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## Mobile system for monitoring plant environment parameters for biogas production

**Abstract.** The main sources of biomass for biogas units can be organic waste, grain, hay, manure, various plant materials, etc. Anaerobic digestion, which consists of a series of complex biological reactions, is a challenging process that requires detailed parameter control to prevent possible losses and to make best use of the material. Therefore, the purpose of this study was to consider the possibility of developing a mobile unit for monitoring the parameters of the plant environment during biogas production with the possibility of storing data and using them in the construction of a mathematical model for predicting gas yield. The algorithm was created based on the principles of fuzzy logic and the structure of neural networks. The architecture of a mobile system for monitoring plant environment parameters for biogas production was proposed. The developed circuit diagram of such a system was presented. The system's operation was presented in the form of a created algorithm for searching and identifying connected devices on the 1-Wire bus. This bus is used to poll sensors and measure process parameters. Software was developed for interfacing several types of sensors, transferring and saving data to the cloud storage with the subsequent possibility of processing it. The biomass can be photographed using the built-in camera. Using the principle of Internet of Things technology, remote access to measured data is provided. The measured process parameters and photos are transferred to the control system server for further analysis, which will allow for a more accurate assessment of the biomass preparation process for fermentation. The obtained results allow improving the control and decision support systems for biomass loading into a biogas unit

**Keywords:** measurement; control; camera; sensor; biomass

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## INTRODUCTION

Considering the growing interest in environmentally friendly energy sources and the need to conserve resources, a mobile plant monitoring system is becoming a valuable tool for modern agriculture. Biogas production is a vital component of renewable energy that helps reduce dependence on hydrocarbon fuels. Monitoring of the plant environment contributes to increasing the productivity and efficiency of biogas production, which is important for sustainable energy development and energy conservation, as reported in V.O. Ferreira *et al.* (2023) and K. Gioulounta *et al.* (2023). Biogas production is becoming increasingly popular in today's environment, both in Ukraine and the European Union. 2021 was a record year for the annual increase in biomethane production (almost 6.1 TWh or 0.6 m<sup>3</sup> more than in 2020). In total, the volume of biomethane produced in Europe in 2021 was 37 TWh or 3.5 m<sup>3</sup> (EBA Statistical Report, 2022). The methods of monitoring operating parameters and finding links between them used in biogas plants are insufficiently effective. For instance, O.O. Olakanmi *et al.* (2021) discusses a smart biogas unit that includes a controlled biophysical system that uses both thermofluidic devices and IoT devices to acquire data and control electromechanical subsystems. However, the above study does not include systems for monitoring the condition of biomass undergoing preparation before being loaded into a biogas unit.

Systems based on neural networks (NNs) and Big Data are widely used to find best solutions in various types of production. A.H. Abdurrahman *et al.* (2020) found that such systems make it possible to collect data for everything that creates the conditions for using proportions and operating modes for maximum biogas production. However, this study does not make provision for the use of a camera for external analysis of biomass, which will allow its contactless assessment, since it involves the processing of large amounts of data using computer-integrated technologies. At the same time, L. Zemite *et al.* (2022), A.A. Siyal *et al.* (2023) proved that modern installations, including the one described in this paper, cannot provide the ability to collect data on system parameters at each stage online.

It should also be borne in mind that scientists are looking for ways to increase biogas production using different approaches. For instance, V.M. Polishchuk *et al.* (2021) discusses the issue of increasing the productivity of biogas production through combined fermentation of raw materials. However, in this paper, the authors evaluate the fermentation process by means of laboratory measurements in separate phases of research. Considering the continuity of the fermentation process, it is necessary to constantly monitor technological parameters for a qualitative assessment of the development of new approaches to increase the productivity of biogas production. Approaches to their solution are considered in the studies of M. Zhou & Z. Zou (2018), M. Silwadi *et al.* (2023), where it is argued

that this requires obtaining accurate and high-quality data for a long time. As a result, in the future, it is planned to process large amounts of data and train the system on correctly formed models with correctly set goals. At the same time, modern biogas units do not have the ability to collect information on process parameters online at every stage of production. It is proposed to improve the existing control systems of biogas units by monitoring the parameters of the plant environment before they are loaded into the plant.

The purpose of this study was to develop software and hardware for a system for monitoring plant environment parameters for biogas production.

## MATERIALS AND METHODS

The production technology was analysed during 2023 based on the Bioenergy Complex of the Astarta-Kyiv agricultural holding, which is characterised by the following indicators: the complex processes 1,200 tonnes of beet pulp per day, 225 tonnes of sugar beet leaf silage and pig manure, and produces about 150,000 m<sup>3</sup> of biogas per day, the equivalent of 75,000 m<sup>3</sup> of natural gas. The design of the plant environment monitoring system was based on the design features of the process equipment and the biomass pretreatment process. Based on the design results, a model of the monitoring system was created. The theoretical stage of the study included an analysis of the works of H. Rahadian *et al.* (2015), V.M. Reshетиuk *et al.* (2016), T. Lendiel *et al.* (2021). Thanks to the review of these studies, the best methods and techniques for the practical stage of the research were selected.

The algorithm was based on fuzzy logic rules and neural network models. The creation of a system for collecting and storing data for long-term storage for further processing and predicting the quality of the plant environment to be fermented began with the architecture of such a system. This architecture included a control device with temperature, air and soil humidity sensors, a camera, and a cloud-based platform for uninterrupted data acquisition and storage.

The NodeMCU v3 module (Espressif Systems, China) was chosen as the control device, built based on the ESP8266 microcontroller (Espressif Systems, China) with the Xtensa L106 processor (Tensilica Inc, USA), which is based on the RISC architecture, uses a frequency of 80 to 160 MHz, which allows for computing and data processing, and is suitable for battery power. One of the key features of the ESP8266 microcontroller was the built-in Wi-Fi module. It supports 802.11 b/g/n standards, which allows devices to connect to wireless networks and share data over the Internet. The ESP8266 features digital and analogue general-purpose input (GPIO) pins that can be used to connect to a variety of devices such as sensors, LEDs, etc. The ESP8266 microcontroller has a Universal Asynchronous Receiver and Transmitter (UART) and a Serial

Peripheral Interface (SPI), which allows it to interact with other devices and microcontrollers when it is necessary to synchronise the operation of devices with each other. The built-in micro-USB port allows connecting the microcontroller to a computer to download the program code.

Temperature measurements on the platform were implemented by several types of sensors:

1) DS18B20 (Analog Devices, USA) is a digital temperature sensor in a waterproof, insulated housing (IP67), which makes it suitable for temperature measurement in various environments. The DS18B20 can measure temperatures from  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  with an accuracy grade of  $0.0625^{\circ}\text{C}$ . The DS18B20 digital interface is based on the 1-Wire protocol, which allows data to be read from the sensor using only one wire.

2) DHT 22 (Aosong Electronics Co Ltd, China) is a universal temperature and humidity sensor. The humidity measurement range is from 0% to 100% with a resolution of 0.1%, and the temperature range is from  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  with a resolution of  $0.1^{\circ}\text{C}$ .

The moisture content of the raw materials will be measured by a moisture sensor combined with a two-channel comparator LM393 (Texas Instruments, USA). The module has both digital and analogue outputs and a potentiometer for threshold adjustment. The moisture sensor consists of two probes that are used to determine the moisture content of the soil. The moisture sensor probes are coated with immersion gold, which protects the nickel from oxidation. These two probes are used to pass current through the soil, which creates the conditions for determining moisture content.

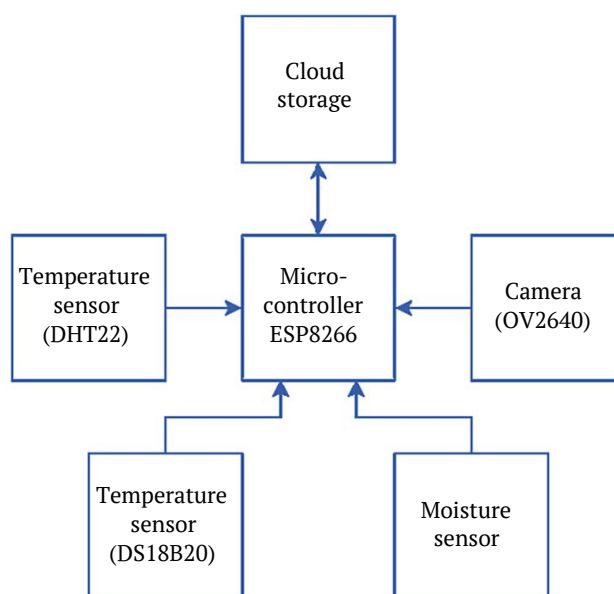
The state of the incoming biomaterial was recorded by the OV2640 camera module (ArduCam China) mounted on the ESP32 microcontroller (Espressif Systems, China). The maximum resolution of the video module's matrix is 1600 by 1200 pixels at 15 frames per second. The colour depth is 8 bits, i.e., the maximum number of colours that can be displayed simultaneously is 256, and the supported formats include 8/10-bit Raw RGB, YUV(422/420), RGB565/555.

The proposed device allowed storing information from sensors with address binding, which makes it possible to accurately monitor changes in parameters in real time. All data is stored in the cloud and can be further processed and used to develop a forecasting model. The code was created and debugged in the Arduino environment.

## RESULTS AND DISCUSSION

Systems for monitoring plant environment parameters for biogas production will open opportunities to create effective control solutions for best biogas unit utilisation using advanced IoT technologies. This approach allows for reliable monitoring of plant environment parameters in real time, which helps to optimise and increase the productivity of biogas production. It will be able to introduce innovative approaches to the control and management of biogas processes, ensuring efficient use of resources and increasing the degree of automation of these processes. The component diagram of the system (architecture) is presented in Figure 1.

A part of the code and a fragment of the data flow are presented in Figure 2. In the console, one can see the temperature and humidity data in real time.



**Figure 1.** Component diagram (architecture) of the system

**Source:** compiled by the authors of this study

```

OneWire ds(D1);
#define DHTPIN D2
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);
void setup(void) {
  Serial.begin(9600);
  pinMode(D5, OUTPUT);
  pinMode(D4, OUTPUT);
  digitalWrite(D5, HIGH);
  dht.begin();
}

void loop(void) {
  byte i;
  byte present = 0;
  byte type_s;
  byte data[12];
  byte addr[8];
  float celsius, fahrenheit;

  if ( !ds.search(addr) ) {
    Serial.println("No more addresses.");
    digitalWrite(D4, HIGH);

    Serial.println();
    ds.reset_search();
    delay(1000);
    return;
  }

  Serial.print("ROM =");
  for( i = 0; i < 8; i++) {
    Serial.write(' ');

```

```

01:00:02.108 -> Temperature = 27.00 Celsius, 80.60 Fahrenheit
01:00:02.150 -> Humidity: 49.60% Temperature: 26.60°C °F Heat index: 27.03°C No more addresses.
01:00:02.227 ->
01:00:03.125 -> ROM = 28 FF C4 6A B5 16 5 E
01:00:03.161 -> Chip = DS18B20
01:00:19.750 -> Data = 1 B0 1 4B 46 1F FF 1F 10 B2 CRC=B2
01:00:19.750 -> Temperature = 27.00 Celsius, 80.60 Fahrenheit
01:00:19.750 -> Humidity: 49.60% Temperature: 26.60°C °F Heat index: 27.03°C No more addresses.
01:00:19.750 ->
01:00:19.750 -> ROM = 28 FF C4 6A B5 16 5 E
01:00:19.750 -> Chip = DS18B20
01:00:19.750 -> Data = 1 B0 1 4B 46 1F FF 1F 10 B2 CRC=B2
01:00:19.750 -> Temperature = 27.00 Celsius, 80.60 Fahrenheit
01:00:19.750 -> Humidity: 49.60% Temperature: 26.50°C °F Heat index: 26.95°C No more addresses.
01:00:19.750 ->
01:00:19.750 -> ROM = 28 FF C4 6A B5 16 5 E
01:00:19.750 -> Chip = DS18B20
01:00:19.750 -> Data = 1 B0 1 4B 46 1F FF 1F 10 B2 CRC=B2
01:00:19.750 -> Temperature = 27.00 Celsius, 80.60 Fahrenheit
01:00:19.750 -> Humidity: 49.60% Temperature: 26.50°C °F Heat index: 26.95°C No more addresses.
01:00:19.750 ->
01:00:19.750 -> ROM = 28 FF C4 6A B5 16 5 E
01:00:19.750 -> Chip = DS18B20
01:00:19.750 -> Data = 1 B0 1 4B 46 1F FF 1F 10 B2 CRC=B2
01:00:19.750 -> Temperature = 27.00 Celsius, 80.60 Fahrenheit
01:00:19.750 -> Humidity: 49.58% Temperature: 26.50°C °F Heat index: 26.94°C No more addresses.

```

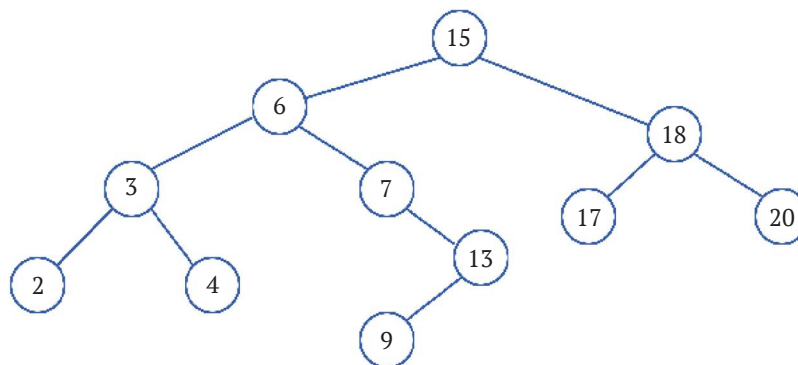
**Figure 2.** Software of the measuring system for monitoring the parameters of the plant environment for biogas production

**Note:** a – a fragment of the programme code; b – a fragment of the data obtained  
**Source:** compiled by the authors of this study

The 1-Wire protocol used for DS18B20 sensors is a data communication protocol developed by Maxim Integrated that uses a single physical wire for data and power, which substantially saves wiring on an extensive sensor network. All data transfer operations start with bit synchronisation between the transmitter and receiver. At the beginning, a short pause is generated, followed by the “START” bit, after which the factual data is transmitted. Notably, several detectors can be connected to one device, creating a parallel network of consumers. A unique 64-bit code is used to identify each sensor. It creates the conditions for determining the address of the device. To

transmit bits, time pulses are used, where a short pulse represents a logical “0” and a long pulse represents a “1”. This method allows transmitting information without using additional conductors. After a bit or byte is transmitted, the receiver sends an ACK or NACK signal, depending on the success of the transmission.

The search and identification of devices connected to the same bus takes place in several stages and using a binary tree is an efficient approach to searching, especially when there are many connected devices. The binary tree helps to reduce the number of checks and operations on the bus, reducing detection time (Fig. 3).



**Figure 3.** Queries in a binary tree

**Source:** compiled by the authors of this study

At the first stage of the binary tree functioning, initialisation takes place, and a reset signal (Reset Pulse) is sent to the bus. In response, the device sends a signal confirming its presence. The binary tree algorithm (Zhuang *et al.*, 2009) with options for possible device addresses is divided into two parts from the range of possible addresses. The simplest binary tree can be represented as nodes. Each node includes two children (branches) and a parent (root key). The distribution of node elements can be described as follows:  $x$  is a node in the binary search tree, and node  $y$  is in the left branch of node  $x$ , then the key  $y$  is smaller than the key  $x$ . If node  $y$  is in the right branch of node  $x$ , then the key  $x$  is smaller than the key  $y$ . The binary tree can be displayed as presented in Fig. 3, where 15 is the parent element and branches from it are 2, 3, 4, 6, 7, 13, 9 on the left, which do not exceed the parent element, and 17, 18, 20 on the right, which are larger values.

The first step of the tree check sends a search signal (OF -Search ROM), when the device responds, the algorithm moves to the branch where it occurred and starts dividing again. Thus, the identification will move until it finds all the addresses of the connected devices (Zhuang *et al.*, 2009). Subsequently, one can associate device addresses and physical locations for further monitoring. The OV2640 camera module is configured and calibrated through the module's software interface (Fig. 4).

The camera was set to the parameters presented in Table 1.

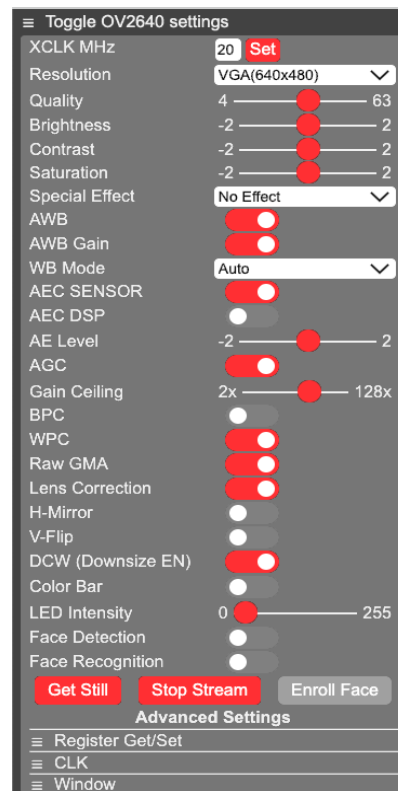


Figure 4. OV2640 camera module configuration software interface

Source: compiled by the authors of this study

Table 1. Calibration options for the OV2640

Parameter name	Designation	Value
XCLK frequency	xclk	20
Pixel format	pixformat	4
Frame size	framesize	8
Quality	quality	38
Brightness	brightness	0
Contrast	contrast	0
Saturation	saturation	1
Sharpness	sharpness	0
Special effect	special_effect	0
White balance mode	wb_mode	0
Automatic white balance	awb	1
White balance gain	awb_gain	1
Automatic exposure	aec	1
Exposure level	ae_level	0
Exposure value	aec_value	168
Automatic gain	agc	1
Gain ratio	agc_gain	0
Maximum gain	gainceiling	4
Correction of black pixels	bpc	0
White pixel correction	wpc	1
GMA settings for RAW	raw_gma	1
Lens correction	lenc	1

Source: compiled by the authors of this study

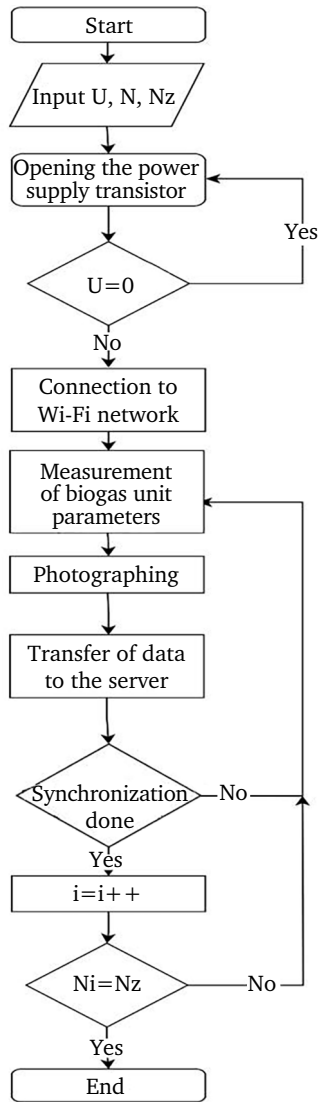
The photos are synchronised with the temperature, humidity, and soil parameters, and stored in the cloud.

Data is transferred via Wi-Fi to the AWS S3 Bucket storage service. Further forecasting of biogas yields will be based

on the Weighted Ensemble algorithm. Two separate models are being built for this purpose:

- forecasting based on the results of parameter measurements;
- prediction based on photo analysis of the input material.

After that, the weights of the influence of each of the parameters in the models are distributed, combined in the Weighted Ensemble algorithm, and the model training begins (Dang *et al.*, 2021). The algorithm of the system is presented in Figure 5.

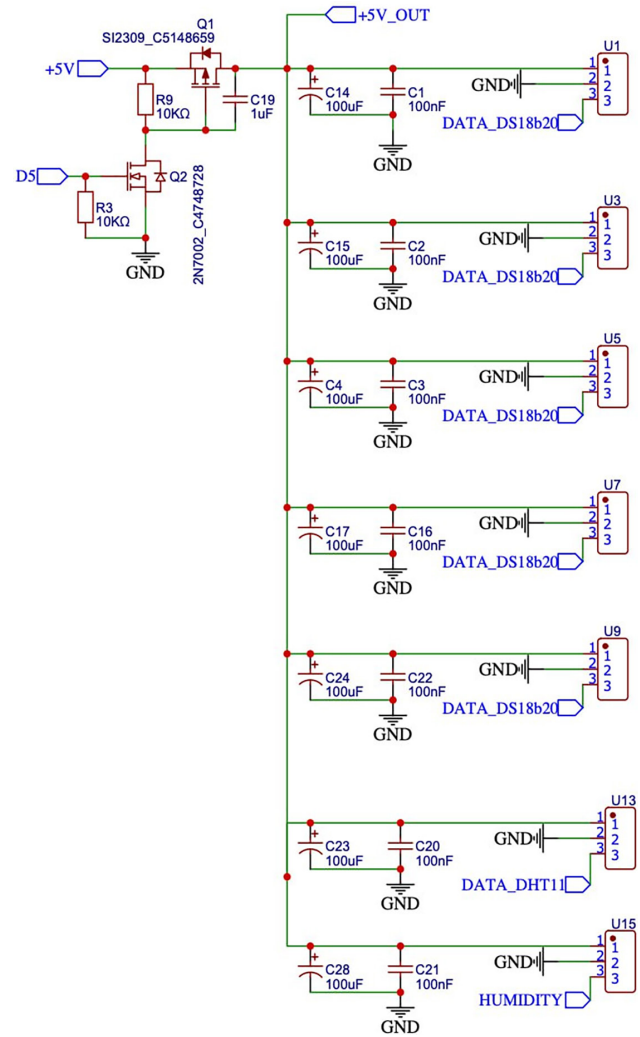


**Figure 5.** Algorithm for measuring parameters of biomaterial for fermentation

Source: compiled by the authors of this study

The algorithm starts with power supply to the controller and its output contacts. The presence of voltage (U) on the controller is checked, and if there is no voltage, the device is switched on again. According to the algorithm, measurements of  $N_i$  (where  $i = 1..z$ ) are carried out, including measurement of technological parameters and creation

of photographs, after which the information is transmitted to the cloud environment to the appropriate address. To ensure the integrity of data transmission, a data synchronization subroutine is used.  $N_i$  measurements are performed until the set number of measurements  $N_z$  is reached. After that, the algorithm is completed. A circuit diagram was developed for the interaction and layout of the device, a fragment of which is presented in Figure 6.



**Figure 6.** A fragment of the schematic diagram of the mobile monitoring system

Source: compiled by the authors of this study

In the above diagram, the cascade of transistors Q1 and Q2 is required to control the opening of the current to the sensor unit. Elements R9 and R3 are reference resistors that create a low signal level at the logic input to which the wire is connected. Pairs of capacitors C14, C1; C15, C2; C4, C3; C17, C16; C24, C22; C23, C20; C28, C21 are shunt capacitors for current filtering and reducing the influence of some circuit elements on those that ensure correctness of sensor measurements. Mounting connectors U1, U3, U5, U7, U9, U13, U15 are used for quick connection of information sensors for bolted connection.

The data is stored and further processed on the Amazon Web Services Internet of Things (AWS IoT Core) platform (Kianijaya & Hasanuddin, 2022). This platform is used to connect devices to the AWS cloud infrastructure to collect, process, analyse, and manage data generated in real time from various devices operating in the IoT. The device connection begins in the Device Gateway, which is the entry point for connecting IoT devices to AWS. The Device Gateway manages all active device connections and implements semantics for multiple protocols to ensure that devices can securely and efficiently communicate with AWS IoT Core. Devices can be connected using the Message Queue Telemetry Transport (MQTT), WebSockets, and HyperText Transfer Protocol Secure (HTTPS) protocols. The MQTT connection protocol was selected for the device (system). The MQTT protocol recognises two types of network objects: MQTT broker and MQTT client. An MQTT broker is a server that receives all messages from clients and then routes these messages to the respective designated clients or services for further processing. An MQTT client can be any device that uses the MQTT library and connects to an MQTT broker via a network. The information is organised in a hierarchy of topics. When the sender has a new set of data to distribute, it sends a control message with the data to the connected broker. The broker sends information to all clients who have subscribed to this topic. The sender does not need to know the number or location of subscriptions, and vice versa, customers do not have to configure any sender data. If a broker receives a message on a topic for which there are no active clients, the broker discards the message unless the sender has marked it as saved. A saved message is a regular MQTT message with the save flag set to 1. The broker saves the last saved message and the corresponding quality of service (QoS) level for the selected topic. Every customer who subscribes to a topic with saved messages receives them immediately after subscribing. The broker stores only one saved message for each topic. This allows newly subscribed customers to receive the most up-to-date incoming information without waiting for the next update from the sender. If it is the first time a data publishing lead client connects with a broker, they can set up a standard incoming message. In the event of an unforeseen disconnection of the lead client from the broker, the broker will send this message to other clients. Clients interact only with a broker, but the system can include several brokers that exchange data based on the topics to which their current clients subscribe. The minimum MQTT control message contains only two bytes of data, and if necessary, control messages can carry up to 256 megabytes of data. MQTT is based on the TCP protocol for data transmission, and it transmits data for connectivity in plain text format, which allows for convenient data processing after it is stored (Yassein *et al.*, 2017).

The problems of building a qualitative model for the formation of a management decision for biogas production include the following:

1) Insufficient data – machine learning models often require a large amount of data to train. If the amount of data is insufficient, the model may be under-trained and have a high error on the test data;

2) data unevenness – data may be uneven, i.e., some values may be represented much more frequently than others. This can lead to the model being over-trained on some values and under-trained on others;

3) Data faultiness – the data may contain errors, omissions, or incorrect values; this can lead to the model being trained on erroneous data, resulting in a result with low accuracy when tested;

4) Incorrect data placement – data placement can affect the model results; e.g., if the data contains multiple sets from different sources, there may be an issue with incompatibility;

5) incorrect choice of features – it is important to choose the right features to train the model; if the features are not selected correctly, the model may be under-trained;

6) overfitting – a problem when a model overlearns on training data and cannot generalise to new data; overfitting can occur if the model is too complex or if there is not enough data to train;

7) Underfitting is a problem when a model is not trained enough to predict new data accurately enough; underfitting can occur if the model is too simple or if insufficient data is used for training;

8) Noise – data can contain noise, i.e., additional details or random deviations that can prevent the model from learning from the data correctly;

9) Outliers – some values in the data may be outliers, i.e., values that are significantly different from other values; this can affect model training and lead to inaccurate results.

There are studies that suggest different approaches to developing a storage platform. For instance, in M.R. Kianijaya & M.O. Hasanuddin (2022), a web-based IoT solution aimed at monitoring and analysing data in the agricultural sector. The purpose of the presented solution is to simplify the monitoring of production processes in this industry using IoT technologies. Real time is achieved based on the MQTT protocol using a brokered publish/subscribe, which is described in detail. This avoids the limitations that arise from the use of networks in rural areas. The information from the sensors is displayed and stored in the web part of the information system. The architecture of a web application is described as a three-tier client-server architecture in which the graphical user interface (presentation tier), application functions and logic (application tier), and computer data storage (database tier) are developed and maintained as independent modules on separate platforms. This solution is based on a platform that is fully managed in-house.

Otherwise, K. Grgić *et al.* (2016) propose a solution for storing such data using both local and online storage. The system has several subsystems, including data transmission, data storage, and power management. It will use

a real-time clock to keep track of time, the Internet for data transmission based on the MQTT protocol, both local storage and a cloud database for data storage, and a power supply system with automatic switching between the main power supply and the backup power supply in the event of an unforeseen event such as a power outage. The cloud database will be available through the AWS cloud service. Using cloud services allows for more flexibility when choosing technologies, as all services are ready to use immediately and do not require additional settings and work on data backup. Data security and accessibility stay important. AWS guarantees a high level of data availability and reliability, and since it will be replicated across multiple regions, it ensures fault tolerance and data security.

The advantages of the MQTT protocol in comparison with other protocols, such as HTTPS, as indicated in the studies of A. Al-Fuqaha *et al.* (2015) and allow opting for it when choosing a data transmission protocol. Most of the protocols used in Internet of Things (IoT) networks are based on data transmission via TCP (Transmission Control Protocol) or UDP (User Datagram Protocol). These protocols include XMPP (Extensible Messaging and Presence Protocol), CoAP (Constrained Application Protocol), DDS (Data Distribution Service, MQTT and AMQP (Advanced Message Queuing Protocol), which are widespread and used in various fields. Each of these protocols has its own concrete functional characteristics and is used to solve specific problems.

This overview will focus on one of the most common application layer protocols, MQTT. The aspects covered include the architecture, message format, scope, and Quality of Service (QoS) for MQTT layers. MQTT is used primarily as a channel for transmitting binary data and provides flexibility in communication patterns. The main goal of MQTT is to provide a publisher-subscriber messaging protocol with minimal bandwidth requirements. Data is transported using the Transmission Control Protocol (TCP). According to M.B. Yassein *et al.* (2017), the advantages of MQTT are as follows: no additional parameters, which makes the protocol less bulky and more efficient for data transmission with a low quality Internet connection; asynchronous data exchange makes it possible to send data regardless of the recipient's state; scalability – the transmission channel does not limit the number of connections, all sent messages are processed in turn; long connection duration without the need to spend resources on reconnection.

The proposed approach will make it possible to form a control decision on the loading of the plant medium into the biogas unit. This uses Internet of Things technologies that provide real-time monitoring of parameters in the system.

## CONCLUSIONS

This study proposed the architecture of a system for monitoring the parameters of the plant environment for biogas production. This will contribute to a more accurate assessment of the future biomass fermentation process; and the development of effective management solutions to increase biogas production. Based on the results of this study, a schematic diagram of the mobile monitoring system was developed; an algorithm for searching and identifying connected devices on the 1-Wire bus; software for interacting with different types of sensors, transferring and storing data in the cloud storage with the subsequent possibility of processing them. The data is transferred via Wi-Fi to the AWS S3 Bucket for storage, and further prediction of the biogas yield will be carried out using the Ensemble algorithm, using two separate models: one based on the results of parameter measurements and the other based on the analysis of the input material photo. The developed system of remote monitoring of biomass parameters before its fermentation creates conditions for modernisation of the biogas production process control system in biogas units.

Further research will focus on the development of monitoring technologies, including the development of more accurate and sensitive sensors for measuring plant environment parameters such as methane levels, temperature, soil moisture, and other important parameters. A significant area for further research is to optimise the system for collecting and transmitting data from sensors to central processing and monitoring. It will explore data transmission technologies, including wireless networks and the Internet of Things (IoT), which provide reliable and fast real-time data collection. An essential component of the research is the development of a predictive model of plant environment parameters based on the collected data, which will help optimise the biogas production process and increase its productivity.

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None.

## CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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**Мобільна система моніторингу параметрів рослинного середовища  
для виробництва біогазу**

**Анотація.** Основними джерелами біомаси для біогазових установок можуть бути органічні відходи, зерно, сіно, гній, різноманітні рослинні матеріали та інше. Процес анаеробного зброджування, який складається з послідовних складних біологічних реакцій, є актуальним і потребує детального контролю параметрів, щоб запобігти можливим втратам і оптимально використати закладений матеріал. Тому метою дослідження було розглянути можливість розробки мобільної установки для моніторингу параметрів рослинного середовища при виробництві біогазу з можливістю збереження даних і подальшого використання їх при побудові математичної моделі для прогнозування виходу газу. Створення алгоритму базувалося на принципах нечіткої логіки та структурі нейронних мереж. Запропоновано архітектуру мобільної системи моніторингу параметрів рослинного середовища для отримання біогазу. Наведено розроблену принципову електричну схему такої системи. Роботу системи представлено у вигляді створеного алгоритму пошуку та ідентифікації підключених пристроїв на шині 1-Wire. За названою шиною виконується опитування давачів та відповідно вимірювання технологічних параметрів. Розроблено програмне забезпечення для взаємодії давачів різних типів, передачі та збереження даних в хмарне сховище з подальшою можливістю їх обробки. Передбачено фотографування біомаси завдяки вбудованій фотокамері. Використавши принцип технології інтернет речей передбачено дистанційний доступ до виміряних даних. Виміряні технологічні параметри та фотографії передаються на сервер системи керування для подальшого аналізу, що дозволить точніше оцінити процес підготовки біомаси для зброджування. Отримані результати дають можливість удосконалити системи керування та підтримки прийняття рішень при завантаженні біомаси в біогазову установку

**Ключові слова:** вимірювання; керування; фотокамера; давач; біомаса