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# IoT SOLUTION FOR LEVEL MEASUREMENT IN THE OIL AND GAS INDUSTRY

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## ABSTRACT

The fundamental goal of this work is to investigate and explore the design and construction methods for an intelligent, adaptable and flexible level measurement system, based on IoT (Internet of Things) technology. This automatic data acquisition, transmission and processing system must allow the level of a substance to be measured in a non-intrusive manner. The system also ensures safe operation for personnel servicing the monitored process and allows customization of the presentation of data sets, in a variety of formats, with maximum relevance to the user.

The level measurement system proposed in the paper bases its operation on the characteristics of ultrasonic sensors. The intelligent modules of the system process, based on software algorithms, the data from the sensors and communicate them to other microprocessor subsystems for conversions, storage and presentation of the results.

This intelligent level measurement system uses two sensor subsystems, with different degrees of complexity, to monitor two reservoirs in a park. These subsystems communicate permanently with a central control unit, the CCU, which collects and processes in real time the data transmitted to it in a WiFi LAN. In order to increase the degree of adaptability of the intelligent system to the measurement needs, it is possible to resort to increasing the number of sensors, placed in various locations, in a park of tanks for the storage of petroleum products.

**Keywords:** IoT, level measurement, ultrasonic sensor, Arduino, Raspberry Pi

## INTRODUCTION

Starting from the definition of the word "level", the height at which a point, a line or a surface of a place, an object, in relation to a given horizontal plane is found [36], the level evaluates the amount of substance, liquid or granular from a container, basin, etc., and is expressed by the height *h* at which the separation surface of two media with different physical properties is located, in relation to a predetermined value [2,3]. So the numerical value of the level is expressed in units of length.

The choice of the measurement method for the correct determination of the level must take into account the physicochemical properties of both the vessel and the measured substance, take into account the pressure and temperature values of the environment in which the transducer will work, restrictions that lead to the use of some systems of specialized measure for the tracked processes.

Level measurement, depending on the objective pursued, can be done for the purpose of monitoring industrial technological processes, in order to warn of limits being exceeded, for level regulation, actions used on a large scale in the oil and gas industry. Measurements where a high degree of precision, repeatability and robustness are required are made by electrical methods [34]. Among these types, the simplest methods are the monitoring of the electrical conductivity, the measurement of the electrical capacity, or more complex methods, which can continuously measure the variation of the level by measuring the proportionality of the hydrostatic pressure, or methods without direct contact, which exploit the properties of electromagnetic waves and ultrasound [4-8] .

Among the technical solutions without direct contact, the use of the properties of elastic mechanical waves of gases allow, similar to the radio pulse measurement method, to determine the level of substances stored in vessels through calculations that include the transit time of ultrasonic or sonic waves. Basically, a correct analogy is to compare the transmitting transducer in this category with the biological vocal cords and the receiving transducer with the ears [10]. It is the same principle of echolocation by which some mammals can estimate distances to obstacles, a principle widely used in other branches of technology [12-14].

The numerical value of the level of the measured substances is determined indirectly on the basis of calculations. The speed of sound propagation in the air having a known value, the time until the reception of the echo is measured and thus the distance to the surface that reflected the wave is calculated:

$$\tau = \frac{D}{v} = \frac{Distance}{sound\ speed} \tag{1.1}$$

The characteristics of mechanical elastic waves are directly influenced by a number of factors, such as the physical properties of the transmission medium such as pressure, temperature, attenuation, the interaction between mediums with different physical properties that produce the phenomena of reflection and diffraction, and by wave quantities such as intensity, wavelength, frequency, etc. Wave propagation is influenced by combinations of all these factors, which cumulatively can lead to ideal conditions but also to the impossibility of making measurements.

Among the characteristics of waves, the frequency, expressed in hertz, is one of the most important parameters. The frequencies used in ultrasonic measurement are in the frequency range 20÷200 kHz and audible around the frequency of 10 kHz. The wave length, λ, is another important parameter that describes the distance between two successive maximum pressure points, along the direction of the propagation vector. It can be calculated as the ratio of the speed of propagation to the frequency of the wave:

$$\lambda = \frac{v}{f} \tag{1.2}$$

Sound intensity quantitatively characterizes the energy found in the sound wave, so it is expressed in $W/m^2$ or in decibels (dB). Reflection is the phenomenon that occurs at the contact surface between two media with different densities and causes the sound wave to return to the media from which it came. The phenomenon of diffraction is influenced by the wavelength of the signal and is characterized by the change in the direction in which the wave propagates, it circulates around the obstacle, without the phenomenon of reflection occurring. Attenuation of sound represents the decrease in the energy of the waves as they travel through the medium they travel through.

Constructively, to generate and measure sound signals, piezoelectric, capacitive or inductive elements are used that directly convert wave energy into electrical energy and vice versa. Disturbing factors that influence the use of ultrasonic waves can be: the temperature of the gas in which the waves propagate. This changes the speed of propagation by changing the energy level of the gas molecules. Thus the need to compensate for this variable may arise; spongy substances or foam attenuate the sound, reducing the effectiveness of the ultrasonic measurement method; turbulence and exposed mechanical stirring elements between the sound wave source and the surface of the liquid to be measured can cause erroneous distance reporting. The measures for reduction of this type of disturbances can be implemented in hardware, such as the use of waveguides or software, by developing algorithms to identify and eliminate those values that are suspected to be incorrect.

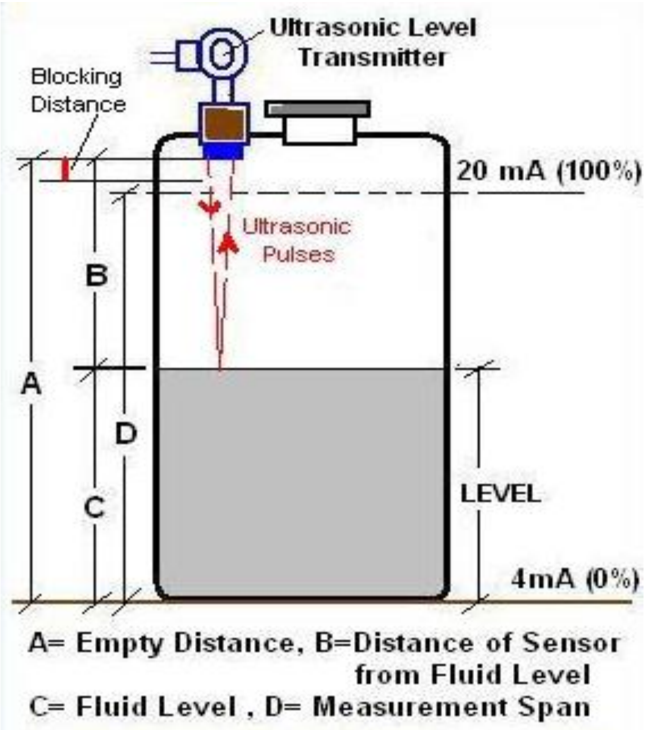


***Figure 1***. *Level measurement with ultrasonic transducer* [14]

The Internet of Things (IoT) is one of the most important technologies in everyday life. The fast pace of development of the Internet of Things will continue as more and more companies, from all fields of activity, realize how much connected devices can help them become more competitive. In other words, the Internet of Things (IoT) is a computing device system interconnected, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and that have the ability to transfer data over a network without requiring human-to-human or human-computer interaction [15-18].

An IoT ecosystem consists of web-enabled smart devices that use embedded systems such as processors, sensors, and communications hardware to collect, send, and act on the data they acquire from their environments. Sensors collect data. IoT devices share sensor data by connecting to an IoT gateway or other edge device. From here, the data is either sent into cloud to be analyzed, or are analyzed locally. Sometimes these devices communicate with other connected devices and act on the information they receive from each other. Devices do most of the work without human intervention (Figure 2). Humans can interact with IoT devices to configure them, give them instructions, or access data [15-18].

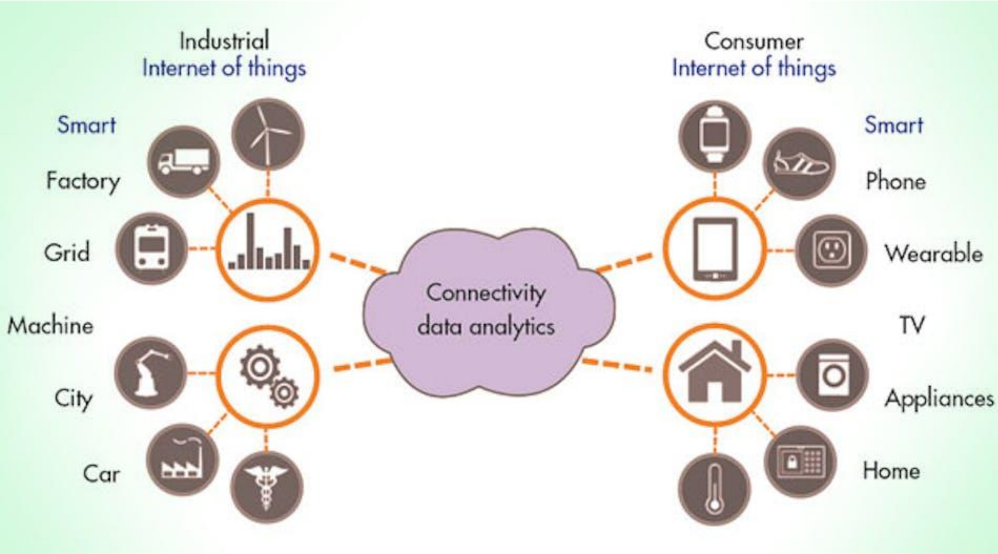


***Figure 2**. The IoT principle* [19]

## SYSTEM DESIGN

The level measurement system proposed in the paper bases its operation on the characteristics of ultrasonic sensors. The intelligent modules of the system process, based on software algorithms, the data from the sensors and communicate them to other microprocessor subsystems for conversions, storage and presentation of the results.

This intelligent level measurement system uses two sensor subsystems, with different degrees of complexity, which will be referred to as S1 and S2 (Figure 3). These subsystems communicate permanently with a central control unit, the CCU, which collects and processes in real time the data transmitted to it in a WiFi LAN. In order to increase the degree of adaptability of the intelligent system to the measurement needs, it is possible to resort to increasing the number of sensors, placed in various locations, in a park of tanks for the storage of petroleum products.

The S1 sensor subsystem has a simple hardware component consisting of the AJ-SR04M ultrasonic sensor connected to an Arduino module [1,20,29] with Wi-Fi capabilities. This subsystem can be replicated and multiplied as many times as needed by simply interconnecting the physical parts and loading the software mode with minimal adjustments for unique identification in the already existing network of connected sensors. The data provided by it can be read exclusively with the help of computer systems, after consecutive processing carried out by the main element of the system, the central control unit (CCU).

The measurement subsystem S2, is a more complex one, fulfilling all the functions of measurement and data transmission, consisting of sensors, display screen, a more complex software component, having the ability to process the measured distance locally, to compensate it with the temperature [1, 31] and present locally, directly for reading, the value of the measured level. It can work autonomously, even if it is interrupted communication with CCU.

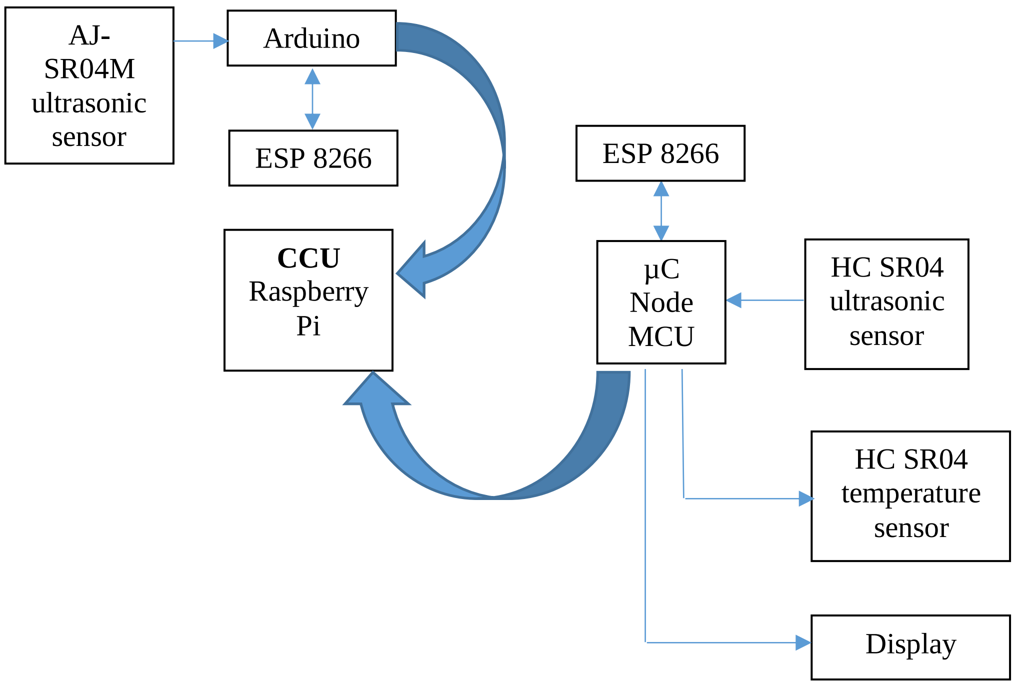


***Figure 3.*** *Structure of the IoT-based level measurement system*

The central component of the measurement sensor subsystem S2 is µC, represented by the NodeMCU D1 Mini module. Built around the WiFi-enabled ESP 8266 SoC, this board simplifies IoT prototyping, allowing you to quickly connect to local networks with just a few lines of code. This microcontroller is responsible for establishing and maintaining communication with the CCU and transmitting measured data. In the case of the S2 subsystem, the ESP8266 [11] module ensures One-Wire communication with the temperature transducer, I2C (Inter-Integrated Circuit) with the display screen, PWM (Pulse-width modulation) ensures the operation of the distance detector, all of these via GPIO ports [33] (General Purpose Input-Output) allocated to software.

The sensor subsystems will connect via a Wi-Fi Ethernet network to a distributed control system (DCS), based on a Raspberry Pi development board (CCU), which will ensure in order the collection, preliminary processing of data for sensor traceability that generated their level calculation and storage in a database where they can be analyzed.

The ultrasonic sensors used in the two subsystems are shown in Figure 3. The HC-SR04 ultrasonic module is made up of a pair of transducers, illustrated in Figure 4, which together ensure the generation of the ultrasonic signal and the measurement of the time until the reception of the echo. The distance measurement sensor, AJ-SR04M, has a different physical construction that gives it a number of advantages in terms of protection against the influences of the environment in which it operates. The unique transducer, with functions for both ultrasonic signal generation and echo reception, is waterproof and placed at one end of a wire that allows the electronic module to be placed in a housing or location protected from the effects of the environment. The operating principle is similar to that of the HC-SR04 sensor, however, the minimum measurement distance is greater, due to the time required to switch the circuit from the transmitter to the receiver and vice versa, and the need to amplify the received signal appears.


***Figure 4.*** *Ultrasonic distance detectors HC-SR04* [23] *and AJ-SR04M* [38]

The role of the temperature transducer, DS18B20 (Figure 5), in S2, is to bring additional information from the measurement environment that allows the S2 subsystem to compensate for the variation in the propagation speed of the generated acoustic signal, with the change in the temperature of the propagation medium [24]. This is an integrated circuit that communicates with the ESP8266 module via the 1-Wire protocol [21]. This protocol allows the operation of a maximum of 32 addressable translators on the data bus.

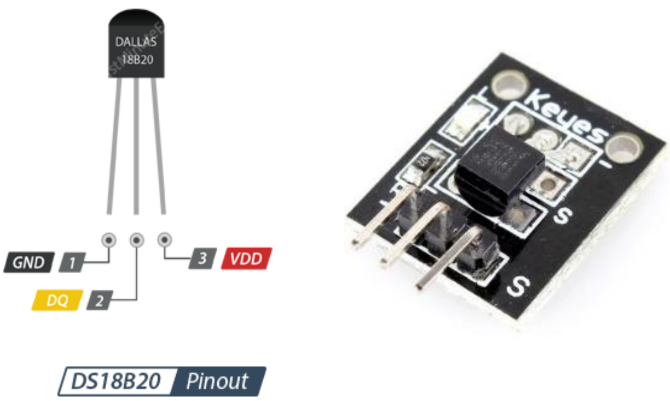


***Figure 5****. Temperature transducer DS18B20 – One Wire* [24,25]

The central component of the measurement sensor subsystem S2 is µC, represented by the NodeMCU D1 Mini module (Figure 6) [27]. This is a compact development board based on the ESP8266EX, designed specifically for IoT projects. With 4MB of memory, this mini Wi-Fi board comes equipped with 11 digital input/output pins (all supporting interrupt, PWM, I2C [22] and one-wire, except D0), a single analog input (3.3V max), and a microUSB connection for easy setup and programming. The S2 measurement subsystem makes use of a 32-character LCD digital display divided into two lines (Figure 7).

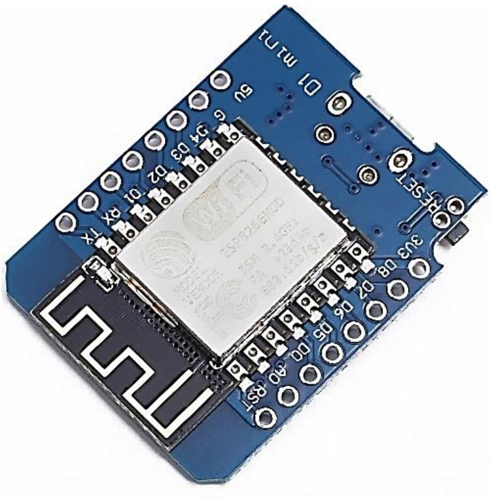

***Figure 6***. *NodeMCU Mini module with ESP8266 (Wi-Fi)* [27,36]

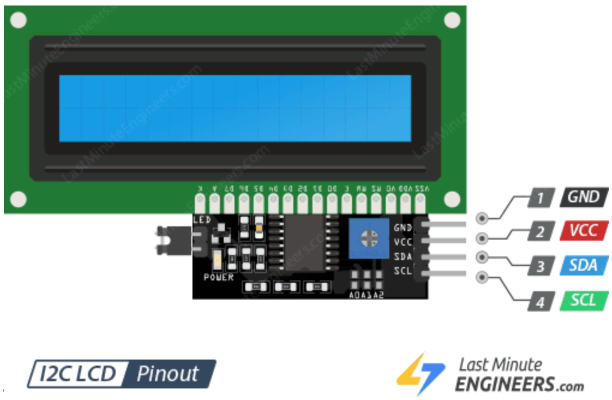


***Figure 7***. *1602 LCD display with I2C module* [22,25]

The key hardware component of the intelligent level measurement system that manages all the resources needed to process the data received by the field of sensor subsystems is the Raspberry Pi 4 minicomputer (Figure 8). He will receive, perform calculations to determine the levels of substances stored in tanks and provide access control to the information in the database to authorized personnel. This unit also provides the server function by making information available on a computer network based on permissions.

***Figure 8.*** *Raspberry Pi 4 Model B 4GB Development Board [38]*

Thus, the ultrasonic sensor will measure and transmit raw information via a computing unit LAN (gateway) that can be parameterized according to the characteristics of the measured process. The system will use the MQTT protocol for publishing, Node-RED for parameterization and data flow, a database for data storage and an application that can realize the numerical display of instantaneous measured values and the time evolution of the system in graphic form.

## HARDWARE SYSTEM IMPLEMENTATION

The connection diagram between the system elements is presented in Figure 9. The main role in the level measurement system belongs to the transducer. Regarding the location and positioning of the ultrasonic measurement subsystems, this is usually done at the top of the container, with the sensors oriented perpendicular to the surface of the stored substance. Also, there are several influencing factors related to the constructive characteristics of the containers, the physical nature of aggregation and the properties of these substances. In the designed system, two constructive variants will be developed to allow the integral placement of the transducer at the top of the storage container and respectively the positioning of the electronic circuit of the transducer in a protected place that has the sensor connected with a cable of the right length in the optimal position for measurement [9]. The sensitive element is connected via the digital GPIO terminals to the microcontroller that manages the wave generation and detection functions. [28]

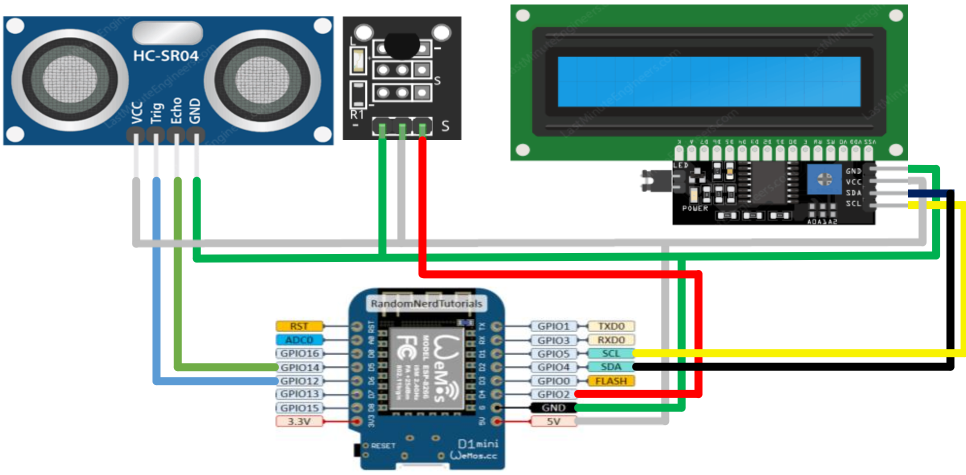


***Figure 9****. Connection diagram between the elements of the measurement subsystem S2*

The acoustic waves are generated according to a pattern that allows the differentiation of disturbing signals and the correct identification of the reflected signal by the receiver. The duration of a signal thus generated is at least 10 μs in which eight pulses with a frequency of 40 kHz are transmitted through the Trigger terminal. After the transmission of these pulses, the Echo terminal is switched to High and is thus prepared, for a determined time interval of 38 ms, to receive the reflection of the transmitted wave. In the absence of signal reception, the Echo terminal is switched to the Low state, thus signaling the exceeding of the measurement range or the lack of elements that reflect the emitted ultrasonic signal.

If after passing the terminal *Echo* in the state *High* the pattern from the emitted wave to the reflected wave is identified, the Echo terminal is switched into state *Low*. Thus the time spent in the state *High* it produces an electrical pulse with a duration between 150 μs and 20 ms corresponding to the minimum and maximum values of the measurement range.

Any time value between these two extremes is processed to calculate the distance value to the reflective element, using relation (1.1). It should be emphasized that the distance traveled by the wave to be received is twice the distance to the target. The propagation speed of sound waves in air, at an ambient temperature of 0 °C, is 331.5 m/s [31]. Using relation (1.6) we obtain the value of the distance to the target:

$$D = \frac{331{,}5 \cdot \tau}{2}[\mathrm{m}] \tag{1.3}$$

Communication through the D6 and D5 (GPIO12 and GPIO14) terminals of the microcontroller will be done via TTL (Transistor-Transistor Logic) signals.

Since the ambient temperature can vary over a wide range of values, influenced either by the respective process or atmospheric conditions, the repeatability of the measurement can be ensured by adjusting the value of the measured distance with a coefficient. Thus, with this compensation, the phenomenon of the temperature variation of the transmission medium is negated. For this purpose, the digital thermometer will be connected to the digital terminal D1 (GPIO2) of the microcontroller. The resolution of the DS18B20 digital thermometer is programmable for discrete steps with values between 0.5°C and 0.0625°C.

Relation (1.1) will thus be completed with the value of the ambient temperature coefficient [31]:

$$D = \frac{(331{,}5+0{,}607 \cdot t) \cdot \tau}{2} \tag{1.4}$$

The measurement subsystem S2 uses a 32-character LCD digital display divided into two lines and has an I2C adapter for bidirectional communication with the microcontroller [33,35]. Data is received serially (SDA) through terminal D1 and a dedicated pin, D2, provides communication synchronization. The I2C adapter handles the conversion of the serial data received from the microcontroller and transmits it in parallel to the display's liquid crystal array. Another function of this adapter is to adjust the contrast of the display.

The two measurement subsystems use 1-Wire and I2C communication protocols for communication between elements. The final assemblies for the sensor subsystems S2 and S1 are shown in figure 10.

## SOFTWARE SYSTEM CONFIGURATION

The central system control unit, CCU, is the main element of this intelligent level measurement system. The resource management of this computing unit is provided by a Debian Linux version optimized for running on the Raspberry Pi platform [39]. The Linux operating system provides the working environment for the operation of the software tools that make up the data flow path, Figure 11, from receiving it to displaying the relevant information.


***Figure 10***. *Final assemblies S2 and S1*

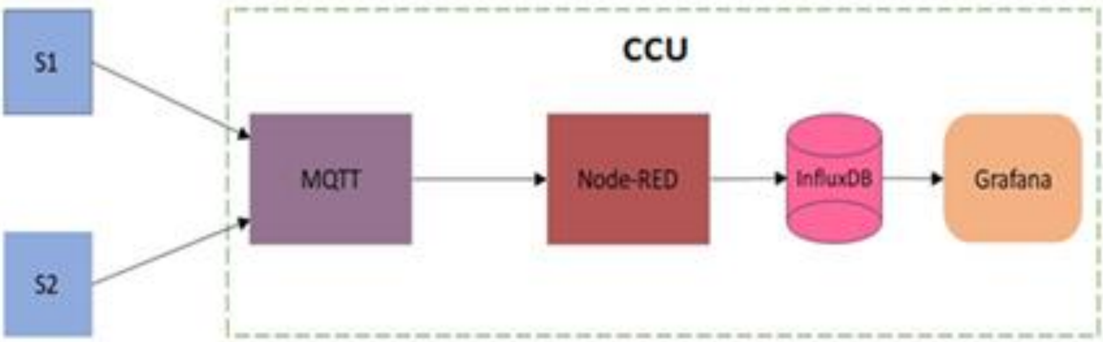


***Figure 11***. *Data flow block diagram*

As shown in Figure 11, the data flow starts from the sensors via the MQTT messaging protocol [32]. This is a simple way for communication between devices connected to the Internet or IoT (Internet of Things) according to the publish/subscribe model. Devices or applications connected to the broker can post messages to lists or subscribe to receive messages posted by other devices to those lists. The Eclipse Mosquitto broker can be installed and configured locally or remotely from the terminal using the SSH protocol. After restarting, Mosquitto is ready to manage mailing lists and subscribed clients [40].

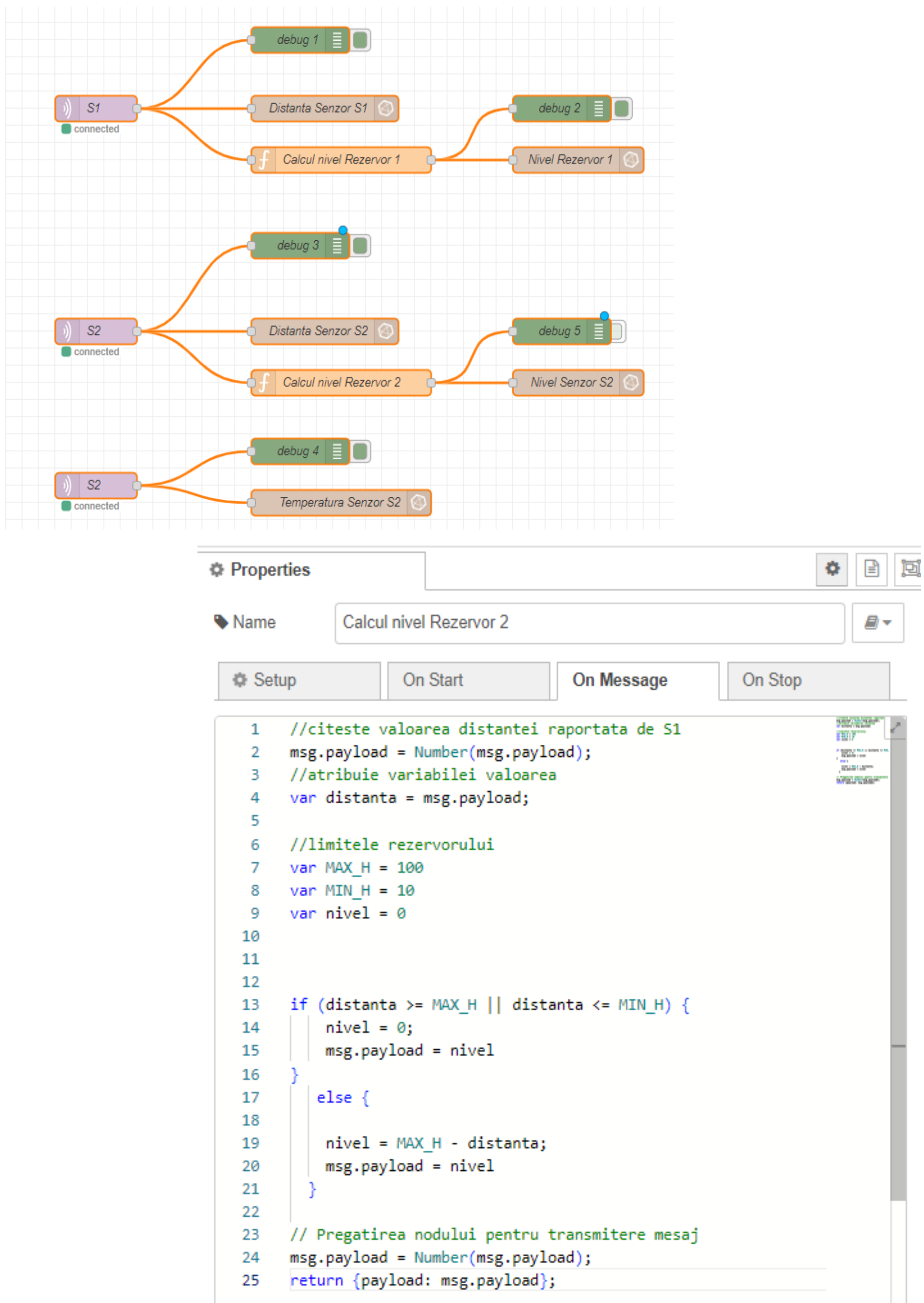


***Figure 12***. *Data presentation on the remote server (the volume of the liquid in the container)*

The Node-RED application [41], connects Mosquitto's publishing lists with the InfluxDB database, where the processed information will be stored, is installed and configured on the Linux platform from the command line. After installation, it is accessed from a web browser and the user interacts with it, programming its data flows graphically, with Node-RED translating data links and nodes into lines of code. The Node-RED application will calculate the volume of the liquid in the vessel based on the declared dimensional and geometry characteristics of the vessels and the distance values transmitted by the sensors (Figure 13).

The InfluxDB database [42] is specialized for storing time series data and is ideal for IoT data analysis and application monitoring.

Grafana [43] is a data analytics platform used for system performance monitoring, widely used in industry, for creating interactive and customized dashboards to display real-time information. Information can be viewed from a web browser, based on permissions.

Time series databases are ideal tools for IoT data analysis and application monitoring.

The major advantage of this type of databases starts from their design, which is aimed at timestamping numerical data for storage and compression, data life cycle management, summarization and time-dependent queries, fast response to volume queries large amounts of data over long periods of time, by managing the level of detail and retention of old data that is sampled, allowing new data to be stored (Figure 14). [42]

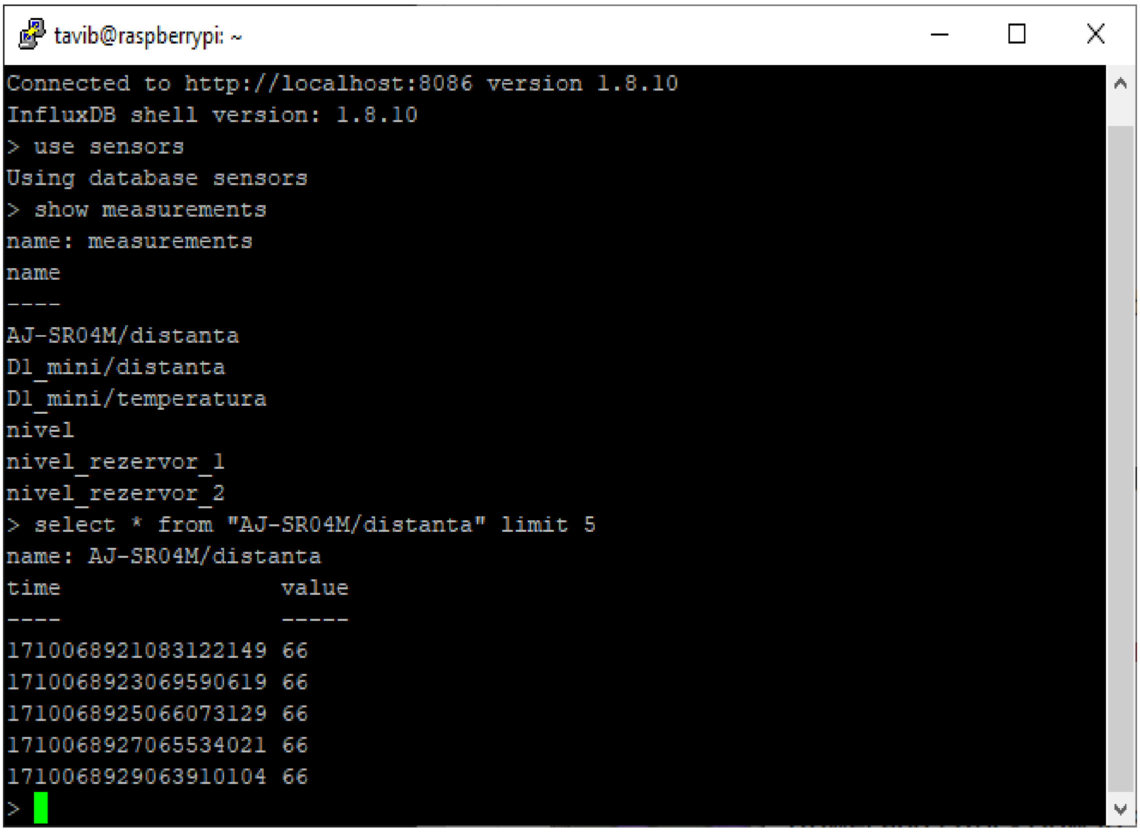


***Figure 13**. View editing panel*

For easy reading of interpreted data or raw data collected from sensors and transducers, Grafana allows a wide range of options to configure and customize data display tables in the most efficient way.

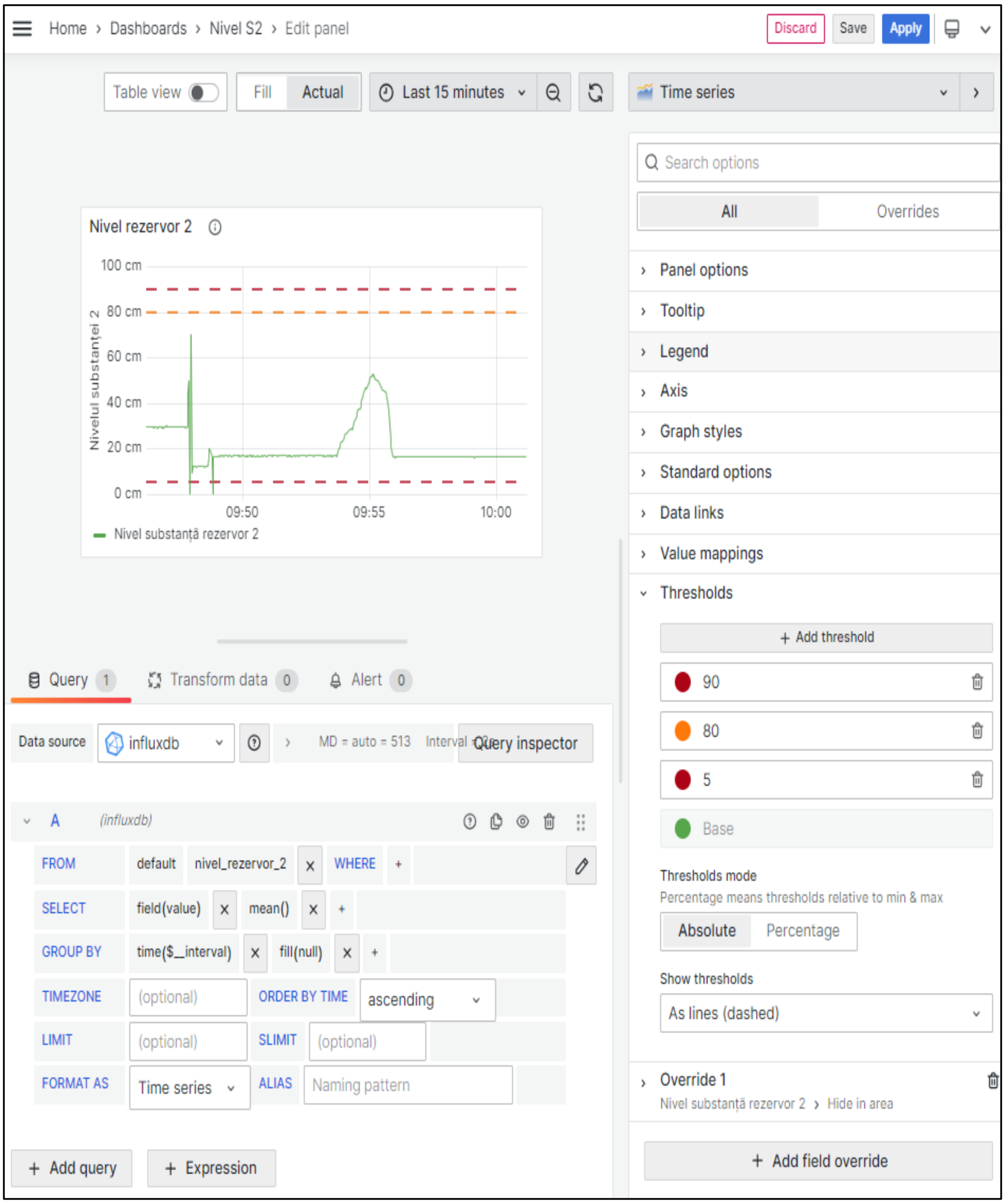


***Figure 14***. *Connecting the Grafana viewer to the InfluxDB database*

## EXPERIMENTAL RESULTS

During the execution of the system, several supporting IT applications were needed, for verification and debugging in different phases of the project. Among them, the functions Serial Monitor and Serial Plotter (Figure 15), which can be found in the Arduino programming environment, and RealTerm_Serial_Terminal [30] (Figure 16). which has the ability to intercept and save in text format data from serial ports.

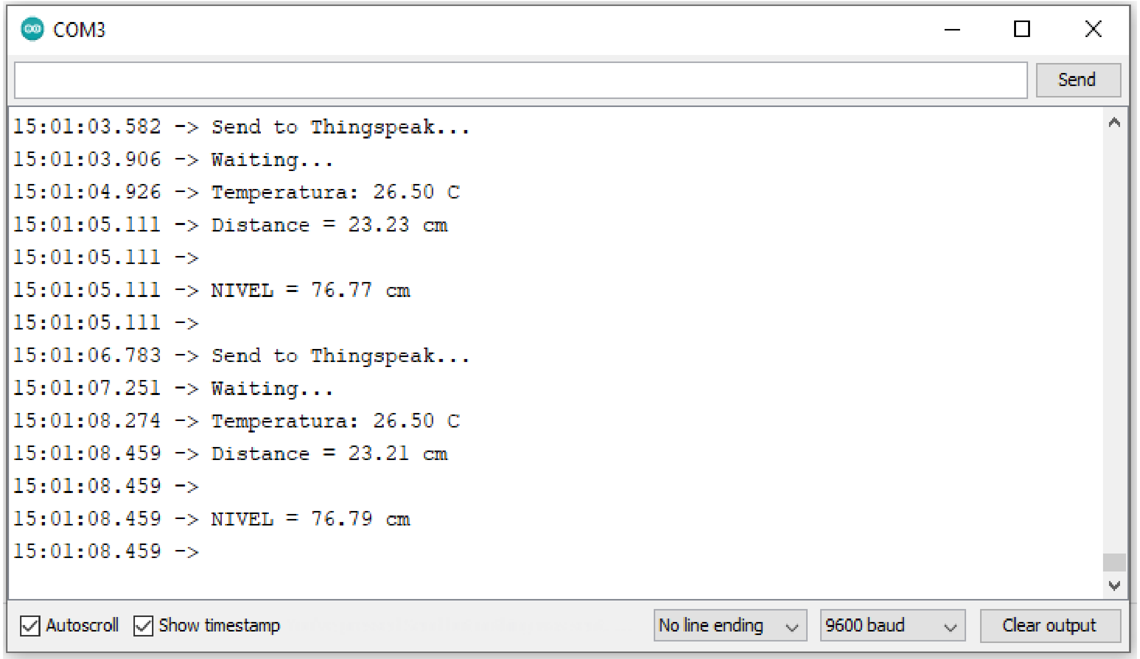


***Figure 15***. *Serial Monitor Arduino*

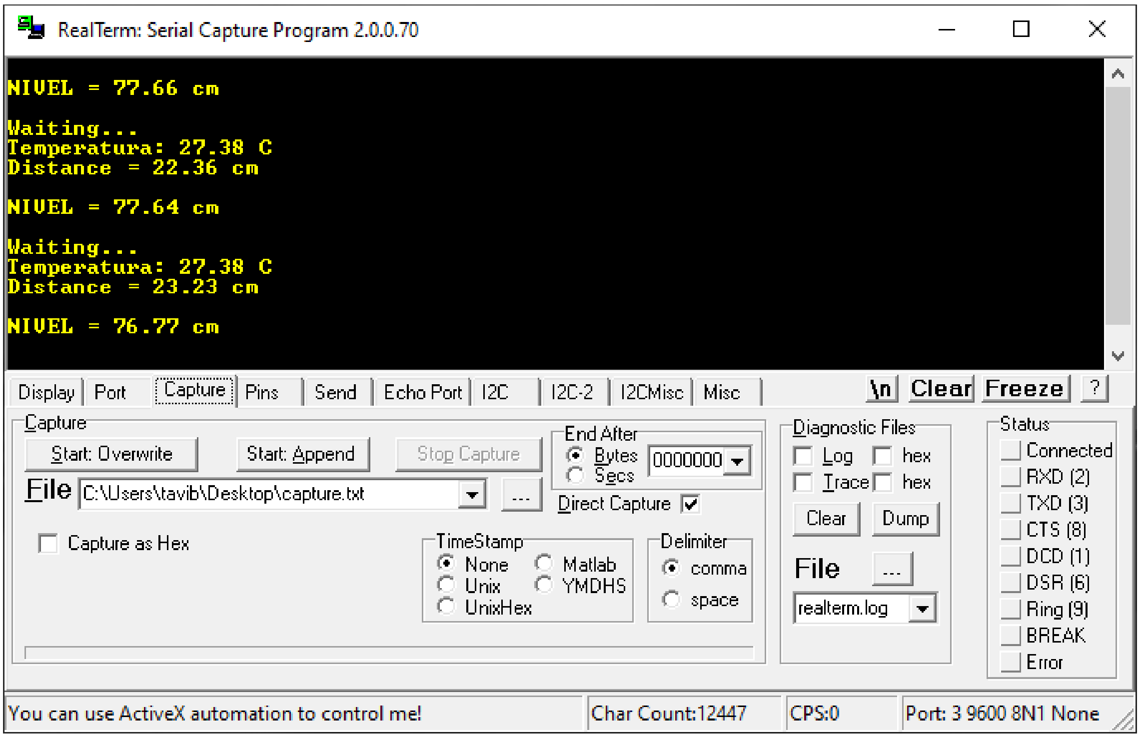


***Figure 16***. *RealTerm application*

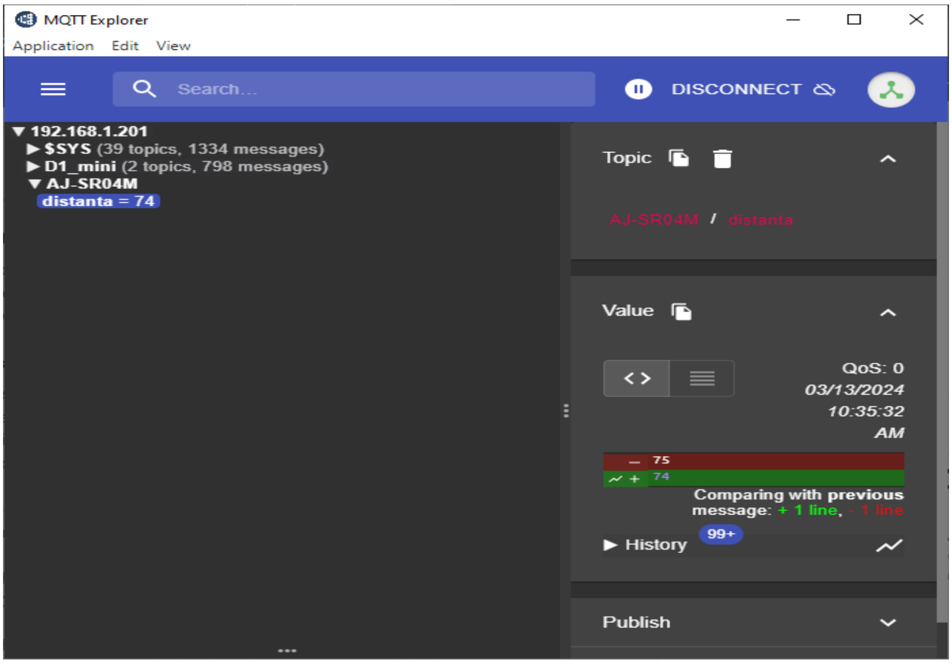


***Figure 17.*** *MQTT Explorer application*

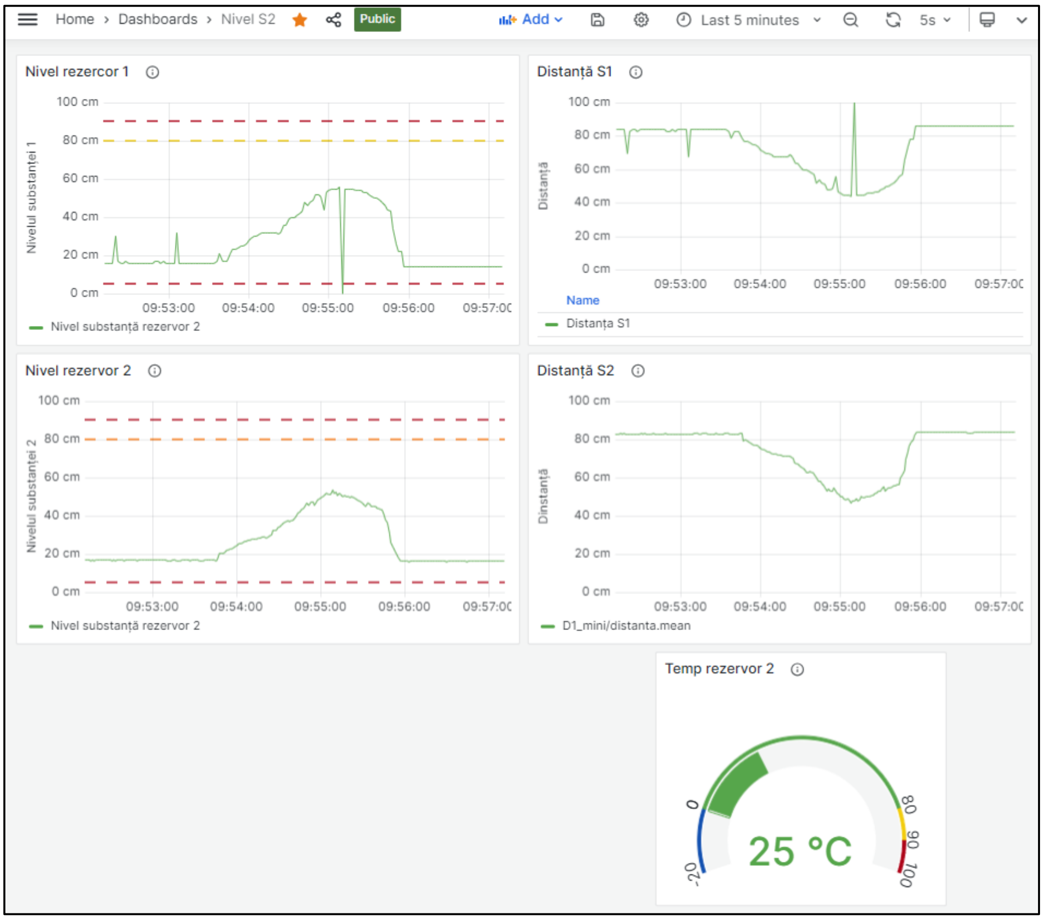


***Figure 18.*** *View panel*

To verify the operation of the MQTT broker, the MQTT Explorer application [32] was used (Figure 17), which also provided the values of the first raw data, published by the distance transducers, which were confirmed by comparison with the information obtained serially, directly from the Arduino microcontrollers, through the RealTerm application (Figure 18).

Viewing the data is possible from the web browser of IT platforms such as workstations, mobile phones or tablets, by accessing the links available in this situation: http://192.168.1.201/:3000/goto/CoFGVq0IR?orgId=1, in the same local network (Figure 18). The image shows both the values measured by the two subsystems of sensors and the calculated value of the level, from the two monitored tanks.

## CONCLUSIONS

In order to meet the requirements of speed in obtaining information for the purpose of analysis and making intervention decisions in the processes pursued by modifying, inventorying, maintaining or troubleshooting systems up to decisions regarding resource management, logistics planning or marketing strategies, which classic systems of measurement with fixed structures cannot provide them directly, programmable, intelligent systems can deliver real-time and historical data over long periods of time for the entire information flow, for all hierarchical levels of control involved in the supervision of various types of systems.

Smart monitoring systems can therefore allow construction on modules grouped into classes that share standardized, unitary controlled functions, which can also lead to economic advantages in different applications of use through reuse after reprogramming and relocation.

The execution of the smart level measurement system was aimed at bringing the study to practical fruition and verifying the ease with which such a system can be built using strictly commercial equipment, free computer applications and knowledge bases available to the general public.

Putting it into practice requires, in addition to the above, an interdisciplinary approach, from the fields of electricity and electronics, computer architecture and computer networks, working with operating systems, programming as well as other disciplines related to information technology.

The versatility of the system developed during the preparation of this work makes it suitable, outside the purpose of measuring the level, in automations to complete safety systems and control of the flows of people and goods, by analyzing and presenting statistical data of interest.

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[43]https://grafana.com/grafana/

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