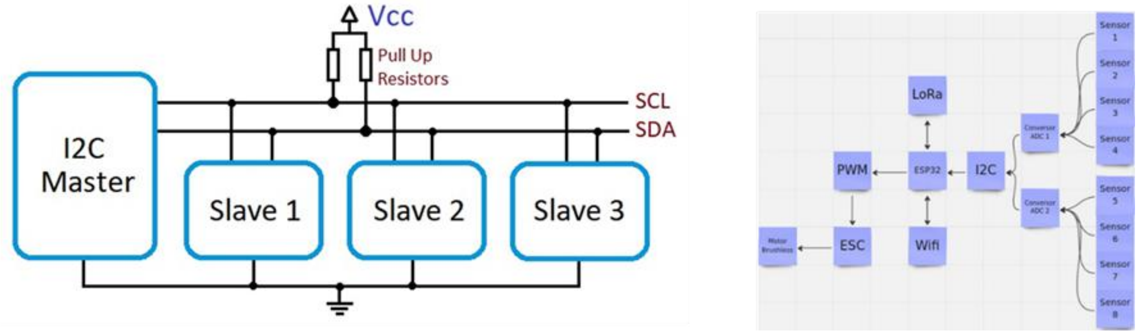
## 2.4 ESP32 system platform (LoRa)

The Arduino was swapped out with an ESP32-LoRa V2 board that had a WiFi and Bluetooth module in order to apply the set of sensors in an Internet of Things system. The board can establish long-distance communication with other LoRa devices thanks to the LoRa SX1278 chip. The electronic system of the bioreactor was split into *Flumen Point* and *Flumen Hub*. Through the use of an ADC (Analog Digital Converter) chip, the *Flumen Point* reads the sensors and transmits the data to the main microcontroller board via the I2C (Inter-Integrated Circuit) protocol (Figure 5).

**Figure 5.** LoRa, brushless motor control, and sensor reading system




**Source:** The authors, 2024

## 2.5 *Point Flumen*: Interaction

A breadboard was used to assemble the system, which consists of two parts: a receiver to evaluate the data on a computer or other receiver, and an analog-to-digital converter and voltage regulator for the biodigester. To function remotely, a battery-powered system has to be implemented in addition to the microcontrollers. A 12.6V, 2200 mA/h battery was used to power the brushless motor (Figure 3). The computer supplied USB power to the hub and biodigester. The ESP32 LoRa V2 Heltec module was used to program the board via the Platform IO extension of Visual Studio Code (https://platformio.org).

The ADC converter on the main board receives data from the sensors, and the computed and processed values are transmitted to the *Flumen Hub* via the LoRa network. The *Flumen Hub* additionally makes use of the ESP32 WiFi LoRa V2, which is the part that receives the signal transmitted by the *Flumen Point* and instantly logs it into the database. Every hour of the day, the signal obtained by the LoRa chip is processed and transmitted to the Google Firebase Realtime Database. The ESP32 establishes an internet connection, stores the data, and retrieves it using its API protocols. The code library Firebase Arduino Client Library for ESP8266-ESP32@14.4.9, created by user Mobizt, 2021, was used to produce the protocols (Figure 6).

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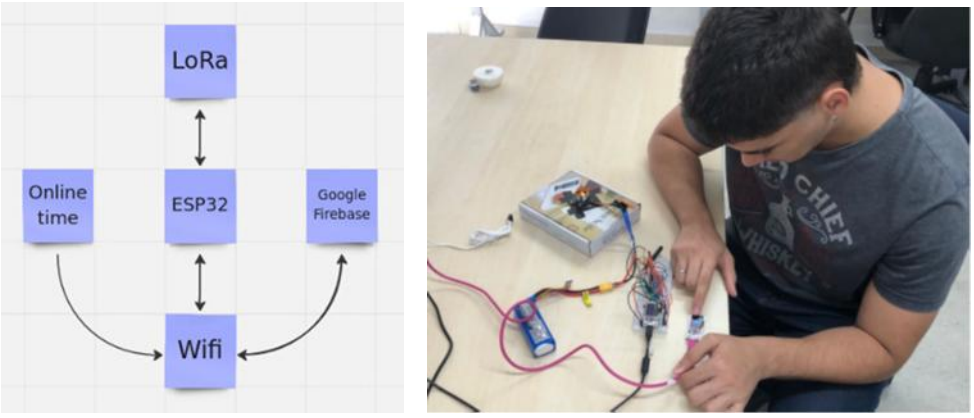
**Figure 6.** ESP32 communication system connected to Google Firebase Realtime Database in real-time via LoRa.




**Source:** The authors, 2024

## 3. RESULTS AND DISCUSSION

### 3.1 Results

A circuit board was used in place of a breadboard to construct the project's physical form (Figure 7). Following the use of the set of sensors to evaluate gas samples in a capsule, the following project execution issues were found: 1. Filtration systems were used to remove any non-flammable gases from the combination, with the primary goal being to get rid of hydrogen sulfide gas ($H_2S$), which corrodes sensors due to its acidity. It was attached to the filter with a PVC capsule and a steel sponge acting as a sacrificial metal to remove $H_2S$.

2. A voltage regulator was added to the system since it was required to have an amperage far more than what the Arduino Uno board could handle. When all of the sensors suddenly dropped in voltage, it was found that a voltage higher than what was deemed safe for the particular electronics was applied. The MQ sensors' and the associated wires' internal resistance was the cause of the drop. As a result, the overall resistance of multiple parallelly connected sensors will be less than that of a single sensor. Consequently, there was a greater overall current flowing through the circuit due to the decreased total resistance.

In order to maintain the proper working of the components, the LM2596 Step Down Voltage Regulator Module was linked to an external power source. The resistance of various tin oxide ($SnO_2$) metal alloys, which varies depending on how they are exposed to various gases, is the basis for how MQ sensors function. These sensors, however, cannot be used to measure mixtures with high gas concentrations. The sensor Methane MQ-4 only has a reading range of 100 to 10,000 ppm. This is in order to achieve the greatest possible concentration of methane gas ($CH_4$), the principal gas in the Lower Explosive Limit (LEL) mixture, which was measured based on a cylinder of known concentration with a 50% LEL (50,000 ppm).

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**Figure 7.** Flumen Gas Project – gas production tests and sensor system used on the Arduino 1 platform.

**Source:** The authors, 2024

### 3.1.1 Electronic system via IoT

The values from the sensors were transmitted by LoRa to *Flumem Hub*, which formatted and converted them into integer values. *Flumem Hub* then relayed the information from the database to *Flumem Point* over the WiFi connection (WPA2) and Google Firebase API. data in real time (Figure 8).

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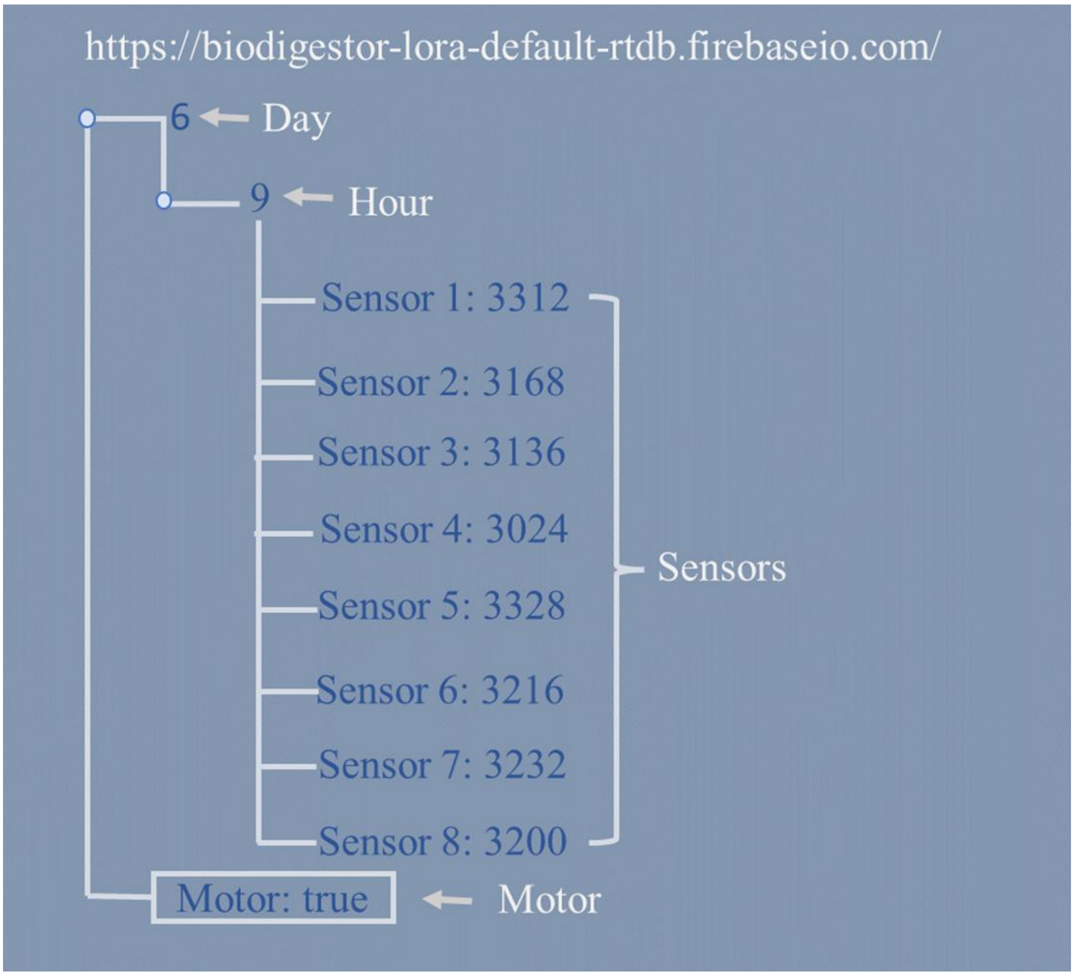
**Figure 8.** *Flumem Hub* relayed the information from the database to *Flumem Point* over the WiFi connection (WPA2) and Google Firebase API. data in real time.




**Source:** The authors, 2024

A variable from the database was read by the *Flumem Hub*, which then transmitted the data to the *Flumem Point* over LoRa. The *Flumem Point* then produced a PWM pulse for the Esc (Electronic Speed Controller), which turns on the Brushless motor.

### 3.1.2 Sketch Structure

Sequential set of commands for the Arduino device

```
#include <avr/io.h>
#define F_CPU 16000000UL
#include <util/delay.h>
#include <math.h>
#include <stdio.h>
//#include <OneWire.h>//~~
//#include <DallasTemperature.h>//~~
```

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## 3.2 Discussion

In remote locations, the *Flumem* gadget offers a feasible substitute for tracking the production of biogas. MQ sensors have a wide range of applications due to their inexpensive cost and accessibility (Mukhtarov *et al*., 2024). Despite these advantages, low-cost sensors have only recently and infrequently been used in the biomass industry (Tabatabaei *et. al*., 2018).

The usage of MQ sensors, which can measure the gas concentration higher than the limit specified for each sensor in the device through calibration curves, is one of the proposed uses for the device. A novel device to be researched would be the dilution of a given mixture in a system that upgrades methane and uses a calibration curve to measure higher concentrations. This device would be highly useful in small-scale, low-cost biogas projects and at the experimental level.

Using iron oxide for biogas desulfurization has advantages over sodium hydroxide, which may be safely released into the atmosphere due to its dry process and non-hazardous waste output (Magomnang; Villanueva, 2015). However, purification using sodium hydroxide may be economically feasible for production units that aim to create biomethane, given the fact that the combination shows large amounts of $H_2S$ (Angelidaki *et al.,* 2018; VUT, 2012).

Utilizing a brushless rotor in conjunction with the open-source ESP32-LoRa to monitor gas output in remote locations offered benefits over the initial prototype put forth by Camargo *et al*. (2024). Gas records can be obtained over the LoRa system through an application or computer screen. When a brush motor is swapped out for a brushless motor to mix the biodigester solution, the system becomes safer since there are less sparks that could cause an explosion in the presence of gasses. It also uses less energy. This new prototype was created in response to this need.

It is crucial to coordinate the receiving and sending of information in such a way that sending occurs first. The next advancement involves creating a printed circuit board that compactly integrates the ESC, the ADC converters, the LoRa module and the ESP32, the battery manager, and, in an effort to increase system autonomy, a solar panel. This is because the first device was constructed and tested on a protoboard system.

## 4. FINAL CONSIDERATIONS

This straightforward, inexpensive, and portable measurement method offers a very appealing way to keep updated on biomass gasification systems in isolated rural locations. It spares local operators from the exorbitant expenses of buying and maintaining traditional measuring equipment like gas chromatographs, allowing them to maintain and enhance current installations. As a result, this work advances rural electrification in isolated regions.

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