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Design And Development Of A Tangible UI Enabled Portable Semi-Automatic Biogas Plant

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Abstract: This paper presents a design for a compact, Arduino-controlled biogas plant with a 20-liter capacity. The system has a main chamber along with 4 liters of buffer storage. The system is equipped with three manual valves and a solenoid valve, along with a pressure and a methane sensor. A 3D printed user interface is also provided with a screen and two buttons. The system prioritizes safety through the integration of a pressure sensor and a methane sensor. If either sensor surpasses a designated threshold (4 bars for pressure), a solenoid valve automatically opens, releasing excess gas. A 16x2 LCD display provides real-time pressure and methane concentration readings. User interaction is facilitated via a two-button remote control. One button enables automatic control, while the other allows for manual operation. A 3D-printed tangible user interface enhances the user experience. This design offers a user-friendly, safe, and efficient solution for small-scale biogas production.

Keywords: semi-automatic biogas plant, methane sensor, pressure sensor, solenoid valve, user interface, biogas production chamber

1. INTRODUCTION

Biogas waste is one of the most useful resources on the planet. It is observed that kitchens in Indian households generate kitchen waste, which can be used to generate biofuel, which can be reused to generate cooking gas, and we all know that India has set net zero by the end of 2040 so it is advisable to save the natural resource and make use of the sustainable resource, making biogas a sustainable option to use in daily cooking. Semi-automatic biogas plants offer a potential middle ground between manual and fully automated systems for biogas production. This review examines the current state of research on semi-automatic biogas plants, focusing on their advantages, limitations, and potential for wider adoption. Advantages: Reduced Labor: Compared to manual feeding and cleaning, semi-automatic systems can significantly reduce labor requirements [1,2]. This is particularly advantageous for larger-scale applications like farms or communities. Improved Efficiency: Automation of certain tasks can optimize feeding schedules and digester conditions, potentially leading to increased biogas yield [3,4]. Enhanced Safety: Automation can help manage pressure buildup and gas leaks, improving overall safety during operation [5,6]. Limitations: Cost: The initial investment for a semi-automatic plant is likely higher than a manual system [7,8]. Complexity: These systems may require more technical expertise for operation and maintenance compared to manual plants [9,10]. Energy Dependence: Some levels of automation may rely on external power sources, which could be a challenge in off-grid locations [11,12]. Future Potential: Research suggests that semi-automatic biogas plants can be a viable option for improving biogas production efficiency while reducing manual labor requirements. Further advancements in automation technologies and cost-effective designs could enhance their appeal for wider adoption, particularly in rural and semi-urban areas. The incorporation of sensor technology into small biogas plants presents exciting possibilities for improved efficiency, operation, and safety. Here, we explore the potential of sensor integration in this context. **Benefits of Sensor Integration: Process Monitoring:** Sensors can continuously monitor crucial parameters like temperature, pH, and biogas composition within the digester [13,14]. This real-time data allows for adjustments to feedstock composition or digester conditions to optimize biogas production. **Early Warning Systems:** Sensors can detect potential issues like pressure build-up or gas leaks, enabling preventative measures to ensure safe operation [15,16]. **Remote Management:** By integrating sensors with communication modules, operators can remotely monitor and control small biogas plants, which is particularly beneficial for geographically dispersed installations [17,18]. **Challenges and Considerations: Cost:** The initial cost of sensor integration may increase the overall cost of a small biogas plant [19,20]. Balancing affordability with the benefits gained is crucial. **Power Supply:** Sensor operation may require an external power source, which could be a challenge in off-grid locations where the biogas plant itself aims to provide energy [21] . **Data Management:** The real-time data generated by sensors needs to be effectively stored, analyzed, and translated into actionable insights for users with varying technical expertise [22]. **Future Direction:** Research suggests that sensor integration in small biogas plants holds promise for enhanced performance and user experience. Continued development of low-cost, energy-efficient sensors, coupled with user-friendly data visualization tools, can make these plants more attractive for wider adoption, particularly in rural and developing communities.

2. PROBLEM STATEMENT AND METHODOLOGY

Conventional biogas plants can be large and complex, limiting their accessibility for individuals or small communities. Additionally, safety concerns arise due to potential pressure buildup and methane accumulation. This project aims to address these limitations by developing a compact, user-friendly, and safe biogas plant suitable for small-scale applications. This research proposes an Arduino-controlled biogas digester with a 20-liter capacity. The system prioritizes safety by incorporating pressure and methane sensors. The Arduino continuously monitors sensor readings [23–28]. If pressure exceeds 4 bar or methane concentration reaches a predefined limit, a solenoid valve automatically opens, releasing excess gas and preventing hazardous situations. For user interaction, a 16x2 LCD display provides real-time data on pressure and methane levels. Furthermore, a two-button remote control allows users to switch between automatic (sensor-driven) and manual control of the solenoid valve. A 3D-printed tangible user interface [29,30] complements the remote control, offering a physical interaction point with the system. This combined approach creates a user-friendly and informative experience.

3. EXISTING PRODUCT ANALYSIS

Table 1 shows a list of existing products with some basic information and challenges. Enhanced Safety Features: While existing portable plants may have pressure relief valves, your design integrates both pressure and methane sensors with automatic release via a solenoid valve. This two-pronged approach offers a more robust safety system. User Interface and Control: Existing designs might have basic controls or gauges. The current project incorporates a 16x2 LCD display for real-time data visualization and a two-button remote for automatic/manual control. The 3D-printed tangible UI adds a unique user interaction element not typically seen in portable plants. Compactness and Scalability: Depending on existing designs, your 20-liter capacity unit might be even more compact, making it suitable for even smaller spaces. Portability could potentially be enhanced with a focus on weight and size optimization. Data Logging and Analysis: Explore if your design can be extended to log sensor data for later analysis, potentially providing valuable insights into biogas production.

Table 1: Existing Product Analysis

Sr. No.	Name of the Existing Product	Information	Issue with the existing product
1	Biotech India Nano Biogas Plant:	This is a small-scale plant suitable for households. It claims to process 1-2 kg of organic waste daily.	Fully Manual, less capacity, only single valve, No buffer storage
2	Zero Power 1 m3 FRP Domestic Biogas Plant:	This FRP (Fiber-reinforced plastic) plant is another domestic option. It offers minimal operating costs and a lifespan of around 15-20 years	No user interface, No pressure sensor, No indication of Methane gas values
3	GreenHome Biogas Plant: (Koshishindia)	This plant is another domestic biogas solution offered by Koshish Sustainable Solutions. They highlight its waste management and clean energy generation capabilities	Big in size, less storage, no buffer storage, No emergency pressure valve / cut-off

4. EXPERIMENTAL SET-UP

In Fig. 1, it is observed that a 20 liter storage tank is used, which is connected with various valves, whose functional condition is mentioned in the table. The first valve, v1, is used to control the main flow of the gas directly from the storage tank. Valve v1 is connected with valve v2 in series, which ensures that the gas generated cannot flow back into the storage tank when valve v1 is closed. When valve v2 is in the operative condition, it is connected with valve v3, which is parallel to the output. The cooking gas is generated and flowed with the help of a flexible hose pipe that is attached to the gas burner on one side and the other side of the pipe is connected to the valve v3. With the connector pin from valve v3, the output can be measured and it can be used for cooking purposes. Similarly, with the extra provisional safety, we have been using the solenoid valve, which will make the system stable to install at various locations. When valves v1 and v3 are closed, the system will be connected to valves v2 and v3, which will allow two conditions, i.e., the first condition is that the gas can be used using the gas burner, and if the generation of cooking gas is greater, the solenoid valve will be activated, and the excess gas can be used to store in the tube, which will make the system stable to install at various locations and if the generation of cooking gas is greater, the solenoid valve will be activated and the excess gas can be used to store in the tube, which can be later used for cooking purposes. The solenoid helps with flow control and makes the system more accessible and more convenient to install at various locations. Figure 2 shows the picture of the 3D printed tangible UI [23,24,26,28,31], which monitors the sensor data and controls the entire system in automatic mode.

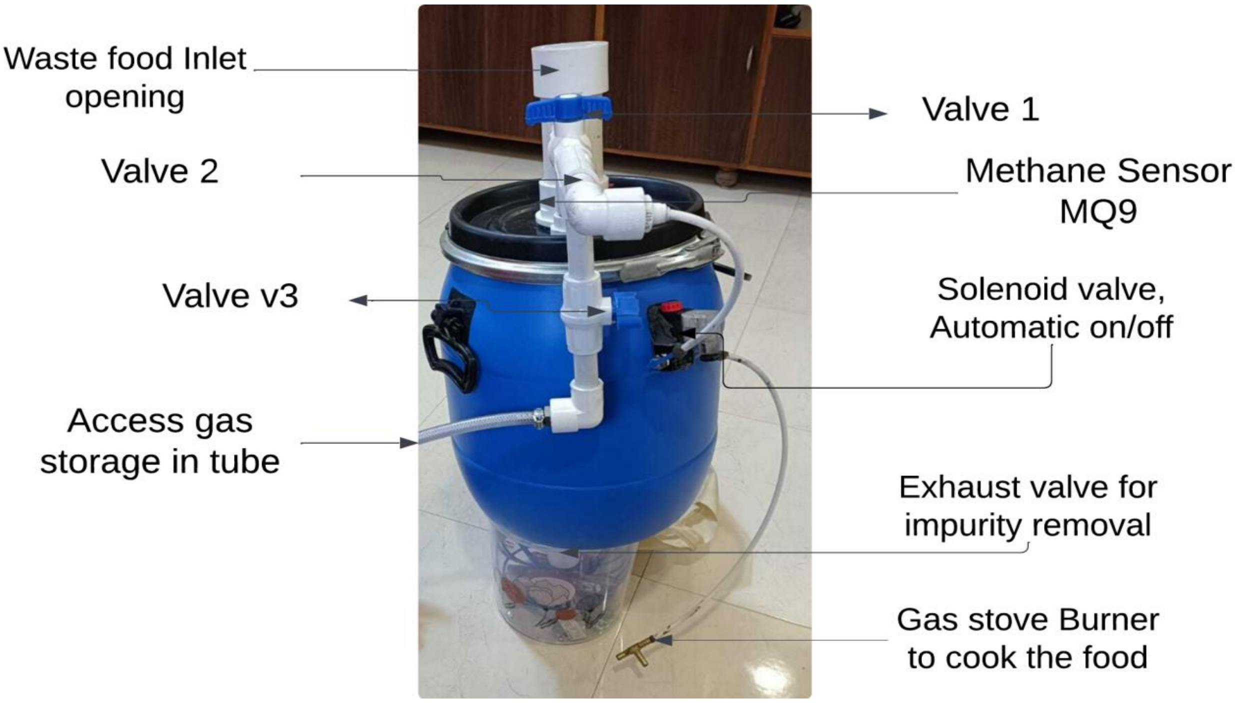

Figure 1: Experimental Setup

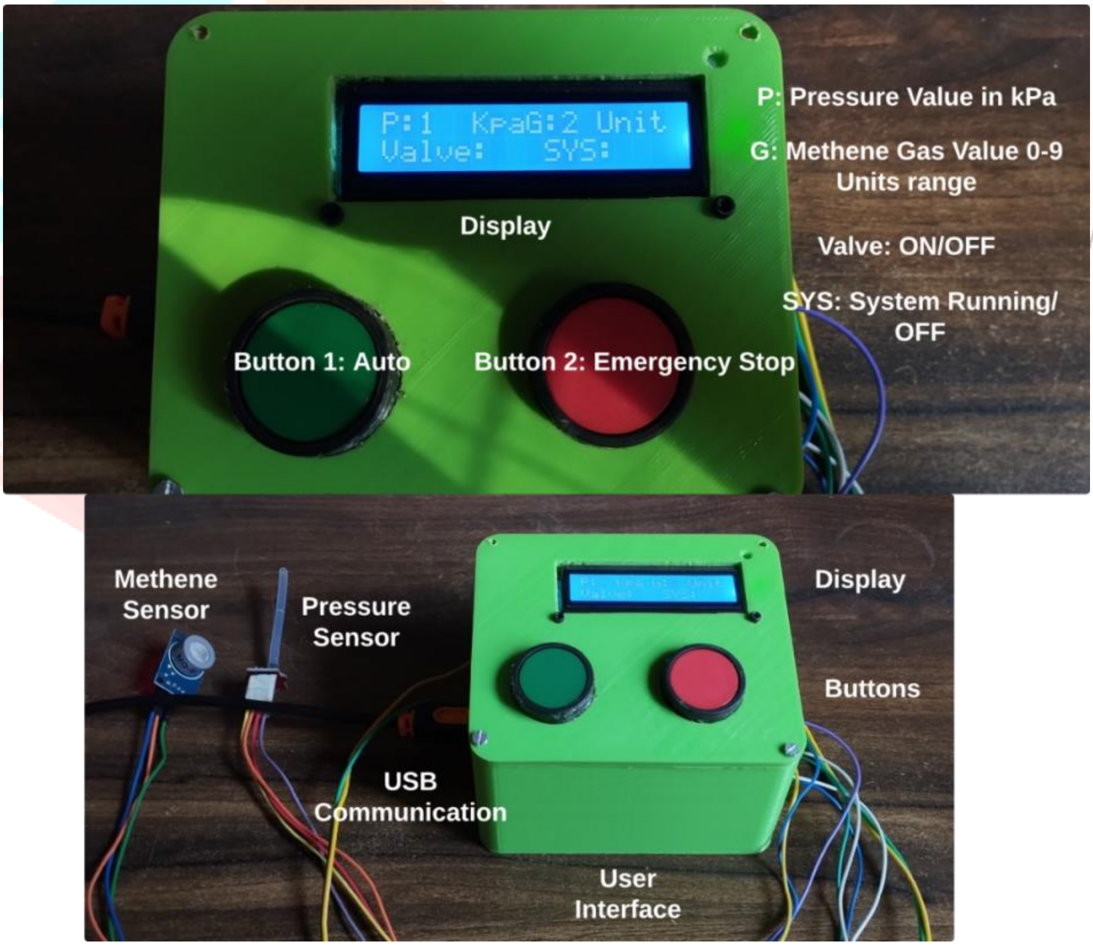

Figure 2: 3D Printed User Interface

5. WORKING PRINCIPLE

The process flow diagram is shown in Fig. 3. The mechanical and electronic block diagrams can be seen in Fig. 4.

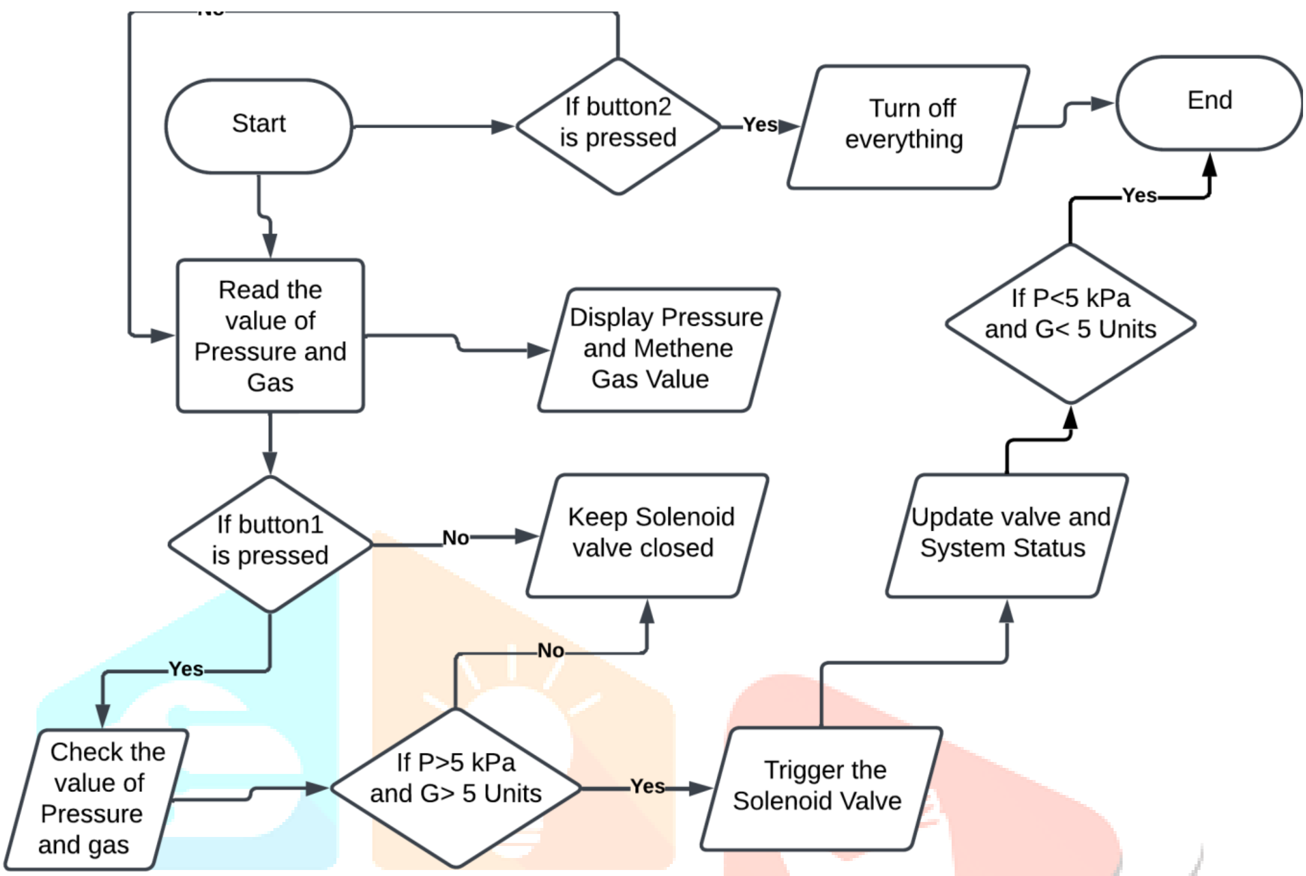

Figure 3: Process flow chart of the system

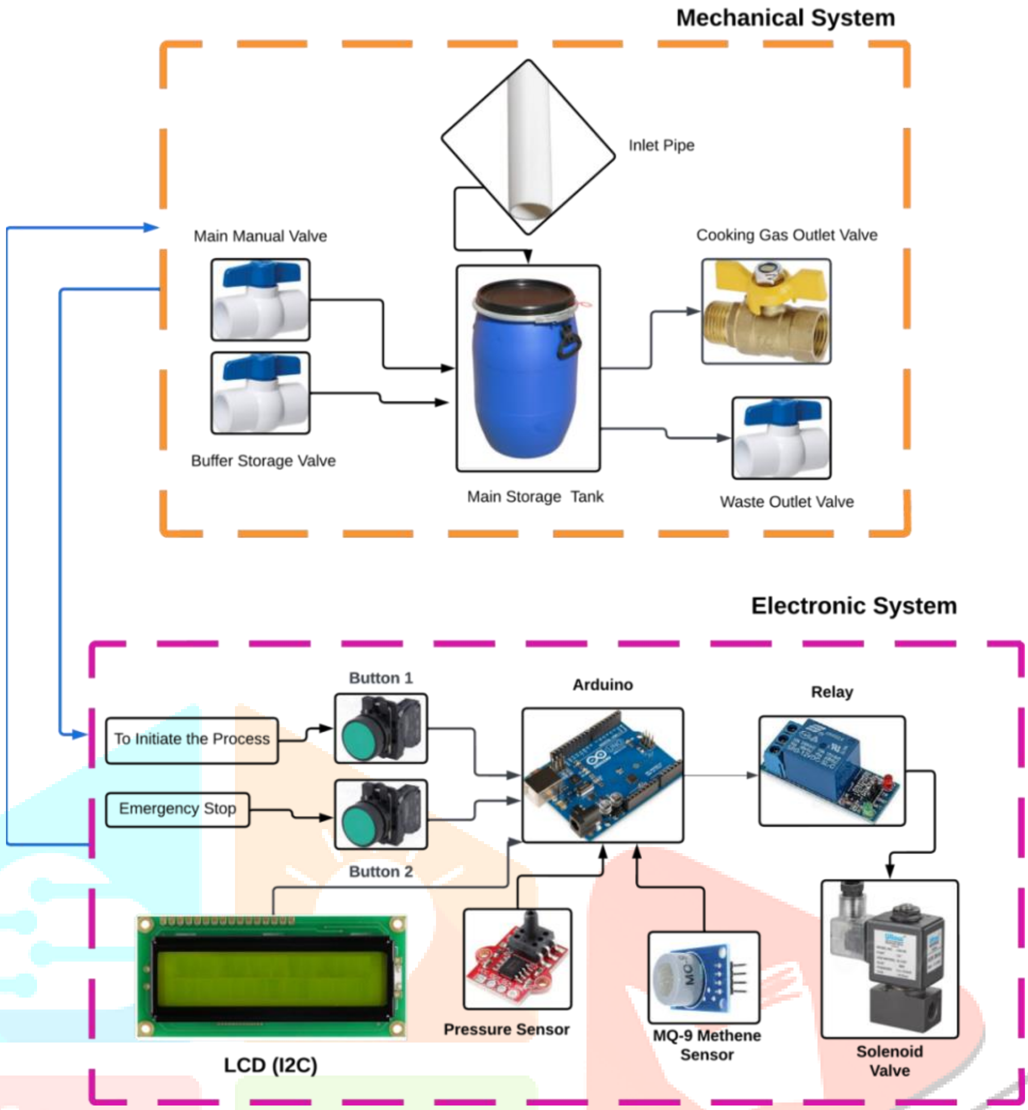

Figure 4: Block Diagram of the System

Figure 3 is a flow diagram of a biogas project using an Arduino controller, solenoid valve, pressure sensor, methane sensor, and LCD display. The system prioritizes safety through integration of the pressure and methane sensors. The flow chart outlines the following steps:

1. Start: The process begins at the "Start" symbol.
2. Read Sensor Values: The Arduino reads the values from the pressure sensor and methane sensor.
3. Check Button 1: The system checks if the first button on the remote control is pressed.
    - Yes: If the button is pressed, the solenoid valve remains closed ("Keep Solenoid Valve Closed"). The system then proceeds to update the valve and system status ("Update valve and System Status").
    - No: If the button is not pressed, the flow continues to the next step.
4. Pressure and Gas Check: The system checks if the pressure and gas readings are within the designated safety thresholds.
    - Safe Range: If the pressure is less than 5 kPa (kilopascals) and the gas value is less than 5 units (specific units not mentioned in the diagram), the system remains stable ("Safe Range"). The flow then proceeds to update the valve and system status ("Update valve and System Status").
    - Unsafe Range: If the pressure is greater than 5 kPa or the gas value is greater than 5 units, the system triggers the solenoid valve to open ("Trigger the Solenoid Valve"). This releases excess gas and prevents a potential pressure build-up or dangerous methane concentration. The system then proceeds to update the valve and system status ("Update valve and System Status").
5. End: The process reaches the "End" symbol.
6. Button 2 (optional): The diagram also includes a branch labeled "If button is pressed" leading to a "Turn off everything" function. However, the placement of this branch suggests it might not be part of the main flow, possibly included to indicate an alternative shut-off option.

7. LCD Display: The LCD display is not explicitly shown in the flow diagram, but it can be assumed that the system continuously updates the pressure and methane readings on the display throughout the process.

This flow diagram illustrates a safety-focused design for a small-scale biogas plant controlled by Arduino. The system prioritizes safety by automatically releasing excess gas if sensor readings surpass designated thresholds.

6. RESULTS AND DISCUSSIONS

Figures 5 and 6 show the responses of the pressure (HX710B) and methane sensors (MQ9). The sensors are tested for 139 seconds. The response time of each sensor is approximately 45 msec. The pressure sensor is calibrated using an air pump by providing variable voltage to the pump. The MQ9 sensor is calibrated in the closed chamber with a cow dung. The HX710B pressure sensor itself lacks user-accessible calibration options. However, software running on the Arduino can account for sensor offset and sensitivity variations to achieve a form of calibration.

Data Acquisition

1. **Gather Pressure References:** Two known pressure values are required. This can involve a pressure reference source like a manometer or a vacuum pump.
2. **Record Sensor Readings:** Apply each pressure value to the sensor and record the corresponding raw output (analog reading) from the Arduino.

Calibration Factor Calculation

1. **Gain (Sensitivity):** This translates the change in pressure to a change in the analog reading. It's calculated as: Gain (G) = (High Pressure Reading - Low Pressure Reading) / (Actual High Pressure - Actual Low Pressure)
2. **Offset (Bias):** This accounts for any non-zero reading when no pressure is applied. It's calculated as: Offset (O) = Low Pressure Reading - (Gain * Actual Low Pressure)

Code Implementation

1. **Offset Subtraction:** Before taking pressure measurements in the Arduino code, subtract the offset value from the raw sensor reading.
2. **Gain Multiplication:** Multiply the result by the gain factor to convert the reading to the desired units (e.g., psi, kPa).

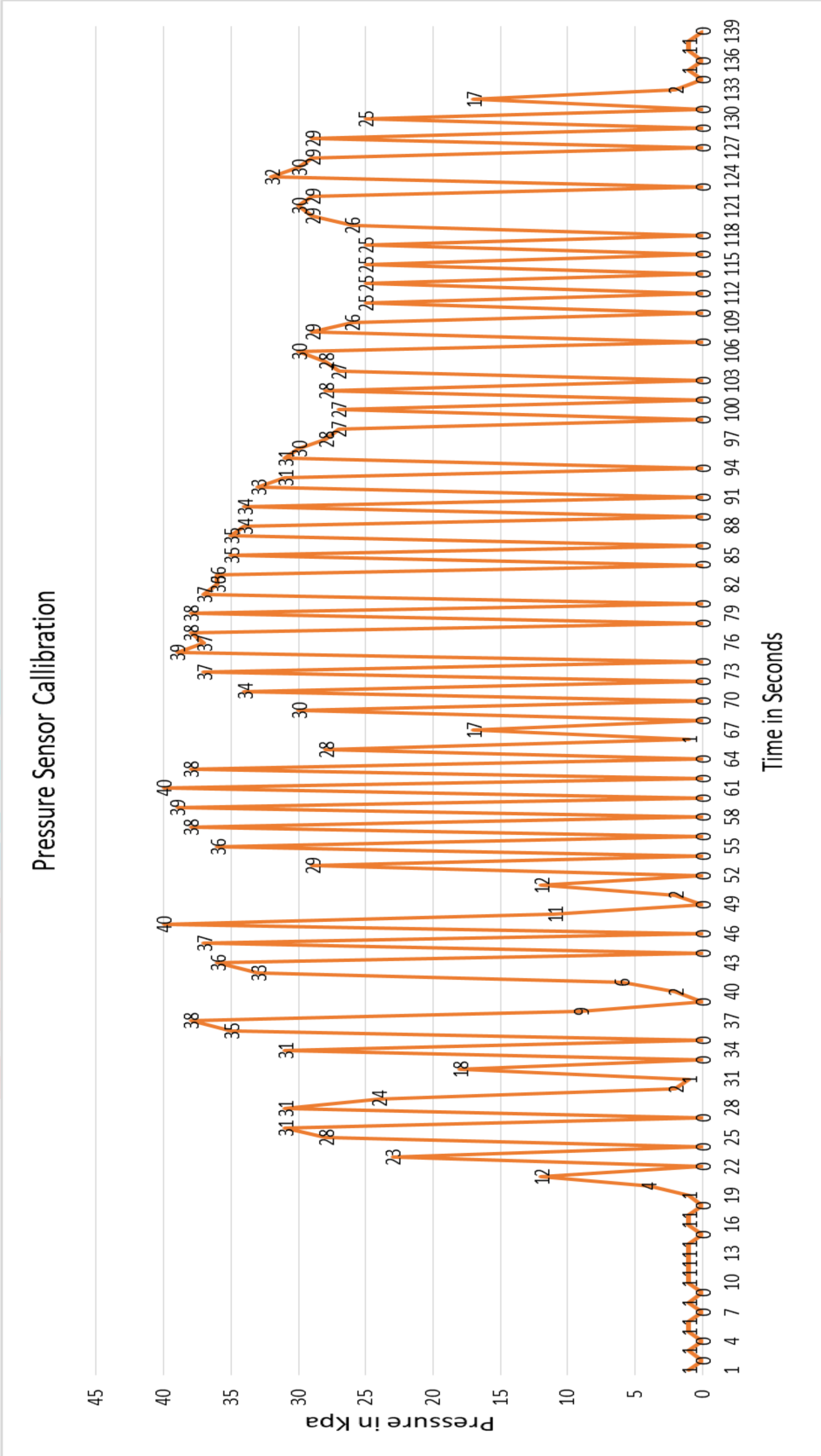

Figure 5: Pressure Sensor Calibration

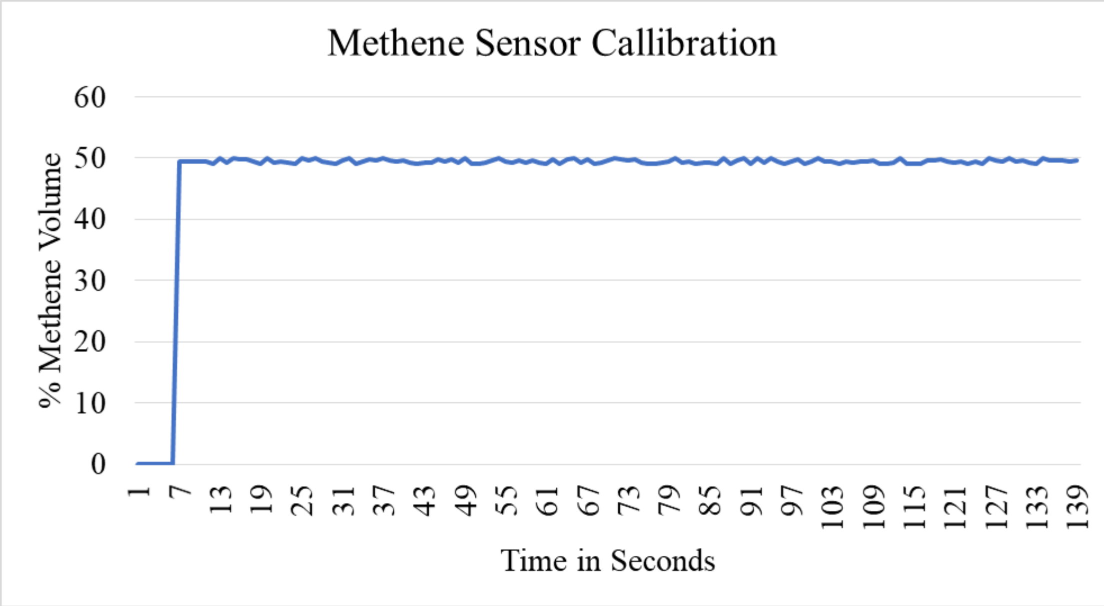

Figure 6: Methane Sensor Calibration

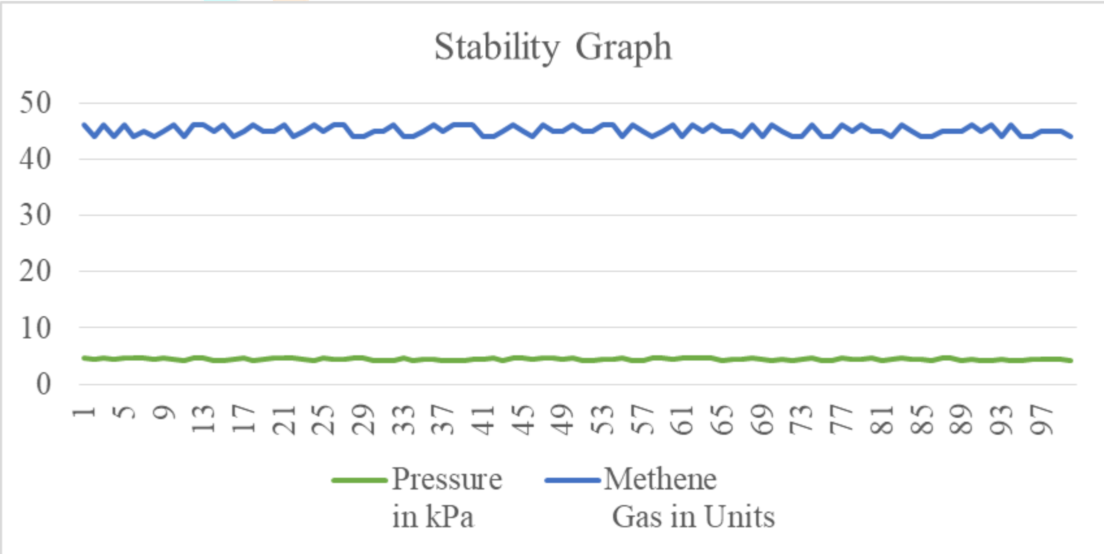

Figure 7: Stability Graph

The MQ-9 gas sensor offers a general sensitivity to various gasses, including methane. However, it's not directly calibrated for specific gas concentrations. To enhance the accuracy of methane detection within a biogas digester application controlled by Arduino, a software-based calibration approach is recommended. This involves establishing a baseline reading in clean air and then exposing the sensor to known methane concentrations. By recording the sensor output at these concentrations, a mathematical relationship between the sensor reading and methane level can be established. This relationship can then be implemented within the Arduino code to convert sensor readings into estimated methane concentrations. It's crucial to acknowledge that this calibration approach provides an approximation and may require adjustments based on the specific gas composition within the digester. Additionally, long-term sensor performance can drift, necessitating periodic recalibration to ensure reliable methane detection. Figure 8 shows the stability graph of the sensor, which proves that the sensor remained stable and accurate for 97 minutes.

7. CONCLUDING REMARKS

This research presented a design for a compact, Arduino-controlled biogas plant prioritizing safety through sensor integration. The system effectively monitored pressure and methane concentration, automatically releasing excess gas via a solenoid valve if thresholds were exceeded. User interaction was facilitated by a remote control offering automatic and manual control modes. A 3D-printed tangible user interface provided a unique physical interaction point. The project successfully demonstrated the feasibility of a user-friendly and safe biogas plant suitable for small-scale applications. However, further exploration can enhance its capabilities.

8. FUTURE SCOPE

- Data Logging and Analysis: Implementing data logging features would allow for long-term monitoring of biogas production, pressure fluctuations, and methane levels. This data could be used to optimize feeding schedules and improve overall digester efficiency.
- Advanced Sensor Integration: Exploring the use of additional sensors, such as temperature sensors, could provide a more comprehensive picture of the digester environment, potentially leading to further optimization of the biogas production process.
- Internet of Things (IoT) Integration: Integrating the system with an IoT platform would enable remote monitoring and control. Users could access real-time data and manage the plant remotely using a smartphone or web application.
- Biogas Upgradation: Investigating methods for upgrading biogas to biomethane, a higher quality fuel source, would significantly increase the project's potential applications.

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