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MONITORING AND TRANSMISSION OF THE PROCESS PARAMETERS ON AGRO INDUSTRIAL FACILITY IN A GSM NETWORK

MAJA KUKUSEVA PANEVA, ELENA ZAFIROVA, SARA STEFANOVA, GOCE STEFANOV

Abstract. In modern technological and industrial development, the application of electronics in measuring, processing, storing and transferring process data in industrial facilities is increasing. In this processing of process parameters, it is essential that users have timely and accurate information about the measurement data in their industrial complex. Modern electronic systems provide the ability to process and store measurement data on-site and transfer it to the IoT and GSM network. On the other hand, the application of sophisticated electronic systems is noticeable not only in power plants, but also in healthy and quality food industries, such as agriculture. We witness daily tribunes and panel discussions sponsored by companies and even governments for the introduction of the terminology of digital agriculture, i.e. the introduction of smart electronic solutions in agriculture. In addition to the commitment to so-called green energy, i.e. obtaining energy from renewable sources, the development of digitization in agriculture is an area in which an enormous application of smart electronic systems is expected in the future. Guided by these reasons, in this paper an electronic system is designed that provides a solution to a problem in hydro-melioration system, i.e. the development, design and practical implementation of the Smart electronic system which enables the measurement of the process parameters of an agro-industrial facility and their transfer to the GSM SIM network. The solution enables the visualization of process parameters locally on LCD displays and remotely on a mobile device in GSM SIM network. A data log file is also provided for storing the value of the process parameters on a local computer.

1. Introduction

In contemporary agricultural production, the introduction of a comprehensive monitoring and quality control system is an essential prerequisite for efficiency and sustainability, [1], [2], [3], [4]. In modern agriculture systems, monitoring and control infrastructures must, on the one hand, provide real- time management of resources inputs to ensure consistent product quality, and on the other hand, enable the acquisition, transmission, and processing of control parametric data within agricultural facilities, [5],[6]. In practice, many industrial-scale agricultural plants operate as standalone units that are geographically isolated from the intranet or internet infrastructure of agriculture production companies. This creates a demand for automation solutions that support remote operation and integration into corporate intranets, as well as broader connectivity through Internet of Things (IoT) platforms and GSM networks [7], [8]. Engineering efforts are increasingly focused on enhancing operation reliability and safety, particular for field operation tasked with maintaining process continuity. These objectives are achieved through the deployment of intelligent electronic devices capable of not only executing control functions but also generating structured log files for systematic storage, transmission, and analysis of measurement data, [9].

Keywords: Agro-industrial facility, process parameters, controller, GSM, SIM, data log file

On the other hand, a modern control system can be considered fully integrated only when connected to an IoT or GSM network, [10], [11], [12], [13], [14]. Such a concept enables process data to be transferred to any remote location, support real-time monitoring and visualization, and ensure data storage both locally on a personal computer and remotely on a cloud- based platform.

Commonly, some standalone industrial agricultural processes might represent a separate entity. Since these plants are far from the Intra and Internet network of manufacturing companies, the data distribution of analog and digital signals from sensors and actuators of some process quantities (e.g. soil moisture, soil temperature, air temperature and humidity etc.) must be made from these remote entities to the master station via wireless communication, most likely a radio frequency (RF), IoT and GSM connection [12], [13], [14].

The choice of remote transmission of measurement process data via RF, IoT or GSM connection depends on the location of the specific industrial (agro) facility and the type and quantity of measurement data. Each of these transmission media has advantages and disadvantages. In the case where an RF connection is used, the transfer is limited in scope and is most often used when a standalone industrial (agro) facility needs to be connected to a master station of a complex industrial facility. The connection in the IoT network requires a reliable and secure internet network and a secure and inexpensive cloud platform. Also, the fact that the designers of cloud platforms periodically come out with new versions that require reworking of the program codes should be taken into consideration. This creates additional time and money problems. Given the limited range of RF communication and the high cost and variability of cloud platforms, the GSM network represents a practical and cost-effective solution for small standalone industrial facilities.

This paper presents an electronic system as a solution to challenges in a hydro-melioration system with focus on the development, design and practical implementation of a smart electronic system capable of measuring, storing, visualizing and transferring of the measured process parameters of an agro-industrial facility via the GSM network.

2. Design of an Electronic System for Monitoring and Transmitting of the Process Parameters of an Agro-Industrial Facility in a GSM SIM Network

The design of the prototype electronic system, the subject of this paper, includes the design of the system for measurement, monitoring and transfer of the process parameters on mobile devices through a GSM network. The block diagram of this electronic system is shown in Figure 1. The primary task of the electronic system is to manage the agro-industrial facility based on the measured process parameters, including air temperature, relative humidity, CO_2 concentration, light intensity, as well as soil temperature and soil moisture. The case study focuses on a closed type agro-industrial facility, specifically a greenhouse environment. The central part of the system is the NodeMCU ESP8266 microcontroller, [15]. The agro-industrial facility is equipped with an air temperature and humidity sensor (DHT22), a soil temperature sensor (DS18B20), a soil moisture sensor

(V2.0), a CO_2 detection sensor (SCD40) and a brightness sensor (VEML7700) on the agro-culture, [16], [17]. These sensors, based on the measured parameter values, send signals to the microcontroller: a digital signal for air temperature and humidity to digital input D8, a digital signal for soil temperature to digital input D7, an analog signal for soil moisture to analog input A0, as well as digital signals for CO_2 and crop brightness to the microcontroller's I2C bus.

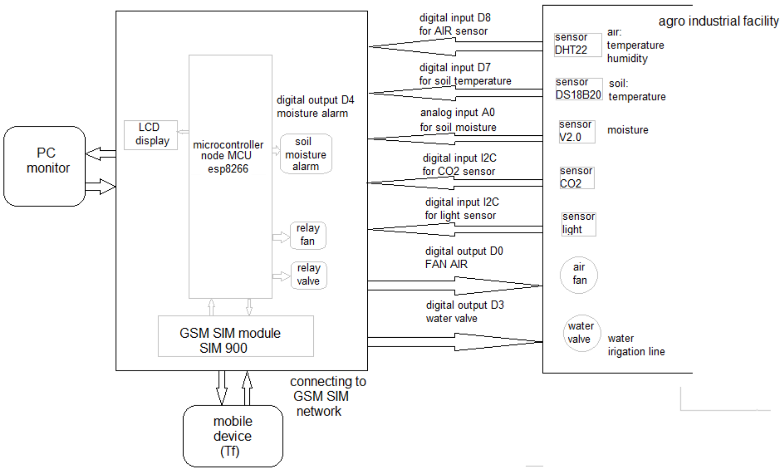


Figure 1. *Block diagram of the electronic system for measurement, monitoring and transfer of the process parameters in an agro-industrial facility on a mobile device through a GSM SIM network .*

Based on the measured values of the process parameters, the microcontroller sends a control signal (digital output D0) to a fan for supplying fresh air to the agricultural facility and a signal (digital output D3) to turn on a valve for supplying water to the irrigation line of the agricultural crop.

The microcontroller is connected to the GSM network via the GSM module SIM900, [18]. This connection ensures that process parameters are distributed bidirectional in the GSM network. This concept allows reading the values of process parameters on a mobile device, management of the supply of fresh air and water, as well as an alarm when any of the controlled variables exceeds the critical threshold.

2.1 Control logic

The GSM module with the built-in SIM card is a medium (intermediary) for sending instructions from the microcomputer to the mobile phone and receiving them from the mobile device to the microcomputer. The GSM module controls the state of the agro-culture by communicating with the microcomputer according to String (text) instructions. These String instructions are received by the SIM900 from the user via a mobile phone. The microcontroller receives the process parameter signals from the agro- industrial facilities, processes them according to predefined logic, and transmits the results to a mobile phone via the GSM SIM900 module. These string instructions include:

1.Instructions on the condition of air parameters

- READ AIR, the SIM900 module receives the string message from a mobile phone and forwards this instruction to the microcontroller for acquiring air parameter data in the agricultural facility. Upon receiving the instruction, the microcontroller processes and calculates the air parameters, then transmits the results back to the mobile phone as a text message via the SIM 900 module: " AIR: Temperature = " + String(t) + "*C " + "," + " Humidity = " + String(h) + "%" + " Light = " + String(lux) + "lux" + "," + " CO_2 = " + String(CO_2) + "ppm". The message contains data on temperature, humidity, light intensity and CO_2 concentration in the air as well as the illumination level of the agricultural crop. Based on these readings, the user evaluates whether any of the process parameters have exceeded its critical value and, if necessary, sends the next string instruction to initiate corrective action.
- AIR FAN ON. This instruction is sent by the user when, based on previous readings, it is determined that humidity, temperature, light intensity or CO_2 concentration in the facility has exceeded the critical value. Upon receiving the instruction, the microcontroller interprets the command, re-evaluates the air parameters, activates the fan to supply fresh air, and transmits a status message to the user's mobile phone via the SIM 900 module: "AIR: Temperature = " + String(t) + "*C " + "," + " Humidity = " + String(h) + "%" + "," + " Light = " + String(lux) + "lux" + "," + " CO2 = " + String(CO2) + "ppm"+ "FAN ON". The message contains information about temperature, humidity and CO_2 concentration of the air as well as the light intensity of the agricultural crop and confirmation that the user's previous command has been implemented, i.e. the fan is turned on.
- The previous two instructions apply when the user wants manually to check the air condition in the facility. However, the program's algorithm includes a built-in loop that enables the microcontroller automatically to monitor process parameters, and if any parameter exceeds its critical value, it sends an alarm string message to the user.
- "CO_2: " + String(CO_2) + "ppm" + "," + "CO_2 is HIGH"; The user of the mobile device receives an alarm that the CO_2 level is high.
- "temperature: " + String(t) + "*C" + "," + "temperature is HIGH";
- "humidity: " + String(h) + "%" + "," + "humidity is LOW";
- "Light: " + String(lux) + "lux" + "," + "light is LOW";
- AIR FAN OFF. This instruction is sent by the user when, based on previous readings, it is determined that the humidity, temperature, light intensity or CO_2 concentration levels in the facility are within acceptable limits. Upon receiving this instruction, the microcomputer reads and calculates the current air parameters, turns off the fresh air supply fan, and sends a text message via the SIM900 module to the user's mobile phone: "AIR: Temperature = " + String(t) + "*C " + "," + " Humidity = " + String(h) + "%" + "," + " Light = " + String(lux) + "lux" + "," + " CO_2 = " + String(CO_2) + "ppm"+ "FAN OFF".

2.Instructions on the condition of soil parameters

- READ SOIL, the SIM900 module receives this string message from the mobile phone and sends the instructions to the microcontroller to read the soil parameters in the agricultural facility. Upon receiving the instruction, the microcontroller measures and calculates the soil parameters and then sends a text message with results via the SIM900 module to the user's mobile phone: "SOIL: Temperature = " + String(tempPocva) + "*C " + "," + "Moisture = " + String(data1) + "%". The message contains information about temperature and soil moisture in the agricultural facility. Based on the measured data, the user determines whether any soil process parameter has exceeded its critical value and, if necessary, sends the text string instruction to correct it.
- VALVE ON. This instruction is sent by the user when, based on previous readings, it is determined that the soil temperature and moisture in the facility have exceeded the critical value. Upon receiving the instruction, the microcontroller processes and calculates the soil parameter data in the facility, turns on the irrigation line water valve to supply water, and sends a text string SIM message via the SIM900 module on user's mobile phone: " SOIL: Temperature = " + String(tempPocva) + "*C " + "," + "Moisture = " + String(data1) + " % " + "," + "Valve ON".
- The previous two instructions are intended for cases where the user requests soil condition data from the facility. However, the program algorithm has a built-in loop through which the microcontroller automatically monitors the process parameters. When any parameter exceeds its critical value, the system automatically sends a string alarm message to the user.
- " SOIL Moisture: " + String(data1) + "%" + "," + " Moisture is LOW "; The user of the mobile device receives an alarm that the soil moisture level is LOW.
- " SOIL Temperature: " + String(tempSoil) + "*C" + "," + " Temperature is HIGH "; The user of the mobile device receives an alarm that the soil temperature level is HIGH.
- VALVE OFF. This instruction is sent by the user when, based on previous readings, it is determined that the soil's temperature and moisture in the facility have values within the working range. Upon receiving this instruction, the microcontroller reads and calculates the soil's parameters in the facility, turns off the irrigation line water valve and sends a text string SIM message via the SIM900 module on the mobile phone: "SOIL: Temperature = " + String(tempPocva) + "*C " + "," + "Moisture = " + String(data1) + " % " + "," + "Valve OFF".

Logical flow diagram of the electronic system is shown in Figure 2.

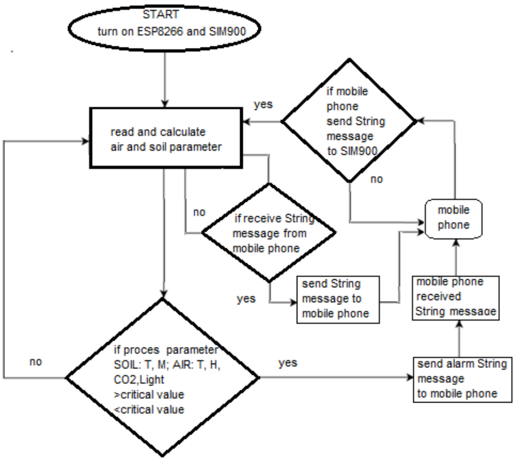


Figure 2. *Block diagram of the flow diagram of the electronic system*

2.1 Design of Hardware Components on Electronic System

In this section, a system is presented that receives signals from the sensors and, after appropriate software processing with NodeMCU8266, visualizes the data on LCD displays and sends it to the GSM network via the SIM900 module. Figure 3 illustrates the electrical connections of the electronic system used for managing the process parameters of the agro-industrial facility. The connections between the hardware components have been described above and are also shown in Figure 3. A brief description of the characteristics of the hardware components used is provided below.

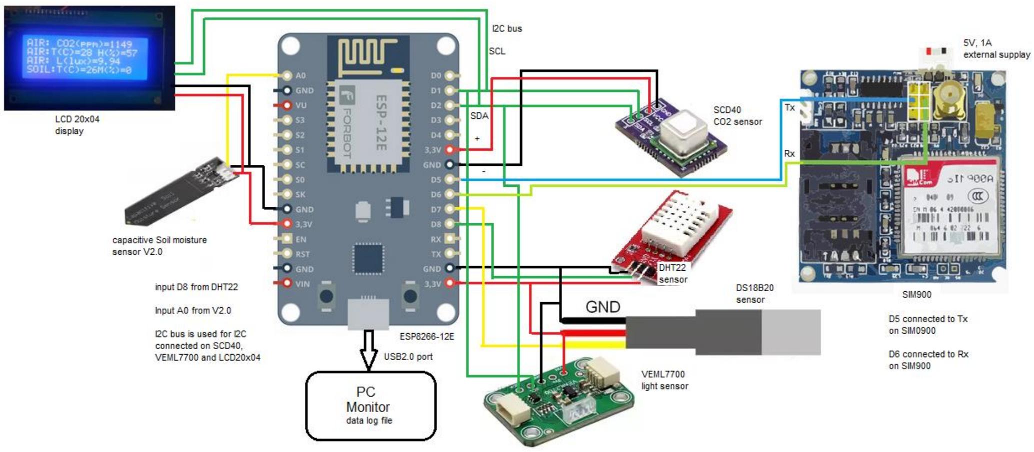
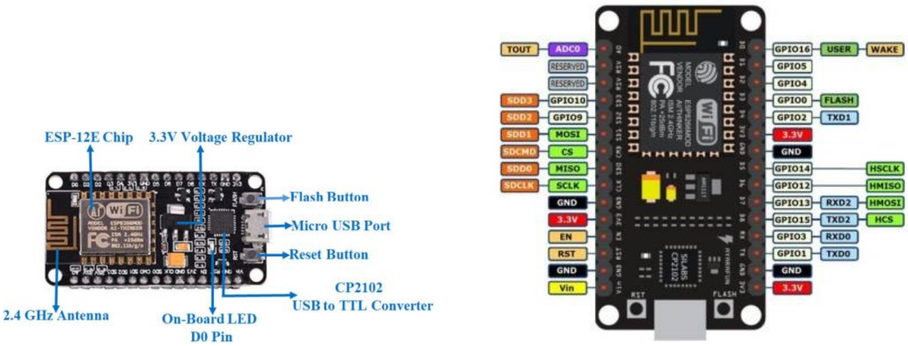


Figure 3. *Electrical connections of the electronic system for managing the process parameters of the agro-industrial facility*

a.) ***Microcomputer NodeMCU ESP8266***

The NodeMCU ESP8266 development board is equipped with the ESP-12E module which integrates the ESP8266 chip featuring Tensilica Xtensa 32-bit LX106 RISC microprocessor, [15]. This microprocessor supports RTOS and operates from 80MHz to

160 MHz adjustable clock frequency. NodeMCU has 128 KB RAM and 4MB of Flash memory to store data and programs. Its high processing power, built-in Wi-Fi / Bluetooth connectivity and Deep Sleep Operating mode make it ideal for IoT applications. The NodeMCU can be powered either through the Micro-USB port or via the VIN pin (external supply). It supports multiple communication interfaces, including UART, SPI, and I^2C. Figure 4 illustrates the NodeMCU ESP8266 board and its pinout configuration.



a.) b.)

Figure 4. a.) *NodeMCU ESP8266 and b.) its pinout*

NodeMCU is an open-source firmware and development board specially designed for IoT applications. It incorporates firmware running on the ESP8266 Wi-Fi SoC developed Espressif Systems, and hardware based on the ESP-12 module.

b.) *GSM SIM900 module*

GSM is a global system for mobile communication. Hence, to communicate with the computing devices, the GSM SIM needs a module. The SIM900 is considered one of the most widely used and reliable GSM/GPRS modules available. It is a quad-band module that works perfectly with four frequencies, 850, 900, 1800, and 1900MHz. The device is compact and compatible with Arduino. It easily allows sending SMS, MMS, etc. Moreover, it also supports audio through UART by using AT commands. Besides, it contains microphones and headphone jacks for phone calls. The sensor needs the 5 V power supply and draws 2 A of current. In Figure 5, the electronic board on the SIM900 is shown. SIM900 is connected to the microcontroller with only 4 wires, that is power connection (VCC and GND), and serial communication pin (RX-TX). If it uses Arduino UNO which has a 5V operating voltage, then it has 5V logic level (TTL). So, Arduino to RXD 5V and TXD 5V should be connected like in the pinout picture above. If NodeMCU8266-12E is used with a 3V operating voltage, then it has a 3V logic level, as in this case study, the pins used are RXD 3.3V and TXD 3.3V. Then plug in the SIM card into the SIM card cartridge. Then the SIM900 and Arduino are connected.

Wire SIM900A module to Arduino UNO is :

- Arduino -> SIM900A
- 5V -> VCC
- GND -> GND

- 10 -> TX
- 11 -> RX

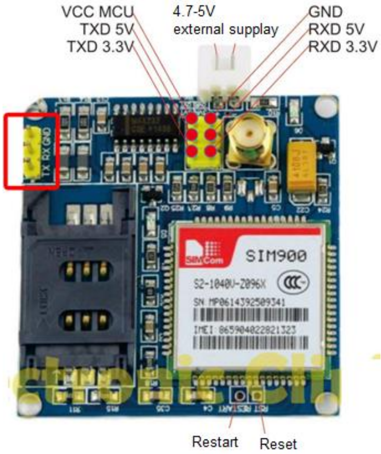


Figure 5. *The electronic board on the SIM900 module*

Power-on procedure

The implementation process begins with inserting a SIM card into the GSM module, followed by establishing a connection between the GSM/GPRS shield and the NodeMCU ESP8266-12E. Subsequently, the control code is uploaded to the Arduino board. The module is then powered by an external 5V supply, after which the power key of the GSM module must be pressed for approximately 2 seconds. Once initialized, the indicator LED on the module is activated, and, upon successful network registration, it blinks at three second intervals. At this stage, the system can transmit and receive SMS messages as well as initializing and receiving phone calls through the Arduino program. Furthermore, alternative programming codes may be employed or modify communication functionalities.

c.) ***SCD40 CO2 sensor***

SCD40 is a photoacoustic-based CO_2 sensor designed to measure the concentration of CO_2 PPM (parts-per-million) composition of ambient air, [16]. This sensor is perfect for environmental sensing, scientific experiments, air quality and ventilation studies, and more. The data is read over I2C, so it works very nicely with just about any microcontroller or microcomputer. There are both Arduino and Python/Circuit Python codes. Figure 6 shows SCD40 CO2 sensors.

There are two variants of this sensor - the SCD40 and SCD41.

- The SCD40 is lower cost and is perfect for indoor/outdoor air quality and CO_2 measurements. It has a range of 400~2000 ppm with an accuracy of ±(50 ppm + 5% of reading)
- The SCD41 is more expensive, and while it can be used for air quality, its wide range means it is best used for industrial or scientific CO_2 measurements where

the ppm can get very high. It has a range of 400~5000 ppm with an accuracy of ±(40 ppm + 5% of reading).

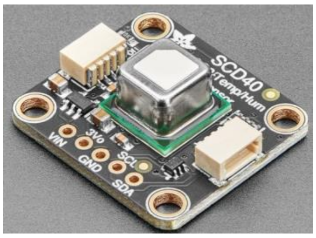


Figure 6. *The electronic board on SDC40 CO2 sensor*

This sensor operates within a supply voltage range of 3.3 to 5V but it is more important for it to have a power supply with low ripple. For that reason, 3.3V voltage regulator and level shifters are integrated in the design. When connected to a 5V microcontroller like an Arduino UNO, the 5V supply is often shared with other electronic components that add noise. The onboard regulator ensures voltage stability and minimizes interference. For advanced users, hardware modifications allow configuration of regulator functionality and selection of the desired I2C logic level.

d.) VEML7700 light *sensor*

The VEML7700 is a high accuracy ambient light sensor with digital 16-bit resolution. It includes a highly sensitive photodiode, a low noise amplifier, and a 16-bit A/D converter and supports a user-friendly Gravity I2C interface, [17]. It outputs a digital signal directly and there is no need for complicated calculations. This is a more accurate and easier to use version of the simple photo resistor which only outputs a voltage that needs to be calculated in order to obtain meaningful data. The output data by this sensor is in Lux (Lx). In photometric terms, when an evenly illuminated surface receives a luminous flux of 1 lumen per square meter, its illumination level is defined as 1lx. To enhance illumination efficiency, reflectors can be used to direct more luminous flux toward specific surfaces, thereby increasing target illumination. Figure 7 represents the electronic board of VEML7700 light sensor.

Figure 7. *The electronic board on the VEML7700 light sensor*

Specification

- Supply Voltage: 3.3-5 V
- Working Current: 45 uA
- Shutdown Mode: 0.5 uA
- Measuring Range: 0-120 klx

- Accuracy: 0.0036 lx / ct
- Working Temperature: -25 ℃ ~ +85 ℃

Information about the DHT22, DS18B20 and V2.0 sensors are available in [19], [20], [21].

3. Experimental Validation and Testing of the Proposed Design

This section presents the experimental results obtained from testing the prototype of the electronic system developed for managing the process parameters of the agro-industrial facility. Figure 8 shows the prototype of the designed electronic system.

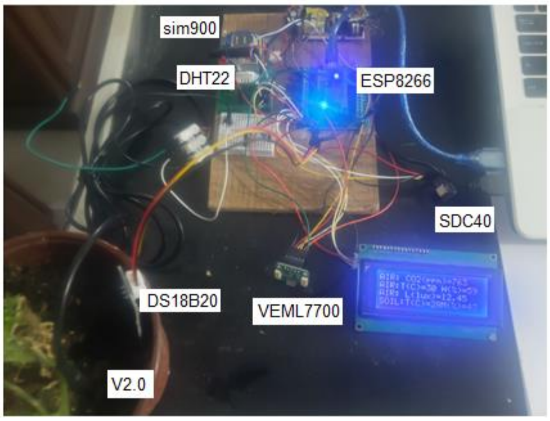


Figure 8. *Prototype of the electronic system*

Figure 9 shows a print screen of a data log file in Excel used for monitoring the process parameters of the agro-industrial facility obtained with the designed system in the paper.

Figure 10 shows the waveforms of the measured parameters in the agro-industrial facility over a certain time interval. Figure 10a shows the waveform of soil moisture, Figure 10b shows the waveform of brightness, while Figure 10c shows the waveform illustrating the change in the CO_2 concentration.

In Figure 11 a print screen of the mobile phone interface that illustrates the correct operation of the electronic system is shown. Figure 11a shows the print screen of READ AIR, AIR FAN ON, VALVE on instruction; Figure 11b shows the print screen on READ SOIL and AIR FAN OFF instruction; Figure 11c is the print screen on VALVE OFF and READ AIR instruction; Figure 11d is the print screen on ALARM from electronic system to mobile phone when the level of CO_2 is HIGH and Figure 11e is the print screen on ALARM from the electronic system to the mobile phone when the level of the soil moisture is LOW.

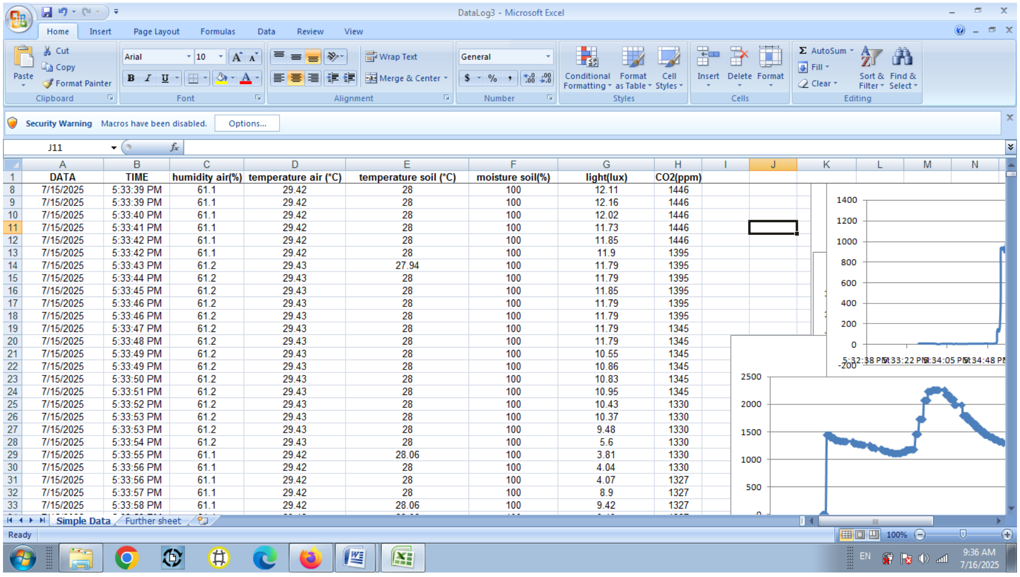


Figure 9. *Print screen of the data log file in Excel for monitoring the process parameters of the agro-industrial facility*

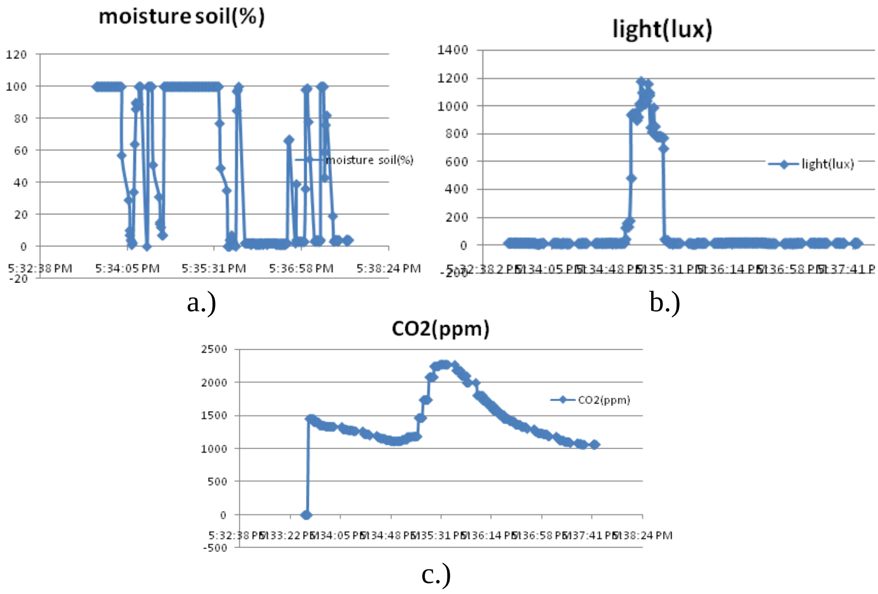
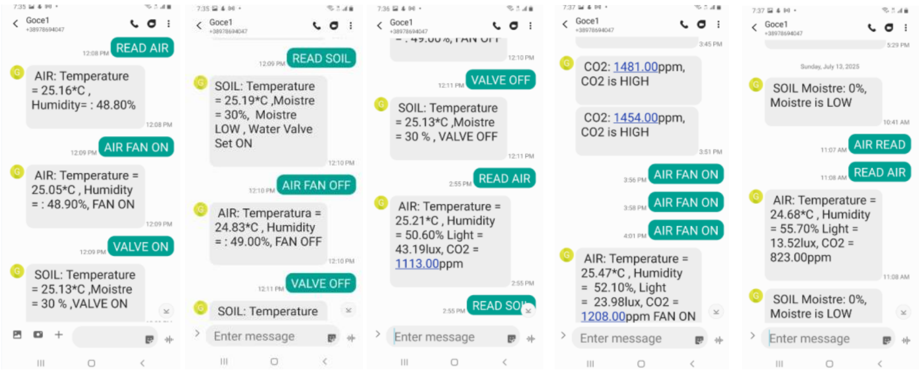


Figure 10. *Waveforms of the measured parameters in the agro-industrial facility over a certain time interval: a) waveform of soil moisture, b) waveform of brightness, and c) waveform of* CO_2.



a.) b.) c.) d.) e.)

Figure 11. *Print screen from a mobile phone: a.) print screen on READ AIR, AIR FAN ON, VALVE on instruction; b.) print screen on READ SOIL and AIR FAN OFF instruction; c.) print screen on VALVE OFF and READ AIR instruction; d.) print screen on ALARM from electronic system to mobile phone when level CO_2 is HIGH and e.) print screen on ALARM from the electronic system to the mobile phone when the level of the soil moisture is LOW.*

3.1 Analysis of the Results and Discussion

The main task of the paper is to design and implement a prototype electronic system for measuring, monitoring and transferring of the process parameters in an agro-industrial facility in GSM SIM network. The verification of the correct operation of the system according to the defined task is illustrated in Figures 8, 9, 10 and 11.

- In point 2, a prototype of the system for measurement, monitoring and transferring of the process parameters in the agro-industrial facility in GSM SIM network was designed and implemented.
- Section 3 gives the results of the experimental work of the solution in the paper.
- The results show that the system measures, visualizes on LCD screens and stores the data of process parameters in log files and sends the data via GSM SIM network.
- The print screen shown in Figure 9 is provided to verify that the solution in the paper stores the data in a data log file in Excel.
- Waveforms shown in Figure 10 illustrate the change of the process parameters in the agro-industrial facility over a certain time interval. They verify that the system measures and monitors the change in process parameters.
- Print screen from a mobile phone given in Figure 11 verifies that the system responds to messages sent from the mobile phone and sends an alarm back to the mobile device as required in point 2.1.

The paper offers a solution that addresses a problem that is currently relevant in the agro-industry. In [7], [8], [10], the subject of analysis is industrial processes from different aspects and in all of them the commitment to connecting measurement data remotely is clear. In some solutions, RF connections are used, in some cloud platforms, [12]. The way in which this is implemented is different and depends on the capabilities and approach of the authors. In the case where the RF connection is used, the transfer is limited in scope and is most often used when a standalone industrial (agro) facility needs to be connected to a master station of a complex industrial facility. The connection in the IoT network requires a reliable and secure internet network and a secure and inexpensive cloud platform. Also, it should be considered that the designers of cloud platforms periodically come out with new versions that require reworking of the program codes, [22]. This creates additional time and money problems. Considering the limited range of the RF connection and the expensive and variable cloud platforms, for small standalone industrial (agro) facilities, it is convenient to use the GSM SIM network.

4. Conclusion

In this paper, a prototype of an electronic system is designed, and it provides a solution to challenges in a hydro melioration system. The work focuses on the development, design and practical implementation of a smart electronic system capable of measuring the process parameters in an agro-industrial facility and transmitting them via the GSM SIM network. The proposed solution supports local visualization of process parameters on LCD displays, as well as remote monitoring on a mobile device through a GSM network. Additionally, a data logging function is implemented to store the process parameter values on a local computer for further analysis.

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