

Determination of the Reliability of the Automated System for Organoleptic Water Quality

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ABSTRACT

Water quality is essential for a healthy life, so it is necessary to look for technologies to measure its parameters in real time and automatically. The purpose of this study was to implement and determine the reliability of an automated system to evaluate the organoleptic water quality intended for human consumption, in the urban distribution network of the district of Daniel Hernandez (Peru), using a programmable logic controller (PLC) and Simulink. The study was carried out from January to March 2024, corresponding to the rainfall season. In the process of the research, a data acquisition and processing algorithm was implemented in a Simatic S7 1500 PLC with analog input module; using the national sanitation foundation water quality index (NSF-WQI) methodology. The work focused on five key water parameters: potential hydrogen (pH), electrical conductivity (EC), turbidity, free chlorine (FCL) and temperature. The methodology included programming in contact language (KOP) of the algorithm for calculating subscripts for each parameter, according to the functions established by NSF-WQI. Measurements were performed with 4-wire sensing devices with 4–20 mA current signals, ensuring data accuracy. The interface to visualize the parameters and the water quality index was implemented in Simulink, communicating via OPC UA with the PLC server, facilitating the graphical representation of the organoleptic water quality index. The overall equipment efficiency (OEE) or automated system implemented was 90.56%, indicating its acceptable reliability for evaluating water quality. By performing the measurements, with the sensors of the five parameters immersed in tap water, at each of the three established sampling points (Dwelling_1, Dwelling_2 and Dwelling_3) along the water distribution network, the system facilitated the automated and real-time evaluation of the quality, resulting in an average NSF-WQI of 83.08%, classifying the water as good for human consumption. This information is important for water quality management and can guide future treatments to achieve better quality.

Keywords: automation, organoleptic quality, programmable logic controller, NSF-WQI, real-time monitoring.

INTRODUCTION

Vital liquid water is essential for human survival, and it is becoming increasingly scarce, about one billion people per year experienced severe water shortages (Falkenmark, 2020). The total amount of water needed per person can vary according to various factors, but a general estimate can be made

by considering the recommendations of the World Health Organization (WHO) and other common uses of water in daily life. Approximately a person needs at least 50 liters of water per day to meet basic needs, including drinking, personal hygiene, and other domestic uses (Gleick, 1996).

Access to clean water is a fundamental human right and represents a significant step

towards improving the overall standard of living (WHO, 2021). Those populations with low economic resources are often faced with a lack of this resource (Oliveira and Pereira, 2020) often consuming water that does not meet adequate standards for human consumption. People who lack water transportation systems face higher expenses by purchasing water from tanker trucks, which can sometimes be contaminated. Others choose to purchase bottled water from commercial establishments, and other sources of water supply also exist (Bonett et al., 2020). The WHO maintains that it is essential that water supply be affordable and of high quality, to reach the greatest possible number of people who require it (WHO, 2022).

Determining water quality involves the management of a considerable amount of data, and it is essential to analyze by methods, tools, or models capable of inferring data (Zhu et al., 2022). The use of water quality indices is important for the evaluation of the quality of water resources, especially in places far from cities in Peru. The tool or methodology selected for this purpose should analyze and integrate in a comprehensible, but technically justifiable manner, the relevance of physical, chemical, and biological parameters of surface waters (Nong et al., 2020). To improve and develop a more effective model, it is essential to select a suitable method to determine water quality efficiently.

Several methodologies of water quality indices were formulated worldwide (Al Chalabi et al., 2022), and these can be used to easily determine the quality of drinking water within a particular locality or sector (Bharti and Katyal, 2011). These indices are based on the comparison of various water quality parameters that are in regulatory standards and give a water quality index (Gupta and Gupta, 2021).

Water quality is determined by its organoleptic, physicochemical, and inorganic-organic characteristics (Minam, 2017). In the Huancavelica region of Peru, the population consuming water with inadequate chlorine levels outside the range (≥ 0.1 mg/L and < 0.5 mg/L) from the year 2010 to the year 2019 has a percentage difference of 24.1 (Bonett et al., 2020), this means, that the water quality in terms of the free chlorine parameter worsened by that percentage. Likewise, systems are needed to monitor the recovery even of household graywater (Carbajal-Morán et al., 2021). Open platform communications unified architecture (OPC UA) communication with a Siemens

S7 1500 PLC is possible and commonly used in industrial environments for system integration and remote monitoring (Cabral et al., 2020). OPC UA is a communication standard that allows interoperability between different devices and systems in the field of industrial automation, so it is possible to communicate with various platforms and devices with support for this communication. PLC S7 1500 incorporates OPC UA communication configurable as a server and/or client (Siemens, 2019). To use it, the PLC must be enabled from the TIA Portal programming software. In the configuration, the variables that will be exposed through the OPC UA communication protocol must be defined, establishing the corresponding security and permissions.

Simulink is a graphical modeling and simulation environment developed by MathWorks, the same company that created Matlab. It is primarily used to design, simulate, and analyze dynamic systems, from control systems and signal processing to communication systems and physical modeling (Saini et al., 2022). Simulink provides an intuitive graphical interface that allows users to build system models using graphical blocks that represent various system components, such as differential equations, mathematical operations, input and output signals, controllers, plants, and so on. Users can connect these blocks to represent the relationship between different system components and define how they interact with each other. Simulink communicates with an S7 1500 PLC via the OPC UA communication protocol, after programming a script to read both nodes and variables (El Zerk et al., 2023).

To monitor water quality it is necessary to have equipment or systems that guarantee the measurements of its parameters in an agile and effective way, allowing the evaluation of water quality in a reliable way, with information in real time and in situ; therefore, in this work we focus on the development and implementation of an automated system of high reliability and with the ability to evaluate the organoleptic water quality (based on five parameters identified as critical) intended for human consumption, using industrial technological devices such as: a PLC S7 1500 for data acquisition and processing, communication by OPC UA with the interface developed in Simulink for the visualization and presentation of the results in numerical and graphical form. The objective of this work is to determine the reliability of the automated system implemented to evaluate the

organoleptic quality of water intended for human consumption in the urban distribution network of the district of Daniel Hernandez (Peru).

MATERIALS AND METHODS

Study area

The study was carried out in the district of Daniel Hernández, department of Huancavelica (Peru), whose location of the reservoir and the three strategic sampling points are shown in Figure 1. The water reservoir for human consumption is located at latitude -12.3936355° , longitude -74.8503436° and altitude 3375 masl. Three sampling points were established in dwellings distributed along the distribution network (near, intermediate, and far from the reservoir) for the adequate measurement of the organoleptic quality of the water. The sampling point near the reservoir was located at “Dwelling_1” located at latitude -12.3916679° , longitude -74.8569591° and altitude 3276 masl; the intermediate sampling point was located at “Dwelling_2” located at latitude -12.3919350° ,

longitude -74.8614818° and altitude 3256 masl, and the far sampling point was located at “Dwelling_3”, where the water distribution network ends, located at latitude -12.3867067° , longitude -74.8636461° and altitude 3234 masl.

NSF-WQI method

The NSF-WQI method developed by Brown et al. (1972) was used as a modified version of the Horton model (1965). It is suitable for evaluating surface water quality in different types of sources. The modified version is a weighted geometric mean function. The water quality index is expressed in Equation 1 (Banda and Kumarasamy, 2020).

$$NSF - WQI = \prod_{i=1}^n S_i^{w_i} \quad (1)$$

where: WQI is the water quality index value; n is the number of sub-indexes of each water parameter; S_i is the i -th sub-index value; and w_i is the i -th weighting value where $w_1 + w_2 + w_3 + \dots + w_n = 1$.



Figure 1. Map of the location of the reservoir and the three strategic sampling points to determine the organoleptic quality of water for human consumption

Parameter selection

The NSF index considered for this work was based on five organoleptic parameters: potential hydrogen (pH), electrical conductivity (EC), turbidity, free chlorine (FCL), and temperature variation (Δ Temperature) (Yalaletdinova et al., 2021), which is the result of the difference of the temperature minus the monthly average temperature (MINSAs-DIGESA, 2009). For the measurement of the organoleptic parameters of the water, pH meters model RMD-ISHP105 (REMOND, 2020) were used, EC model RMD-ISEP105 (REMOND, 2023a), turbidity model RMD-ISST105 (REMOND, 2023b) and FCL model RMD-ISCT105; which are 4–20 milliamperes (mA) 4-wire current sensors-transmitters with submersible protection in water; while for temperature the PT100 device was used with a 2-wire 4–20 mA current sensor-transmitter, measuring the temperature parameter in the range 0–100 °C.

Subindex generation

The corresponding water parameter subindices were generated based on Brown’s development (Brown et al., 1972), which was based on expert panel judgment. The value of each subindex of the selected organoleptic water parameters varies from 0 to 100%, conditioned to different values along this interval. The subscript of the pH parameter is obtained with the functions of Equation 2.

$$\begin{aligned} & \text{If } \text{pH} < 2 \text{ And } \text{pH} > 12; \text{ then } \text{Sub}_{\text{pH}} = 2 \\ & \text{else if } \text{pH} < 6.5; \text{ then } \text{Sub}_{\text{pH}} = 0.4289e^{0.8042 \cdot \text{pH}} \\ & \text{else if } 6.5 < \text{pH} < 8.5; \\ & \text{then } \text{Sub}_{\text{pH}} = -18.407\text{pH}^2 + 270.68\text{pH} - 901.16 \\ & \text{else if } \text{pH} > 8.5; \text{ then } \text{Sub}_{\text{pH}} = 394707e^{-1.002 \cdot \text{pH}} \\ & \text{end} \end{aligned} \tag{2}$$

The subscript of the EC parameter is obtained with the functions of Equation 3.

$$\begin{aligned} & \text{If } 0 \leq \text{EC} < 2000; \\ & \text{then } \text{Sub}_{\text{EC}} = 0.00003 \cdot \text{EC}^2 - 0.1072 \cdot \text{EC} + 100.01 \\ & \text{else if } \text{EC} \geq 2000; \text{ then } \text{Sub}_{\text{EC}} = 2 \\ & \text{end} \end{aligned} \tag{3}$$

The subscript of the turbidity parameter is obtained with the functions of Equation 4.

$$\begin{aligned} & \text{If } \text{Turbiedad} \leq 5 \text{ UNT}; \\ & \text{then } \text{Sub}_{\text{Turb}} = -2.2 \cdot \text{Turbiedad} + 100 \\ & \text{else if } 5 < \text{Turbiedad} < 100 \text{ UNT}; \\ & \text{then } \text{Sub}_{\text{Turb}} = 87.32e^{-0.016 \cdot \text{Turbiedad}} \end{aligned}$$

$$\begin{aligned} & \text{else if } \text{Turbiedad} > 100 \text{ UNT}; \\ & \text{then } \text{Sub}_{\text{Turb}} = 5.0 \\ & \text{end} \end{aligned} \tag{4}$$

The subscript of the FCL parameter is obtained with the functions of Equation 5.

$$\begin{aligned} & \text{If } \text{FCL} < 0.5 \text{ mg/L}; \\ & \text{then } \text{Sub}_{\text{FCL}} = 200 \cdot \text{FCL} \\ & \text{else if } 0.5 \leq \text{FCL} < 1.0 \text{ mg/L}; \\ & \text{then } \text{Sub}_{\text{FCL}} = 100 \\ & \text{else if } 1 \leq \text{FCL} < 1.5 \text{ mg/L}; \\ & \text{then } \text{Sub}_{\text{FCL}} = -100 \cdot \text{FCL} + 200 \\ & \text{else if } \text{FCL} \geq 1.5 \text{ mg/L}; \\ & \text{then } \text{Sub}_{\text{FCL}} = -13.714 \cdot \text{FCL} + 70.571 \\ & \text{end} \end{aligned} \tag{5}$$

The subscript of the parameter Δ Temp is obtained with the functions in Equation 6.

$$\begin{aligned} & \text{If } \Delta \text{Temperatura} \leq 3 \text{ }^\circ\text{C}; \\ & \text{Sub}_{\Delta \text{Temp}} = -1.2778 (\Delta \text{Temperatura})^2 - \\ & - 0.1667 \cdot \Delta \text{Temperatura} + 93 \\ & \text{else if } \Delta \text{Temperatura} > 3 \text{ }^\circ\text{C}; \\ & \text{then } \text{Sub}_{\Delta \text{Temp}} = 99.613e^{-0.077 \cdot \Delta \text{Temperatura}} \\ & \text{end} \end{aligned} \tag{6}$$

Parameter weighting

The model uses weight values of different parameters that sum to 1. The original weight values were obtained using a panel of experts, but subsequent applications of the model have used modified weight values to assess surface water quality (Noori et al., 2019). In this study, to calculate the NSF-WQI, modified weights for pH ($w_1 = 0.26$), EC ($w_2 = 0.19$), turbidity ($w_3 = 0.20$), FCL ($w_4 = 0.17$), and Δ Temperature ($w_5 = 0.18$) were established.

Water quality index evaluation

The model generates a WQI ranging from 0 to 100%. 0 indicates the worst water quality and 100 indicates excellent water quality. The model proposed 5 levels of water quality classification: 1. excellent (WQI = 90–100), 2. good (WQI = 70–89), 3. medium (WQI = 50–69), 4. poor (WQI = 25–49) and 5. very poor quality (WQI = 0–24). The NSF-WQI was obtained with Equation 7.

$$\text{NSF - WQI} = \prod_{i=1}^n S_i^{w_i} = \text{Sub}_{\text{pH}}^{w_1} \cdot \text{Sub}_{\text{EC}}^{w_2} \cdot \text{Sub}_{\text{Turb}}^{w_3} \cdot \text{Sub}_{\text{FCL}}^{w_4} \cdot \text{Sub}_{\Delta \text{Temp}}^{w_5} \tag{7}$$

Overall efficiency of the automated system

To calculate the OEE, the availability, performance, and quality of the implemented automated system were taken into account. The availability ratio (*A*) of the automated system was calculated using Equation 8 (Bai et al., 2018).

$$A (\%) = \frac{AET}{PT} \times 100 \quad (8)$$

where: *A* – availability, *AET* – actual execution time; *PT* – planned time.

Performance (*P*) known as process rate, measures the rate at which the automated system determines water quality, considering the total units sampled per ideal time between actual run time (Heng and Hee, 2018), according to Equation 9.

$$P (\%) = \frac{TU \times ICT}{ART} \times 100 \quad (9)$$

where: *P* – performance (%); *TU* – total units; *ICT* – ideal cycle time; *ART* – actual run time.

Quality (*Q*) also called process yield, represents the units sampled correctly as a percentage of the total units (Chong and Ng, 2016), according to Equation 10.

$$Q (\%) = \frac{N}{TN} \times 100 \quad (10)$$

where: *Q* – quality, *N* – number of correct measurements of water parameters, *TN* – total number of water parameter measurements.

Overall equipment efficiency measures the efficiency achieved in the production process of

a piece of equipment (Bhade and Hegde, 2020), specifically the efficiency with which machines and equipment operate. In more basic terms, OEE is the ratio of the factors *A*, *P*, and *Q* presented in Equation 11.

$$OEE (\%) = A \times P \times Q \% \quad (11)$$

Automated system implementation

The automated system was implemented to evaluate the organoleptic quality of the water, with the general diagram shown in Figure 2. This diagram presents the blocks to evaluate the organoleptic quality of the water based on the selected parameters: pH, EC, turbidity, FCL, and ΔTemperature. The PLC S7 1500 configured as a server for OPC UA communication, acquires the parameter data from the sensors, processes them, calculates the NSF-WQI, and sends it to the interface developed in Simulink.

The AI 8xU/I/RTD/TC module of the PLC S7 1500 allowed to acquisition the electrical signals coming from the sensors immersed in water, to convert them into numerical values from 0–27648 that correspond to the range of each sensor. After normalization (0–1) and scaling in ranges established by the sensors for each parameter, the block diagram in Figure 3 is obtained, and implemented in Siemens TIA Portal.

The NSF-WQI algorithm was implemented in the “CALCULATE” instruction block in Figure 4, based on Equation 7, taking into account the subscripts set in Equations 2–6.

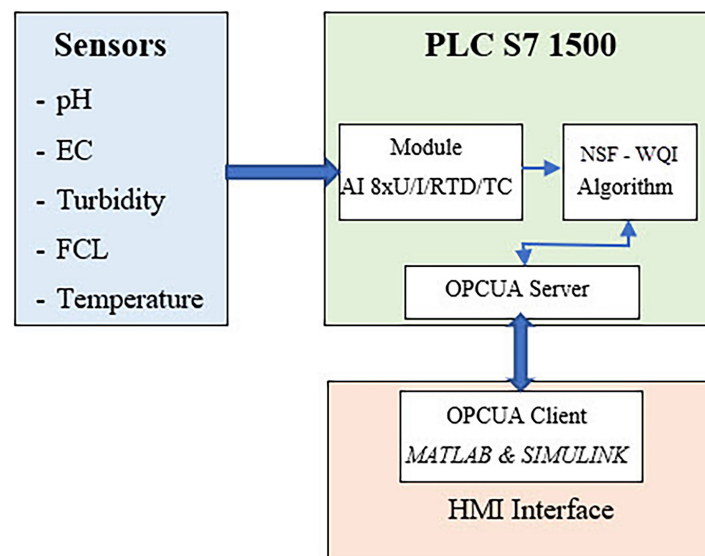


Figure 2. General diagram of the automated system to evaluate the organoleptic quality of water

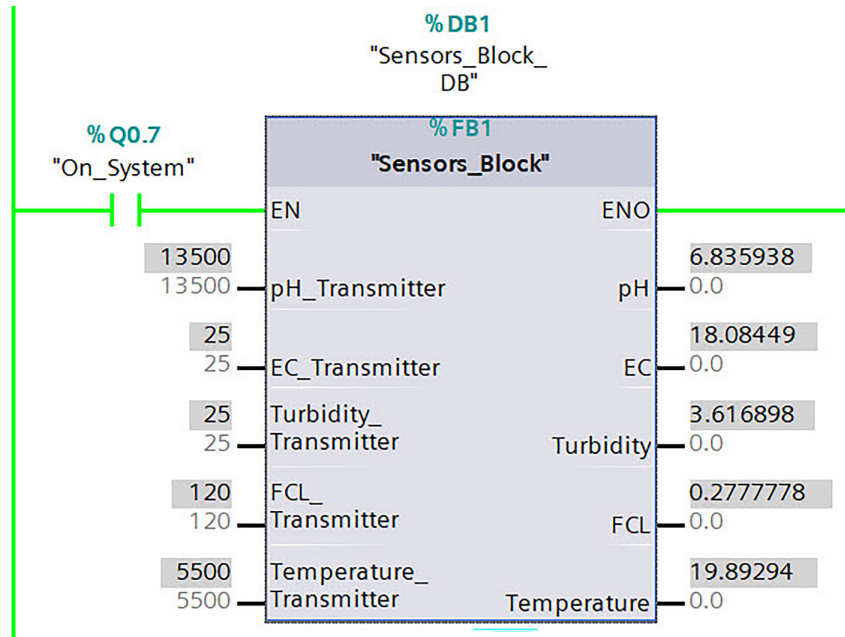


Figure 3. Block diagram of measuring parameters pH, EC, turbidity FCL, and temperature in TIA portal with PLC S7 1500 and analog signal input module

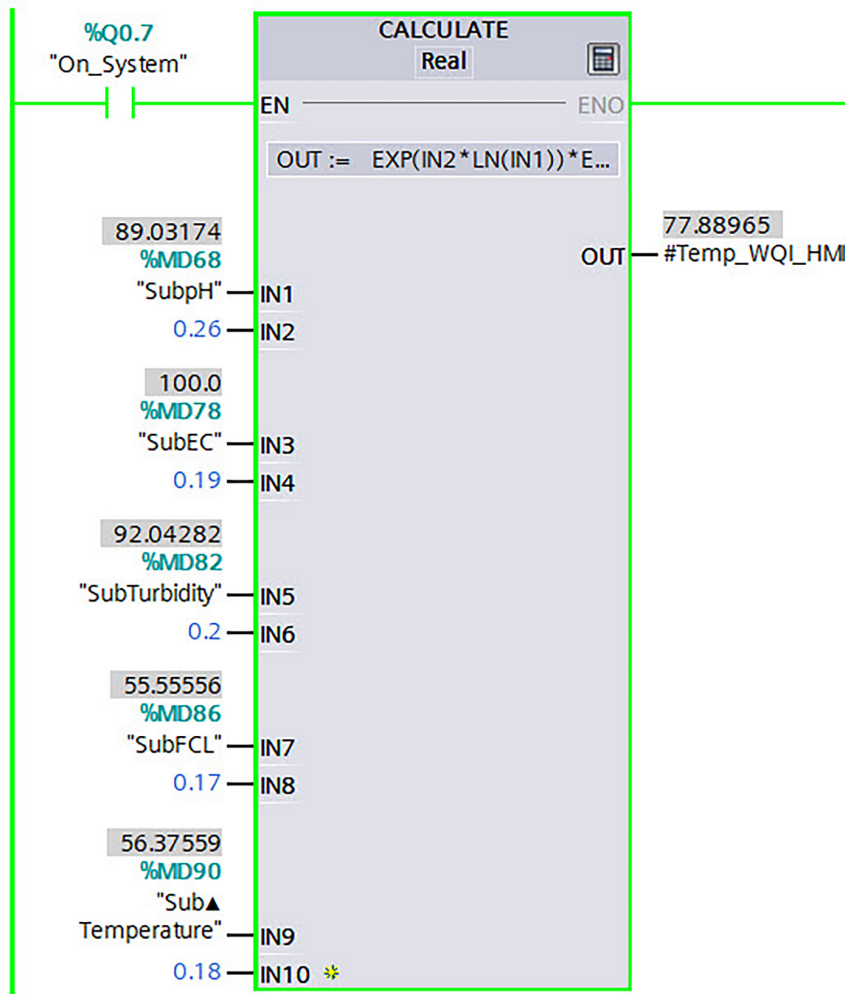


Figure 4. Block diagram for calculating water quality based on the NSF-WQI algorithm implemented in TIA Portal

The OPC UA server was configured to be accessible to the S7 1500 PLC, with the address `opc.tcp://192.168.0.1:4840`, as shown in Figure 5. This process enables communication between the server and the client. Employing the OPC UA client implemented in Simulink, the NSF-WQI water quality monitoring is performed, as shown in Figure 6. To achieve this interface in Simulink, two “Interpreted MATLAB Fcn” functions were implemented, which allow to establish the OPC UA communication with the server, and to acquire Real type values of the water parameters (OPC UA Connection1), and Boolean type values for water quality level indicators (OPC UA Connection2). The interface is activated from the control

panel by the green “Start” button and deactivated by the red “Stop” button. To warn of the presence of water with unsatisfactory quality below medium (NSF-WQI < 75%), the implemented system has conditional instructions implemented with SCL in the PLC S7 1500 (Fig. 7), to activate a visual alarm on the interface developed in Simulink; in order to take external corrective actions by the user or manager of the water supply.

Collection of water parameter samples

With the automated system previously implemented with its respective HMI developed in Simulink, water samples for human

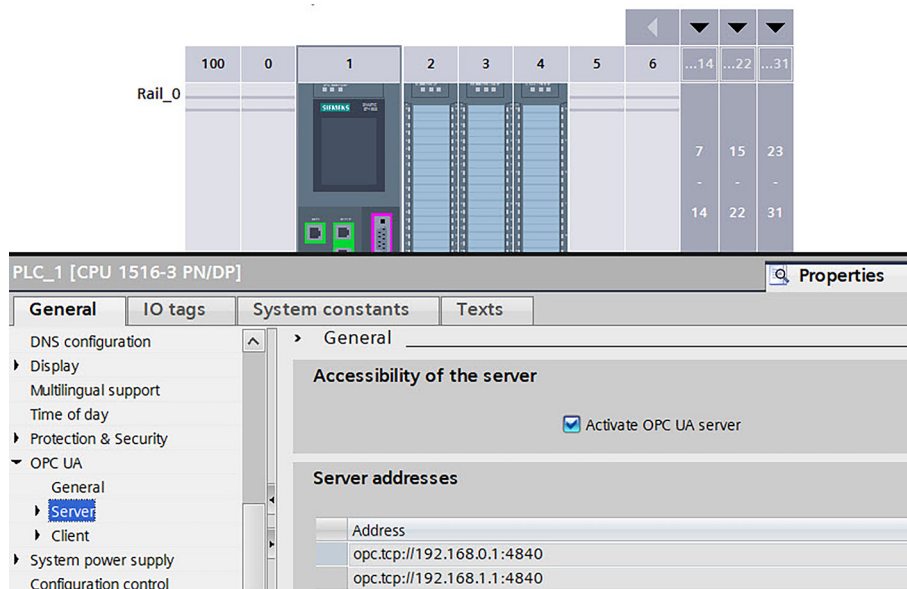


Figure 5. Configuring OPC UA server accessibility on S7 1500 PLC with 1516 CPU

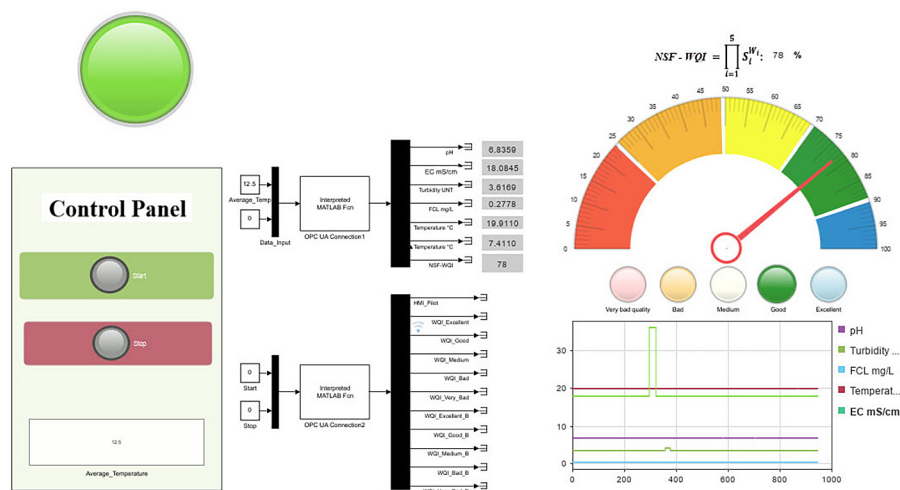


Figure 6. Interface for automated water quality monitoring with NSF-WQI via OPC UA communication in Simulink


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1 IF ("OPCUA_Interface".WQI < 25) THEN
2     "OPCUA_Interface".WQI_Very_Bad := 1;
3     "OPCUA_Interface".WQI_Bad := 0;
4     "OPCUA_Interface".WQI_Medium := 0;
5     "OPCUA_Interface".WQI_Good := 0;
6     "OPCUA_Interface".WQI_Excellent := 0;
7     "OPCUA_Interface".Alarm := 1;
8 END_IF;
9
10 IF (25 <= "OPCUA_Interface".WQI AND "OPCUA_Interface".WQI < 50) THEN
11     "OPCUA_Interface".WQI_Very_Bad := 0;
12     "OPCUA_Interface".WQI_Bad := 1;
13     "OPCUA_Interface".WQI_Medium := 0;
14     "OPCUA_Interface".WQI_Good := 0;
15     "OPCUA_Interface".WQI_Excellent := 0;
16     "OPCUA_Interface".Alarm := 1;
17 END_IF;
18
19 IF (50 <= "OPCUA_Interface".WQI AND "OPCUA_Interface".WQI < 70) THEN
20     "OPCUA_Interface".WQI_Very_Bad := 0;
21     "OPCUA_Interface".WQI_Bad := 0;
22     "OPCUA_Interface".WQI_Medium := 1;
23     "OPCUA_Interface".WQI_Good := 0;
24     "OPCUA_Interface".WQI_Excellent := 0;
25     "OPCUA_Interface".Alarm := 1;
26
27
28
29
30
31
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34
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Figure 7. Instructions conditions for activation of “Alarm” when water quality is unsatisfactory for drinking water

consumption were collected at the three pre-established points in the district of Daniel Hernández and geolocated on the map presented in Figure 1, for which the implemented automated system had to be moved to each point; the data of the organoleptic parameters of the water (pH, EC, turbidity, FCL and temperature) were measured by the sensor-transmitters and sampled automatically and in real time from the PLC S7 1500 by means of the analog input module AI 8xU/I/RTD/TC. This sample collection was carried out during the rainy season comprising the months of January, February and March; where a daily sample was taken at each sampling point, making a total of 89 samples during the period of the study; which were later processed to calculate the organoleptic water quality based on the NSF-WQI methodology and visualized in Simulink.

RESULTS AND DISCUSSION

Evaluation of overall equipment efficiency

To determine the overall efficiency of the automated system it was necessary to determine the availability, throughput, and quality. Availability

was calculated based on the ratio of the time required for measurements, based on the theoretical responses of the sensors and PLC S7 1500 (Table 1), to the Actual run time of the automated system (Table 2). From Tables 1 and 2, Equation 8 was used to calculate the availability (A) of the automated system presented in Equation 12.

$$A (\%) = \frac{4.0}{4.39} \times 100 = 91.11\% \quad (12)$$

$$A = 91.11\%$$

where: *A* – availability.

The throughput of the automated system was determined based on total units × ideal cycle time calculated as planned time from Table 1 plus 60 s reset, with 10 sample measurements, and actual run time for the 10 measurements resulting from actual execution time from Table 2 plus 60 s reset. Equation 9 performs (*P*) presented in Equation 13.

$$P (\%) = \frac{(4.0 + 60) \times 10}{(4.39 + 60) \times 10} \times 100 = 99.39\% \quad (13)$$

$$P = 99.39\%$$

where: *P* – performance.

To calculate the stability of the automated system measurements, the sensors were kept in continuous operation for 10 hours and 2 minutes, establishing

Table 1. Planned time, based on theoretical responses of sensors and PLC for water parameter measurement and WQI calculation

Observations	Sensor delay time (s)					Process delay time in PLC S7 – 1500 – Simulink (s)	Planned time(s)
	pH	EC	Turbidity	FCL	Temp		
Manufacturer’s reference	> 3	> 2	> 2	> 2	> 0.5	1	4

Table 2. Actual execution time of the sensors and PLC in measuring the water parameters and calculating the WQI

Run order	Sensor delay time (s)					Process delay time in PLC S7 – 1500 – Simulink (ms)	Total delay time (s)
	pH	EC	Turbidity	FCL	Temp		
1	300.20	123.00	220.70	235.30	145.10	61.80	6.03
2	202.70	121.70	191.50	121.70	116.80	61.40	4.40
3	250.10	182.90	220.20	122.60	122.60	62.90	5.22
4	234.00	210.90	188.40	122.60	122.20	53.80	4.80
5	201.20	170.80	188.50	122.10	131.70	64.20	4.42
6	171.80	190.70	170.30	121.70	151.20	64.40	3.94
7	192.00	151.30	121.50	121.00	184.80	51.40	4.06
8	244.50	203.00	223.00	121.50	226.40	59.00	5.06
9	221.10	208.00	192.40	121.10	211.00	60.60	4.70
10	232.80	132.50	183.00	120.70	233.00	58.60	4.86
11	181.20	121.20	121.80	122.00	596.00	61.60	4.05
12	180.60	120.40	121.10	120.10	529.70	62.30	4.05
13	180.10	122.80	120.40	121.40	596.60	61.40	4.03
14	183.90	120.80	121.30	122.00	545.30	61.40	4.09
15	180.20	122.00	121.70	120.20	551.30	60.80	4.02
16	180.90	122.00	122.50	122.50	515.30	63.40	4.07
17	185.00	120.70	121.60	121.30	546.90	64.90	4.17
18	180.80	122.70	120.90	122.60	589.10	62.60	4.06
19	182.10	121.20	121.80	121.20	575.50	60.90	4.05
20	180.30	121.60	120.80	120.60	564.60	61.60	4.03
21	181.20	121.20	121.50	120.70	577.10	63.70	4.08
Average: actual execution time							4.39

a single measurement point on the distribution network with water flowing continuously, to ensure homogeneous values for each measured parameter; the sample variance of each sensor was determined experimentally in two cuts, which are presented in Table 3. The first cutoff is 100 s after activation of the system (0t-10t), where the sample variance of the measurements made for each parameter is significant (pH = 0.34, EC = 85.78, turbidity = 3.47, FCL = 0.01 and temperature = 13.25), the second cutoff is at 36120 s, which corresponds to 10 hours and 2 minutes, for the calculation of the sample variance it was considered from minute 2 of operation (120 s); observing a not very significant sample variance (pH = 0.00, EC = 0.04, turbidity = 0.00, FCL = 0.00 and temperature = 0.03), which indicates that the measurements are of high precision.

From Table 3, 2 minutes were estimated as the stabilization time to avoid erroneous measurements due to lack of precision of the sensors. After this time, samples were taken to calculate the quality of the automated system, based on the correct measurement of each parameter by the corresponding sensor (Run order 1–21); being: total number of water parameter measurements 110 as well as number of correct measurements of water parameters. Using Equation 10, the quality (Q) of the automated system presented in Equation 14 was calculated.

$$Q (\%) = \frac{110}{110} \times 100 = 100\% \quad (14)$$

$$Q = 100\%$$

Therefore, the overall equipment efficiency (OEE) or automated system calculated with

Table 3. Sensor operation test for 10 hours and 2 minutes at a single preset homogeneous measurement point and with 2 cut-off points for sample variance calculation

Run order	Time	Duration (s)	pH	EC (mS/cm)	Turbidity (UNT)	FCL (mg/L)	Temperature (°C)
0t	08:00:00	0	5.92	16.40	3.06	0.29	18.00
1t	08:00:10	10	7.21	19.90	3.53	0.21	11.85
2t	08:00:20	20	7.09	15.90	6.54	0.30	22.00
3t	08:00:30	30	7.18	38.00	1.98	0.12	21.48
4t	08:00:40	40	7.78	13.40	2.33	0.13	21.17
5t	08:00:50	50	6.65	29.40	6.51	0.46	21.23
6t	08:01:00	60	6.72	14.00	3.62	0.30	21.17
7t	08:01:10	70	6.72	26.30	3.63	0.27	21.89
8t	08:01:20	80	6.75	18.70	3.52	0.24	21.29
9t	08:01:30	90	6.79	18.70	3.52	0.24	21.44
10t	08:01:40	100	6.78	19.00	3.55	0.21	21.46
Sample variance			0.34	85.78	3.47	0.01	13.25
1	08:02:00	120	6.79	19.00	3.52	0.24	21.01
2	08:32:00	1920	6.80	19.00	3.52	0.24	21.25
3	09:02:00	3720	6.78	18.50	3.55	0.22	21.31
4	09:32:00	5520	6.75	18.50	3.53	0.24	21.14
5	10:02:00	7320	6.75	19.00	3.51	0.23	20.99
6	10:32:00	9120	6.79	19.00	3.55	0.20	21.46
7	11:02:00	10920	6.80	18.80	3.52	0.23	21.09
8	11:32:00	12720	6.80	18.70	3.52	0.25	21.18
9	12:02:00	14520	6.80	18.90	3.50	0.25	21.28
10	12:32:00	16320	6.79	18.90	3.52	0.24	21.20
11	13:02:00	18120	6.78	18.50	3.52	0.22	21.49
12	13:32:00	19920	6.79	18.80	3.50	0.21	21.42
13	14:02:00	21720	6.80	18.70	3.51	0.21	20.98
14	14:32:00	23520	6.75	18.80	3.52	0.20	21.12
15	15:02:00	25320	6.77	19.00	3.55	0.22	21.00
16	15:32:00	27120	6.76	18.50	3.54	0.25	21.40
17	16:02:00	28920	6.80	18.60	3.52	0.22	21.26
18	16:32:00	30720	6.80	18.70	3.54	0.21	21.29
19	17:02:00	32520	6.79	18.90	3.52	0.23	21.03
20	17:32:00	34320	6.79	18.60	3.51	0.23	20.90
21	18:02:00	36120	6.79	18.80	3.51	0.24	20.94
Sample variance			0.00	0.04	0.00	0.00	0.03

Equation 11, based on A , P , and Q , is 90.56% as shown in Equation 15.

$$OEE (\%) = 91.11 \times 99.39 \times 100\% = 90.56\% \quad (15)$$

This efficiency of 90.56% indicates that the implemented automated system is reliable allowing to properly evaluate the water quality based on the preset organoleptic parameters, which are the key performance indicators (KPI). OEE above 60% is acceptable for

measuring equipment, which is also applicable to equipment used in industry (Yuan et al., 2021), such as in-line production (Vejjanugraha et al., 2022) and production plants (Zibane and Telukdaric, 2021) by identifying the KPIs.

Automated evaluation of the organoleptic quality of water

The automated system was used to measure the water parameters (pH, EC, turbidity, FCL, and

temperature) used to determine the organoleptic quality of water for human consumption (NSF-WQI) in the Daniel Hernández district during the rainy season. As a result, the water quality indices show seasonal and geospatial variations. In Figure 8, it is observed that at the seasonal level during the days of February, the NSF-WQI is slightly reduced in the three sampling points (Dwelling_1, Dwelling_2, and Dwelling_3), while during January and March the water quality indexes are better concerning the month of February.

At the geospatial level, the NSF-WQI at the Dwelling_1 sampling point is higher than the others, this occurs because it is located closer to the water reservoir that supplies the entire district of Daniel Hernández; the water quality index at Dwelling_3 is lower than Dwelling_1 and Dwelling_2, this is explained by its location away from the water reservoir within the same water distribution network. When evaluating the organoleptic quality of the water based on NSF-WQI, in the study period, the following is obtained from the Box Plot in Figure 9: the average NSF-WQI in Dwelling_1 is 86.19% (Figure 9a), in Dwelling_2 is 83.41% (Figure 9b) and in Dwelling_3 is 79.66% (Figure 9c). NSF - WQI = 78.65% (in Dwelling_3) is the minimum; while NSF-WQI = 87.08% (in Dwelling_1) represents the maximum. Therefore, on average, the organoleptic quality of drinking water in the Daniel Hernández district is 83.08% (Figure 9d). From the results of the evaluation of the organoleptic

quality of water using the NSF-WQI methodology using the automated system; a remarkable variability was observed in the values recorded at different sampling points. The results indicated an average NSF-WQI of 83.08% which classifies water as good for human consumption (Brown et al., 1972; Noori et al., 2019). The variation in water quality due to the geospatial distribution of the distribution network is mainly produced by the decrease in FCL and increase in temperature along its path, due to the poor condition of the water distribution networks, and lack of conservation and maintenance as indicated by (Fatima et al., 2022). It is important to note that the study period coincided with the rainy season (January-March), which had a significant impact on seasonal water quality. This phenomenon was reflected in the decrease of the NSF-WQI to 78.65% in Dwelling_3 corresponding to the month of February with the highest rainfall, mainly influencing water turbidity and pH (Nobre et al., 2020). The observation of this temporal fluctuation highlights the need for continuous monitoring and adaptation of management strategies to cope with changing seasonal climatic conditions (Singh et al., 2020).

Regarding the measurement of the organoleptic parameters of the water that were obtained automatically and in real time, it is noteworthy the advantage that this process avoids the contamination of the parameters with respect to the studies developed in a traditional way by other authors

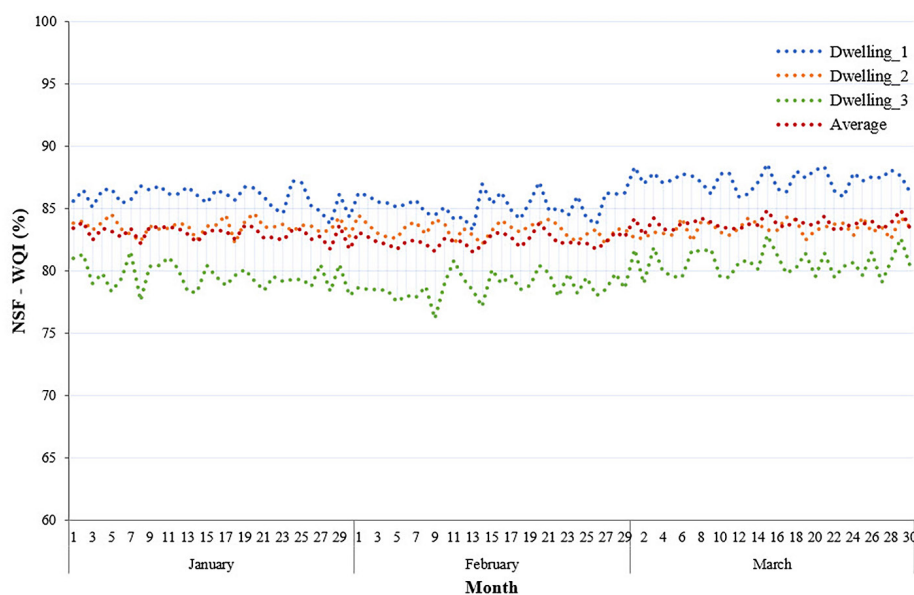


Figure 8. Behavior of NSF-WQI at the three sampling points located in households of the Daniel Hernández district during the days of the months January to March 2024

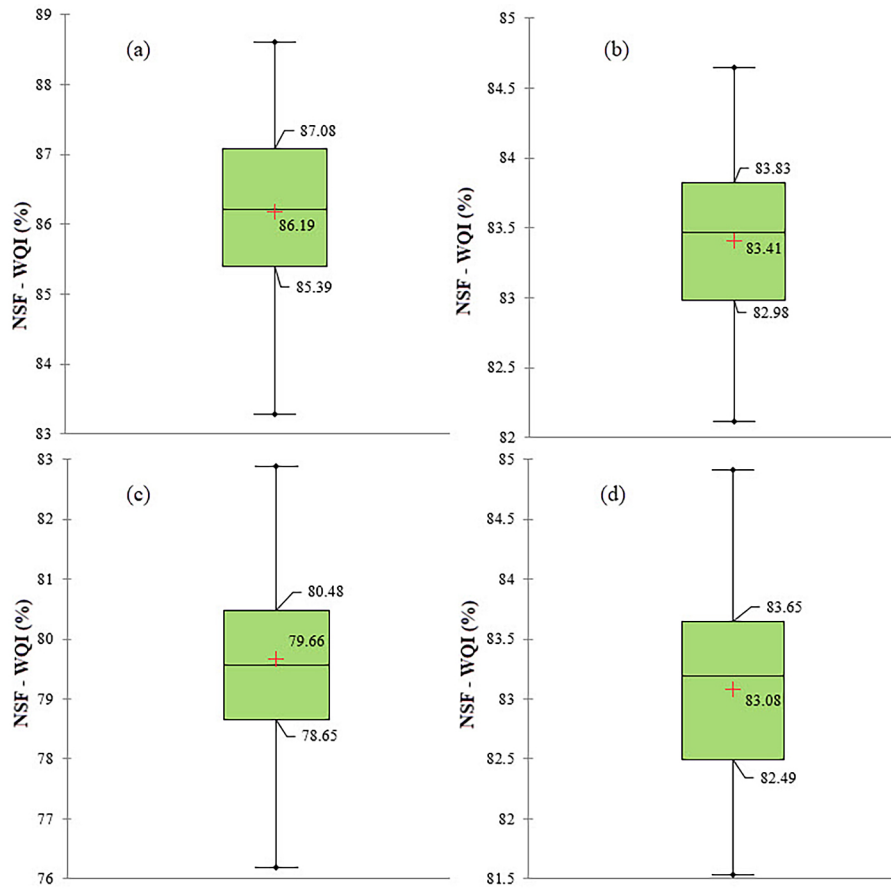


Figure 9. Box Plot of the NSF - WQI at the three sampling points located: (a) Dwelling_1, (b) Dwelling_2, (c) Dwelling_3, and (d) Average of NSF - WQI

(Nobre et al., 2020). The samples were collected manually at 27 monitoring stations monthly from March 2016 to February 2019; likewise, the WQI was determined with only five parameters that they considered crucial (phosphorus, temperature, *E. coli*, Hg, and dissolved oxygen) for river water in the south-north basin of China. Like this study, in our work, we also considered 05 important parameters such as pH, EC, turbidity, FCL, which allowed the implemented system to evaluate in an automated way the organoleptic quality of water in the urban distribution network using PLC and displaying results in the Simulink interface.

CONCLUSIONS

The development of an automated system to evaluate the organoleptic quality of water in the district of Daniel Hernandez, Peru, using a PLC S7 1500 and Simulink, has proven to be an effective and reliable tool; where 4–20 mA sensors-transmitters were integrated for its application,

allowing the measurement of the most important organoleptic parameters of water such as pH, EC, turbidity, FCL and temperature. The automated system obtained an OEE value of 90.56%, which supports its efficiency and reliability.

The evaluation of the organoleptic quality of the water using the NSF-WQI methodology revealed a remarkable variability in water quality at different sampling points, with an average of 83.08% classifying the water as fit for human consumption. However, this variation was influenced by factors such as the decrease in FCL and the increase in temperature due to the poor condition of the distribution networks and lack of maintenance. In addition, the study was conducted during the rainy season, which significantly affected water quality, especially in terms of turbidity and pH, highlighting the importance of continuous monitoring and the adaptation of management strategies to seasonal climatic conditions.

Automating the measurement of organoleptic parameters in real time and in situ avoided sample

contamination, a significant advantage over traditional manual collection methods. This automated system, which evaluates key parameters such as pH, EC, turbidity and FCL, has been shown to be a viable and efficient solution for the evaluation and monitoring of water quality in urban distribution networks. These findings highlight the importance of having an automated system to streamline the assessment and management of water resources.

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