Automatic Control Technologies to Enhance Water

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Additional information is available at the end of the chapter

Abstract

Due to the explosive population growth, the demand of adequate hygiene drinkable water has been increased. Therefore, it has become more necessary to apply the automatic control system for water treatment production, in order to attain the health required outcomes. According to complexities of the process and the intersection of the treatment states, the suggested methodology in this chapter anticipates for the development of an automatic control based on wireless sensing networks (WSNs) to be applied in water treatment process. The wireless automatic systems are deployed in order to manage the processes of the production and increase the efficiency to the maximum level, along with the minimum cost. It is, therefore, important that the automated system works professionally, in order to get the utmost profit from the processes of the production. Practically, an effective control models have been designed and implemented using simulation software. Therefore, the research successfully managed to automatically control in the working pumps operation. The addition of purification and disinfection chemicals doses successfully calculated and added to the water in a real-time operation mode. In filtration phase, the process of filters backwashing has been completely automated. The obtained results were essential, beneficial and prove the system's applicability with minimum cost.

Keywords: water treatment, WSN, automatic control, pumps, filter backwashing, chemicals addition, sensors and valves

1. Introduction

One of the significant applications of the wireless automation system is to ensure the safe operation of the plant and to avert fatal possible accidents, which can also be catastrophic disaster and can have an adverse effect on the environment [1]. The undesirable incidents at the site of the plants can be condensed with the installation of the well-designed safe WSN

automatic system [2]. It can also reduce the overall cost and possible systematic error to a remarkable extent. Consequently, high reliability of the automation system is mandatory for the safety and economic reasons [3]. **Figure 1** shows examples of wireless application with different wireless devices connected to central automation control systems [4].

WSNs represent one of the most interesting research areas, with profound impact on technological development [6]. WSNs are regarded as a revolutionary technological that builds the information gathering method of the system. The information and communication built will greatly improve the reliability and efficiency of infrastructure systems. Compared with the wired solution, WSNs feature easier deployment and better flexibility of devices. With the rapid technological development of sensors, WSNs will become the key technology for Industries [7]. Several applications are being proposed, such as detected physical phenomena (e.g. light, heat, pressure, and flow), environmental monitoring (e.g. detection of fires in forests), structural monitoring of civil engineering structures, and industries monitoring and control [6]. Whereas the replacement of the wired technology with that of the wireless is illustrated in the below mention **Figure 2**.

The main purposes of this chapter are: to establish a WSNs as the key ingredient in the course of the applications of the process control. To inculcate the wireless systems in industries and environment process control in order to replace old traditional systems especially those related to human beings health and safety such as a water treatment plant.
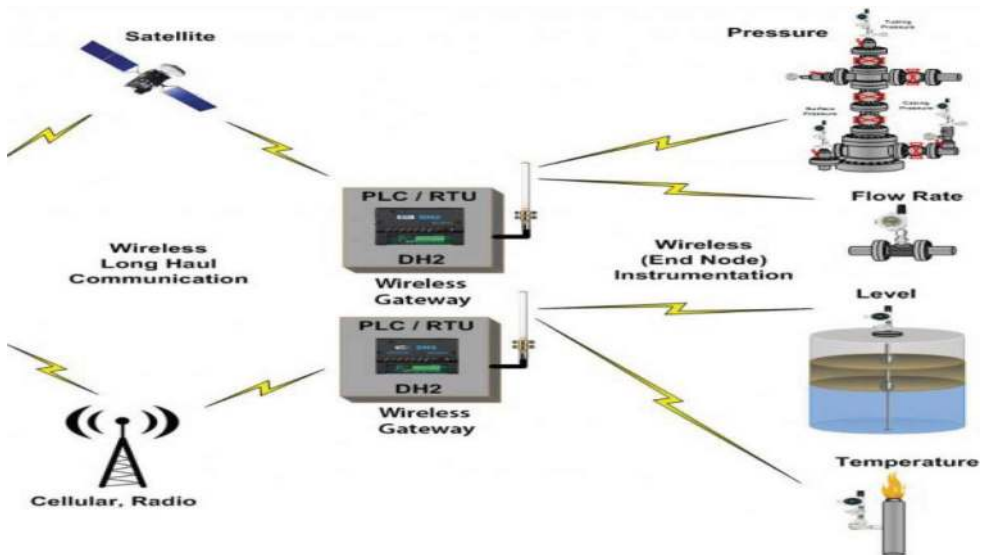
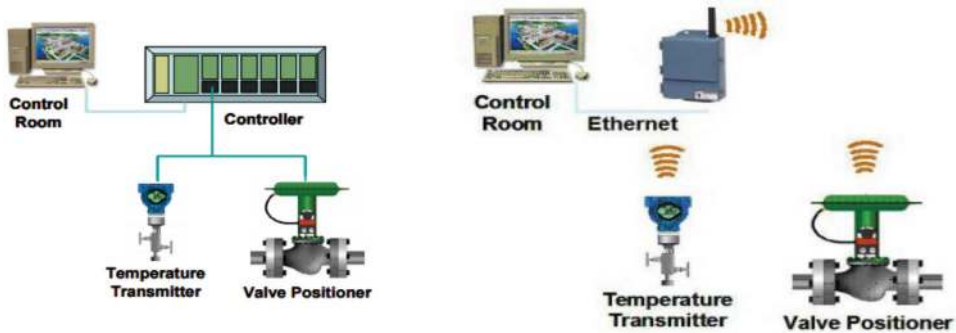**Figure 1.** Applications of wireless sensor network [5].

Figure 2. Replacement of the wired technology with that of the wireless [8].

2. Wireless sensing networks in industrial applications

According to [9], WSNs are being widely deployed in process industries, in order to ensure reliable and integrated control and monitoring of the processes. In this regard, [10] has stated that process control and monitoring is the combination of algorithms, mechanisms, and architectures, which ensures the reliability of different industrial processes. According to [11], several applications of process control are critical mission and possess stringent requirements. In such circumstances, flawed control loop may result in unpredictable and unwanted shutdown of the plant. It has been recognized from the study of [7] that such failures may also result in fatal accidents in process controlled plants. Thereby, it can be asserted that wireless networks also comprise wide range of challenges and issues, which are needed to be considered to ensure the integrity of industrial operations.

It has been claimed by [12] that main stream process control devices, like motors, valves, temperature sensors that are ready-equipped with wireless transmitters, foolproof wireless process control systems and network standards are not yet accessible.

It has been stated by [13] that WSN systems are widely being used in different applications of industrial automation. In this regard [14] has claimed that such applications provide commendable safety, efficiency, conservation, and control to the processes of the industry. On the other hand, it has been asserted by [15] that automated sensing applications play an inevitable role in improving the reliability of process control systems as well as pre-existing manufacturing. However, [16] has stated that sensing applications are found to be highly effective, in terms of improving and enhancing management of industry's assets. It is due to the fact that such systems foster continual monitoring of critical equipment, which may create different issues in industrial processes. It has been documented in the research, which was conducted by [17] that sensing applications play a major role in reducing and minimizing excessive cost, which is required for optimized processes of manufacturing.

In addition to this, sensing applications also assist in identifying and recognizing inefficient operations or malfunctioned equipment. According to [15], sensing applications enable the process industry in automating the process of data acquisition, from remote sensors, in order to minimize user intervention. It has been affirmed by [18] that application of automated sensing, within process industry, assists in implementing certain networks, in order to improve and increase public and employee safety. It has been stated by [16] that automated and wireless sensing applications also enable process industry to streamline the process of data collection for more integrated and valuable compliance of reporting.

2.1. Monitoring and controlling

It has been documented in the research, which was conducted by [10] that one of the major industrial applications of WSN includes monitoring and controlling of industrial processes. In this account, [9] have claimed that WSN assists the plant operators to evaluate and ensure the performance and health of machine and products. According to [18], WSN systems were developed, in order to support machinery CBM (machinery condition based maintenance). It is due to the fact that process industries have to face various issues, in terms of enabling new functionality and higher costs of maintenance and implementation. In such circumstances, wireless sensors can be located in the problematic and vulnerable areas, where wired systems cannot be reached easily. These areas may include un-tethered vehicles and rotating machineries.

Data logging can also be considered as one of the greatest industrial applications of wireless sensors. It is due to the fact that wireless sensor networks facilitate the practices of data collection, in order to monitor environmental conditions of the plant. These may include temperature, pressure, density, flow rate, overflow tanks, volume, etc. In addition to this, WSN systems also assist in gathering statistical information, which enables the machine operators to examine and evaluate potential malfunctioning of the machines. Waste water monitoring and water consumption monitoring can also be performed by the help of WSN systems. All of these features eventually results in the reduction of water wastage. It has been recognized from the assessment of studies carried out by [17] that WSN systems can also be adopted in order to evaluate the integrity of physical infrastructure as well as geo-physical processes, which are closed to real time and over long periods, through the process of data logging, by the help of interfaced sensors.

3. Wireless sensing networks in water treatment applications

The standards of water quality and quantity are necessary for survival and reduce the risk of disease. The main health problems associated with drinking water contamination are caused by insufficient water for hygiene purposes and consumption of that contaminated water [19]. There are two standards defined for water supply standards. The first standard involves the quantity of water, while the second standard regulates water quality [20]. The minimum amount of water for safe and healthy consumption is summarized by around 7.5–15 l of water per person per day. Water quality is a secondary standard, according to [20], therefore, once water quantity has been assured, water quality should be improved to reduce the risk of dysentery and other diseases.

The quality parameters such as turbidity, coliforms, and chlorine residual are specified as the minimum standards that must be met by water treatment technologies.

This work intends to enhance the production of water treatment plant by controlling the treatment processes and their affecting parameters by using controlling and measuring instruments such as what it uses to adjust the clarification and disinfection chemical materials addition. Besides, the instrument's readings are used for further studies concerns.

In the following sections the traditional systems and the proposed techniques that have been developed for water treatment plant will be discussed. The proposed control system design consists of five phases: intake, sedimentation, filtration, disinfection, and distribution as shown in **Figure 3**.

The devices used this design and its abbreviations are shown in **Table 1**. Various types of devices such as sensors, valves, pumps, microcontrollers, communication modules and PLC are communicated wirelessly.

3.1. Sukking/distribution pumps operation

The operation of the intake and distribution pumps is based on the Delta/Star control circuit called (starter). In the traditional plants, the starter and pump are basically located at the main supply bank, therefore, the operation process of these pumps is applied manually using start/ stop pushbuttons. The starter circuit as shown in the **Figure 4** consists of three main contactors (K1, K2 and K3) in addition to a timer control to accomplish the pumps' starting conditions. K1 controls the pump's main power supply and protects it from short circuit and current overload circumstances. K2 is adjusted by the timer control circuit to initialize the pump at Star (Y) condition. Finally, K3 operates simultaneously when K2 releases (by means of interlock) to inject full supply voltage to operate the pump at Delta (Δ) condition [21].

3.1.1. The subsystem developed for intake/distribution pumps

The intake/distribution pumps (P1, P2, …, Pn) work through WSN control circuits (C1, C2, …, Cn). The circuits operated according to wireless control signals generated by a central control unit and sent wirelessly via communication module to the new installed power switch (on/off) sensor.

The reservior water level changed regulary during a day time according to the treated and distributed water. Thus, control on reserviour water level can be achieved by regulating the operated and standby pumps. Therefore, resourvoir level sensors has been used to continously collect levels readings and feed the central control module that uses a designed program to specify the number of pumps to be work and which should be in standby state. **Figure 5**, illustrated the developed system in case of intake phase, while distribution phase illustrated in **Figure 6**.

3.2. Chemicals materials used

Physical properties such as suspended mater and turbid caused by these matters, and the living organisms on the other hand threat the health of consumers, thus water treatment plants are designed and established to remove the risk of these problems, and to put the final product within the standard guidelines of potable water.
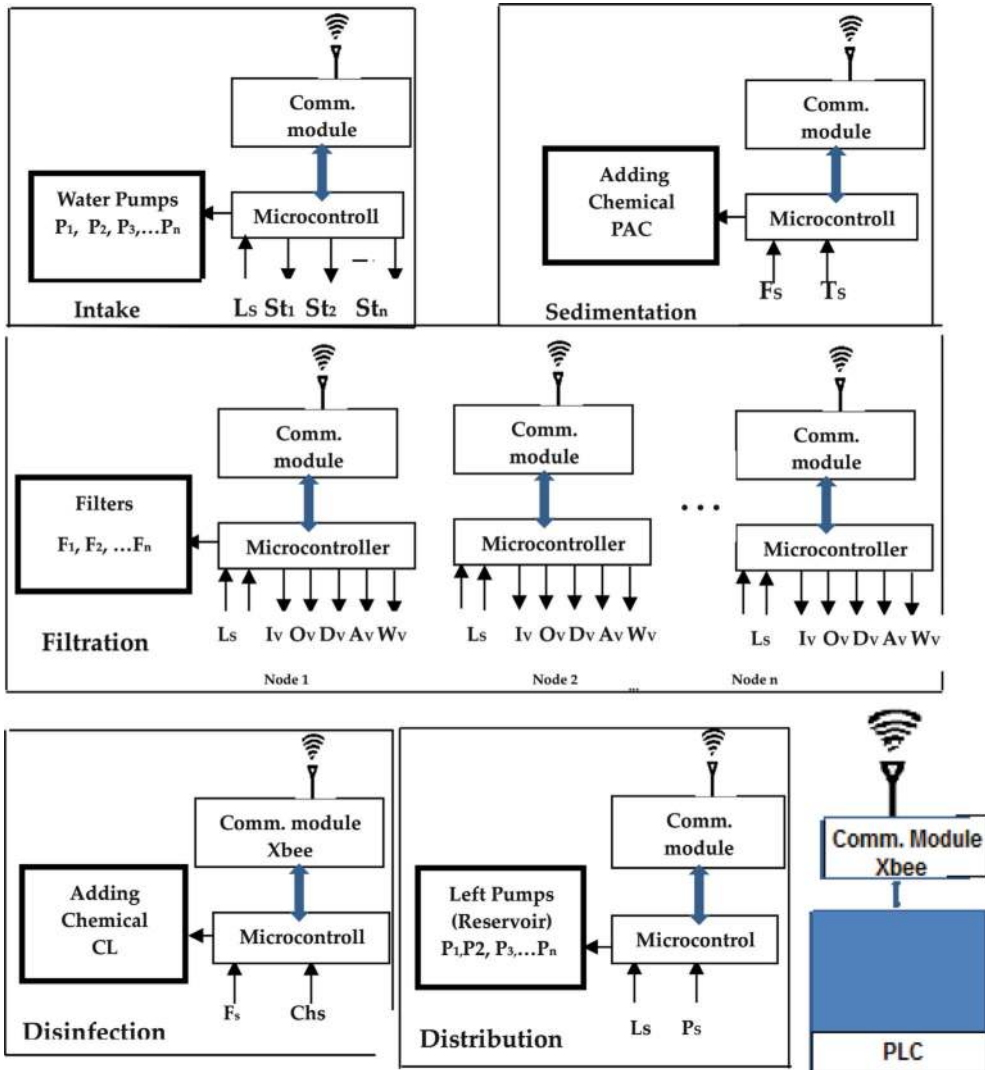
Figure 3. The wireless control system designed for water treatment plant.

Purified water and safety to be drunk depend on added sedimentation and disinfection chemicals materials, which are defined by reading many parameters concerned with quantity and quality of raw water as shown in **Figure 7**.

In water treatment plants there is a chemical room for preparing chemical materials. This unit includes feeding machines, chemical coagulants daily tanks and other equipment. The popular chemicals added are:

| Pump motor	Pm	Level sensor control	Ls	Inlet valve	Iv
Injection motor	Im	Flow sensor control	Fs	Outlet valve	Ov
Power switch	SW	Turbidity sensor control	Ts	Drain valve	Dv
Power supply	P	Chlorine sensor	Chs	Wash valve	Wv
Communication module	Cm	Pressure sensor control	Ps	Air valve	Av
Microcontroller	Mc	Pumps control circuit	St	Backwashing	BW

Table 1. Devices and abbreviation.
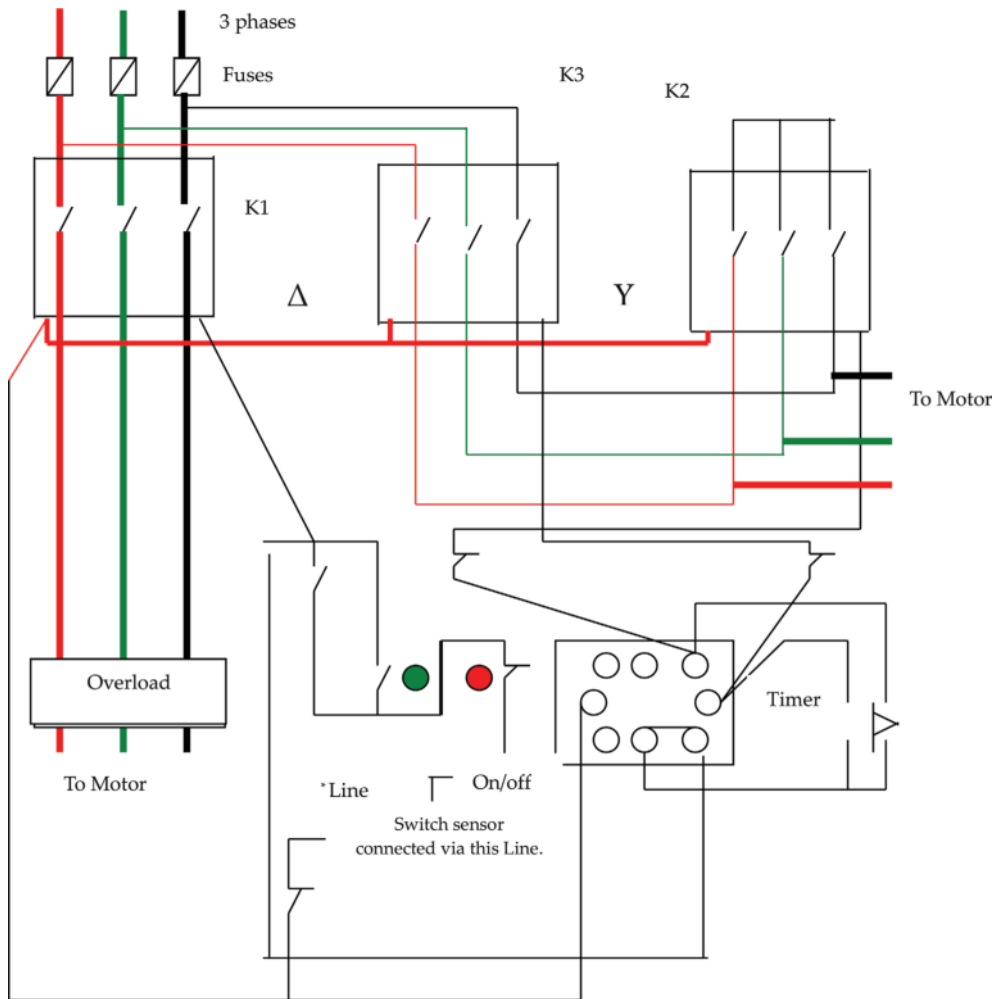
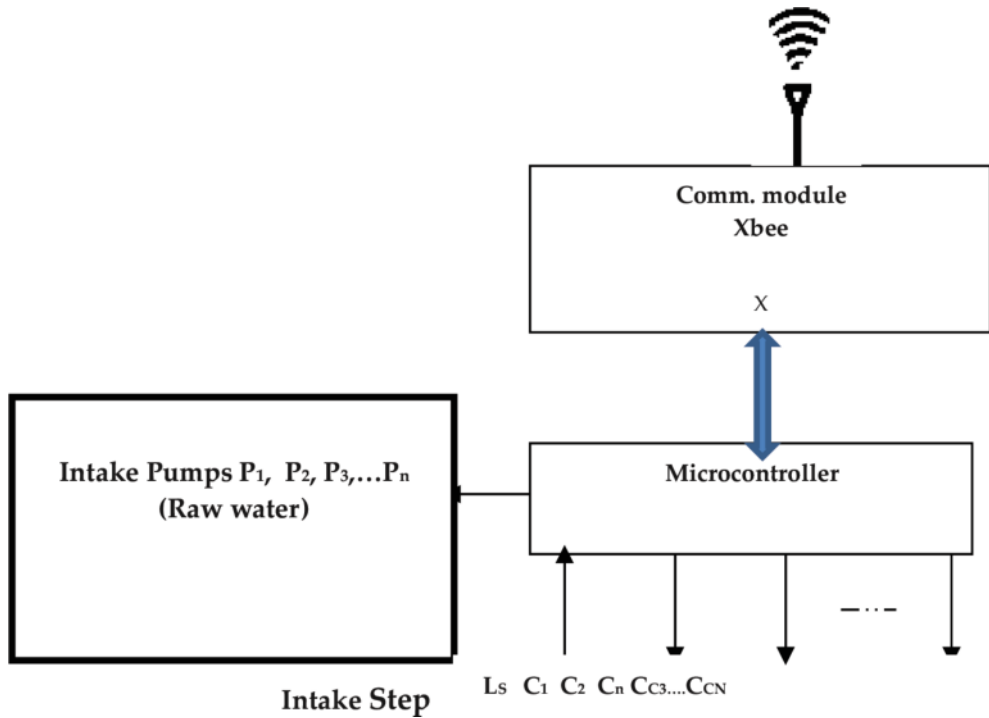**Figure 4.** Control circuit of the pump operation.

Figure 5. The intake subsystem.

- Poly aluminum chloride

Extra power inorganic aluminum salt used as cationic coagulant, max permissible dose 250 mg/l.

- Chlorine gas

Oxidant uses in trace dosage for the removing bacteria, so the recommended dose is 1 mg/l.

3.2.1. Adding chemical material

In case of turbidity removal a process called a Jar Test was used to identify the estimated dose from purification chemical material. This test conducted every 2 h to check the amount of change in water quality. While in case of disinfection, the current process is to inject the estimated chlorine first then read the residence chlorine in the water every 2 h to decide in increasing or decreasing the injected doses.

3.2.2. Suggested techniques

In any fraction of time the water types and flow rate are subjected to change. Therefore, the suggested developed model intends to enhance the addition of chemicals materials by introducing a real-time application that reads the water parameters and immediately adds the corresponding doses.
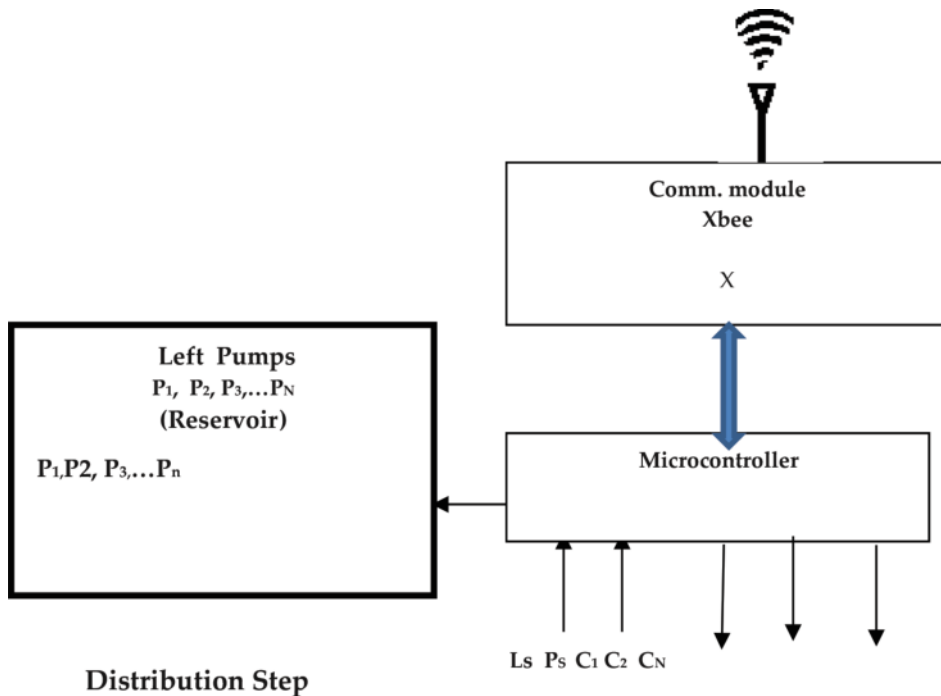
Figure 6. The distribution subsystem.

To implement this system, a control unit using a PLC has been suggested to accomplish the process in order to raise quality to the best possible level without chemical materials misuse. The modification focuses mainly on improving the quality of treated water in plant using instruments to measure parameters that affect the quality. Depending on the reading, the accurate doses from chemical materials which are used for water sedimentation e.g. poly aluminum chloride (PAC) and disinfection e.g. chloride (Cl_2) will be determined [22]. Accordingly, pumps are used to inject the corresponding doses to the water. Therefore, it is important that automated system works efficiently to ensure good quality produced water, prevent possible fatal error or even disasters that might affect people, as well as, to reach the highest level of production [23].

3.2.3. Control system implementation

The proposed control systems to be implemented are demonstrated in **Figure 8**. In these systems sensors with different functions has been used. Therefore, sensors are used to read water turbidity, flow rate, pH, and resident chlorine in the water and connected directly to microcontroller.

The microcontroller used a designed algorithm to calculate the required doses from clarification and disinfection chemical materials to be added to water in real-time application mode,
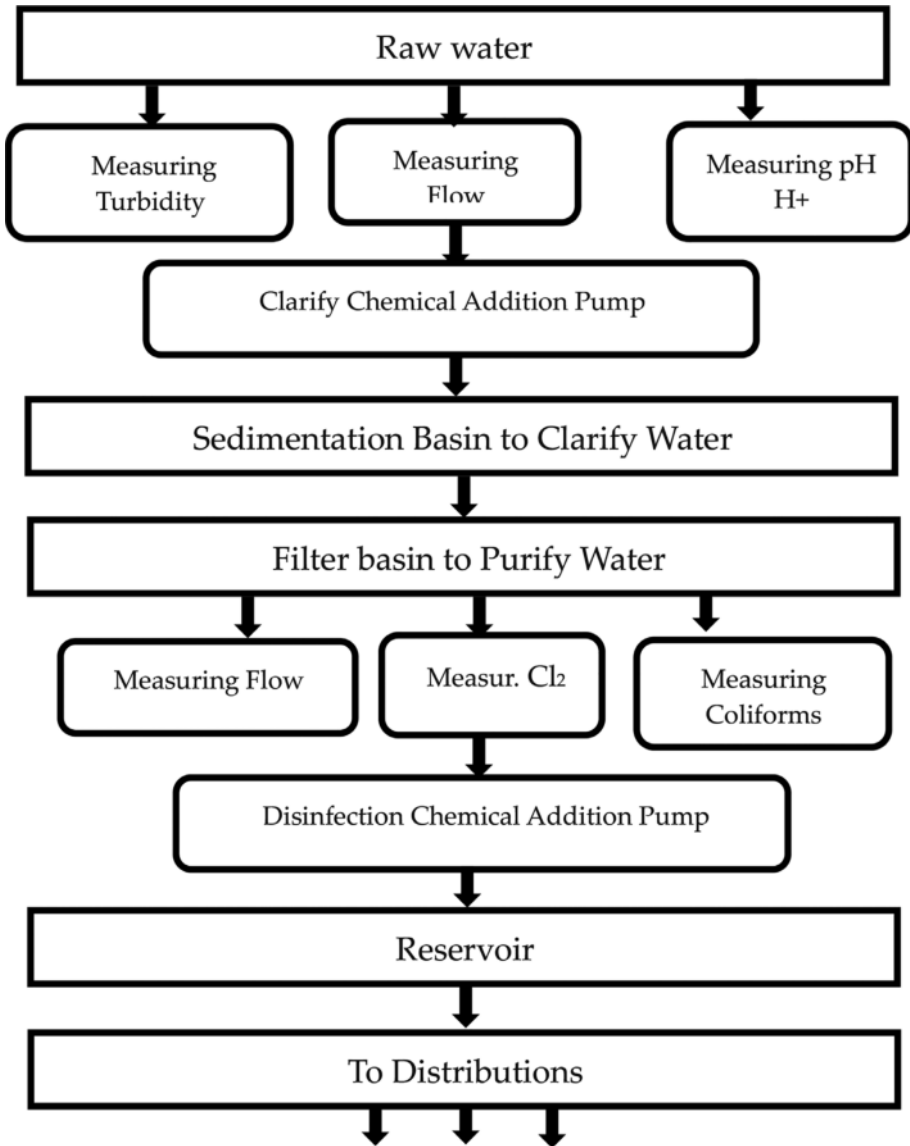
Figure 7. The water treatment proposed control instruments.

and sends appropriate signals to the central PLC via a wireless communication module. The PLC generates the corresponding output pulses and communicates with actuators that govern the working dosing pumps. These dosing pumps have broad range of flow rate in litters per hour (l/h) [24].
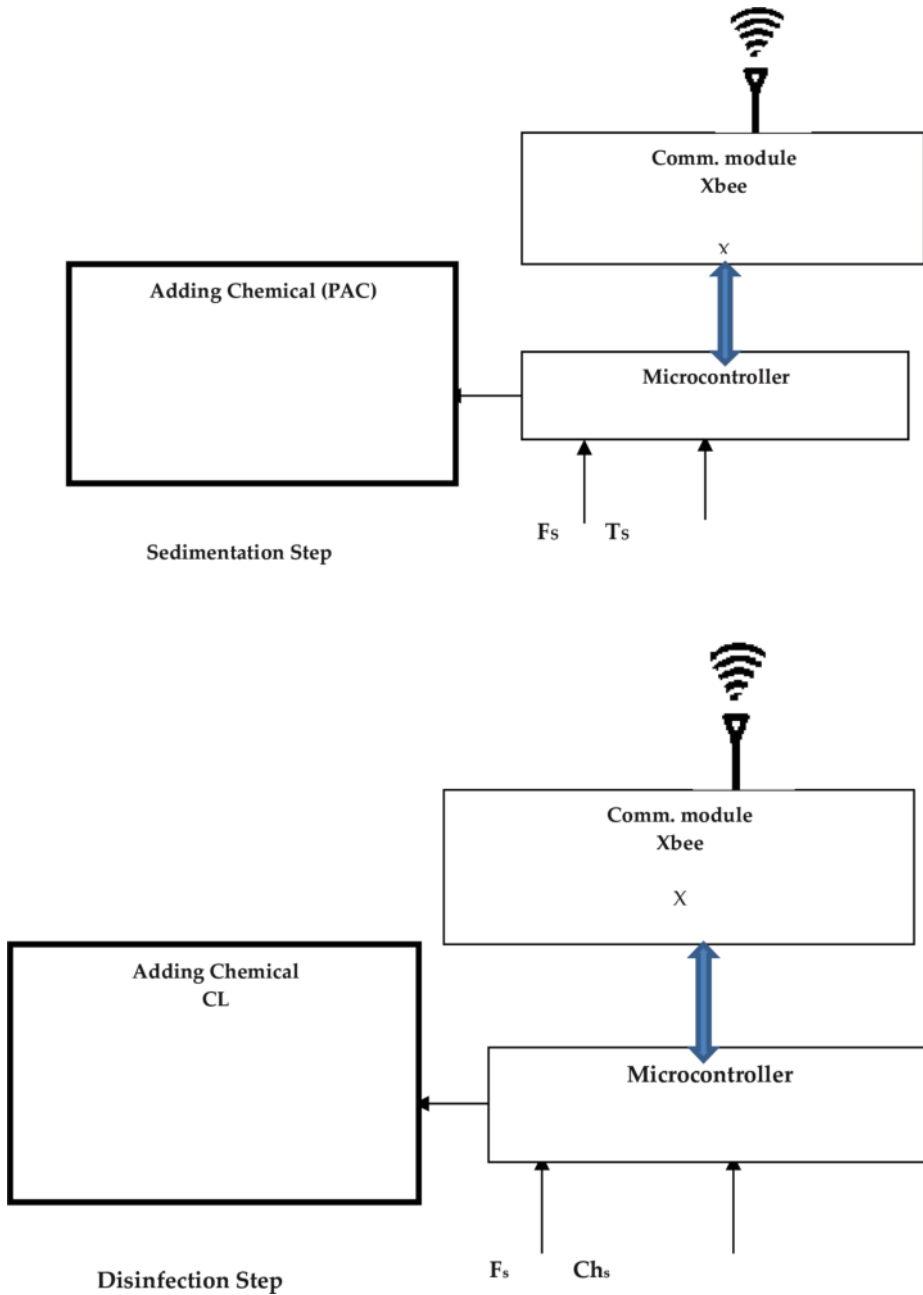
Figure 8. The sedimentation and disinfection systems.

3.2.4. System algorithm

The following algorithm designed to calculates the amount from purification and disinfection chemical materials to be added to water [25].

Algorithms: Calculation of clarification and disinfection chemicals

For $i=0$ to ∞ do

Input: read (T_{S1}, T_{S2}), read (F_{m1}, F_{m2}), read ($Ref._{Cl2}$), read (F_{m3}), read ($Ref._{Dose}$)

Calculate:

T_S Average (T_{S1}, T_{S2}).

F_m Average (F_{m1}, F_{m2})

Convert water rate (W_{rate}) to water volume (W_{volume})

$W_{volume1} = W_{rate1} \cdot t$

$W_{volume2} = W_{rate2} \cdot t$

Clarification (e.g. Ploy Aluminum Chloride) injection

Calculate the dosing $Clar_{dose}$

$Clar_{dose} = Ref._{Dose} \times T_S \times W_{volume1}$

Set injector control pulse P_{C1}

Calculate injection time T_{i1}:

$T_{i1} = \frac{Clar_{dose}}{Injector_{rate}}$

Output: pulse control P_{C1} (To drive injector)

P_{C1} = pulse modulation (P_{i1}, T_{i1})

Disinfection (Residual chlorine injection)

Calculate the dosing (Di_{dose})

$Di_{dose} = Ref._{Cl2} \times W_{volume2}$

Set injector control pulse P_{C2}

Calculate injection time T_{i2}:

$T_{i2} = \frac{Di_{dose}}{Injector_{rate}}$

Output: pulse control P_{C2} (To drive injector)

P_{C2} = pulse modulation (P_{i2}, T_{i2})

End

3.3. Filtration phase

The water from sedimentation basins distributed to the filtration basins by gravity. The filtration process involves passing water through fine granular materials, such as sand [26]. As more and more raw water passed through the filter, suspended particles are accumulating within the filter media, reaching impermissible levels that lead to one of the two destructive events. They can either cause the filter head loss within the filter to reach excessively high levels, or hardly pushed through the media, resulting of bad quality of treated water. Therefore, in order to maximize the use of a given filter within a safe mode, it becomes necessary to remove these entrapped particles from the media itself. Filter backwashing is the process by which this is accomplished. It refers to pumping water and compressed air backwards through the filters media as illustrated in **Figure 9**.

3.3.1. Suggested techniques

In order to be safe and function perfectly with full capacity through a day, the filter efficiency influenced by the effectiveness of the backwashing methods. This efficiency can be controlled by installed water level sensors in the filter basin. When the water level inside the basin exceeds impermissible level, backwashing operation is executed automatically with the PLCs program aid.

To implement the system, the researcher used sensors for measuring the water level, XBee as a wireless communication module, microcontroller as a data acquisition unit, automated water valves for inlet (Iv), outlet (Ov), drain (Dv), washing (Wv), and compressed air valve (Av) to be opened and closed according to the received signals from the PLC control module. The illustration of the system design is shown in **Figure 10**.
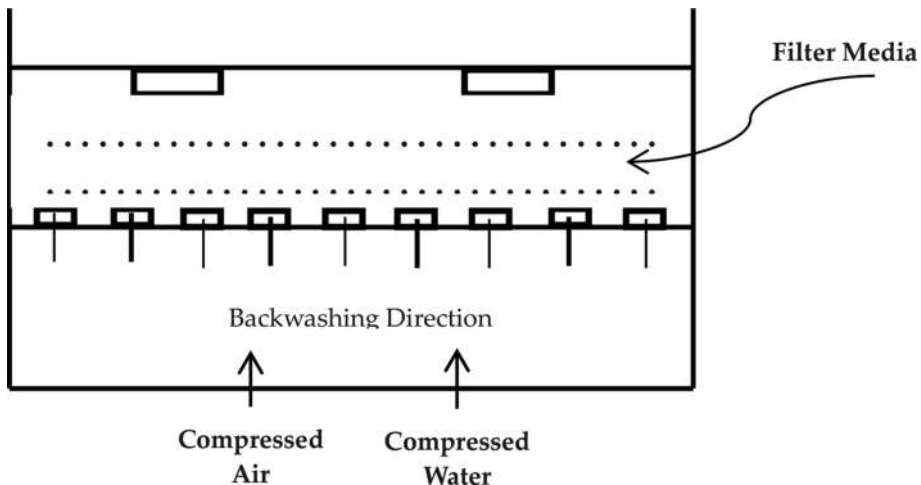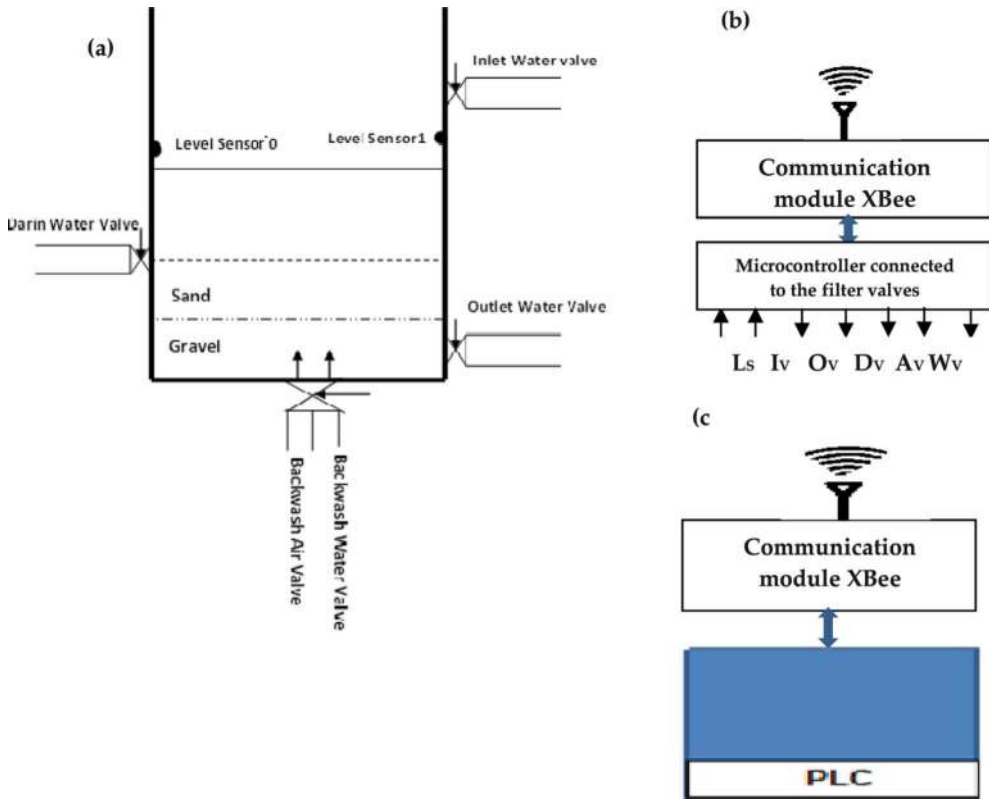

Figure 9. Washing filter.

Figure 10. System model. (a) Filter basin components, (b) communication module and actuators, and (c) control module.

4. Results and discussion on implemented systems

The obtained simulation results for the implemented subsystems will be discussed in this section. The PLCs is communicated wirelessly with inputs and outputs through communication modules and microcontrollers as demonstrated in in the previous developed subsystem design. The different water treatment processes consideration has been setup, where the subsystems have been controlled successfully under various operations settings.

4.1. Control on motor operation

The Motor operation is controlled by a motor starter (M) which is connected in series with a normally open (NO) momentary pushbutton (Start), a normally closed (NC) momentary pushbutton (Stop), and the normally closed (NC) overload relay (OL), as shown in Ladder Logic diagram **Figure 11**. The NO start pushbutton is connected to the input I0.0 while the NC stop pushbutton is connected to input I0.1. The NC overload relay contact as part of the motor starter is connected to input I0.2. The input (I0.0–I0.1–I0.2) forms an AND circuit and controls
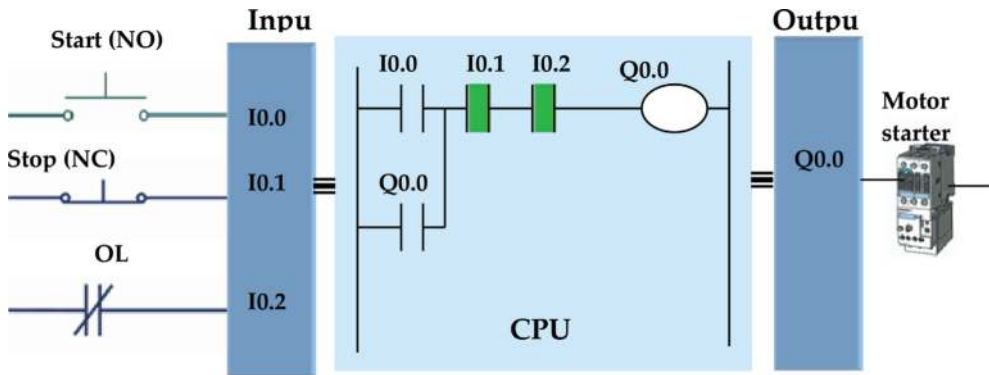
Figure 11. Ladder logic diagram represents the motor's operation.

the operation of output (Q0.0). The logic state of input bit I0.1 is logic 1 because of the NC stop pushbutton. The logic state of input bit 10.2 is logic 1 also because protective overload relay is NC. By A program a NO contact Q0.0 is added to ladder logic, which is in direct relation with output (Q0.0) and forms an OR circuit with input (I0.0). Motor starter is connected to output Q0.0 at output module [27].

When the pushbutton is initialized, unit CPU receives logic 1 signal from input I0.0 at input module. This causes contact I0.0 at ladder logic to close. In this case, all contacts are on ladder logic 1 state, so the logic condition of output Q0.0 on the ladder logic is logic1 [27].

4.2. Control on purification and disinfection addition

In this section the results obtained from the simulations of the model developed using MATLAB will be presented. The modeled system was successfully executed. The simulation program fed with measured data of water quality values, and then generated the required doses in four modes of injection methods at different times.

Figure 12 shows the time relation between the flow rate and the injected doses of materials in mg/l. The system collects the values of turbidity and flow rate intervals of 10, 20, 30, and 40 s. These obtained reading values are feed the modes from one to four consequently. According to the equation used in the model mode 1, the injected purification material was due to the optimal dose, this is presented in **Figure 12** with black graph. The system injected doses in the other modes (2, 3, 4) varied from the required value in respect to the time differences specially in mode 4 (green graph). For example, in case of 45 l/s flow rate, mode 4 injects excess material by around 30 mg, mode 3 injects less material by around 20 mg, while at 80 l/s flow rate mode 4 injects less material by around 60 mg from the reference mode (mode 1). Therefore, according to the frequent changes in water turbidity and flow rate, the injection at higher rate (mode 1) is likely to be accurate and close to optimal dose.

Figure 13 illustrates the efficiency of the four modes according to the change in flow rate and random values of turbidity. In mode 1 as nominated to be the optimal reference mode, the
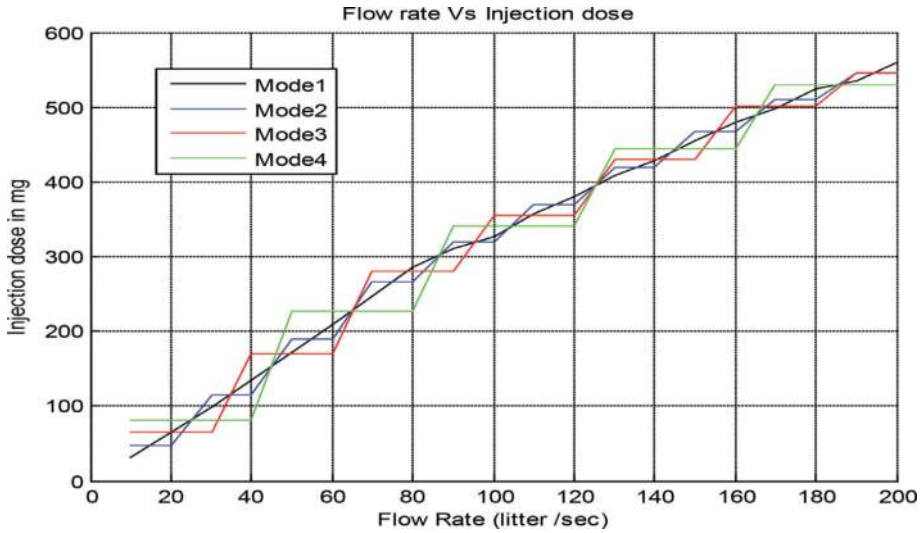
Figure 12. The relation in time between the flow rate and the injected doses.

efficiency represented in **Figure 4** by black graph bounded between 83 to 87%, so that the system in mode 1 is likely to be stable. In mode 2 which is represented by blue graph, the efficiency is bounded between 80 to 90% but there are large fluctuations. The remaining higher modes gave unstable and poor efficiency fluctuated between 0 and 95%.
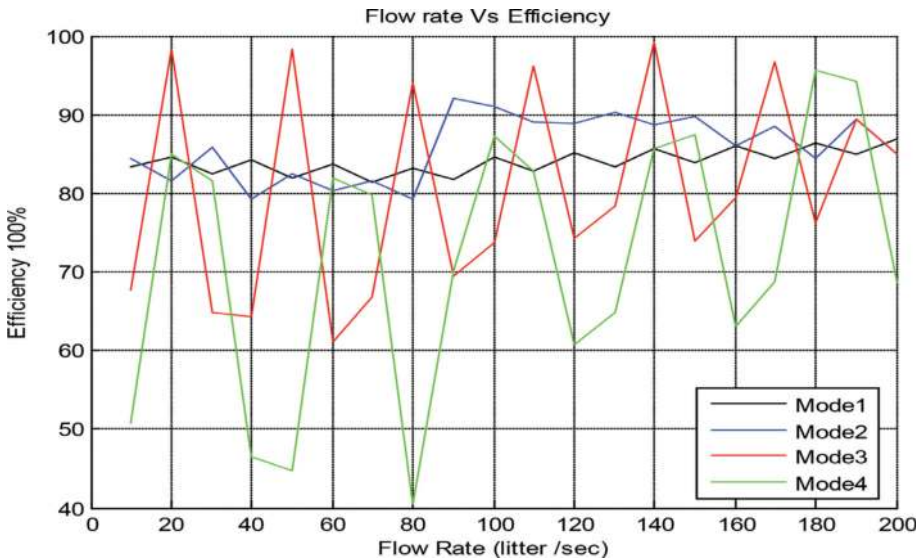
Figure 13. The relation between injection efficiency and the flow rate.
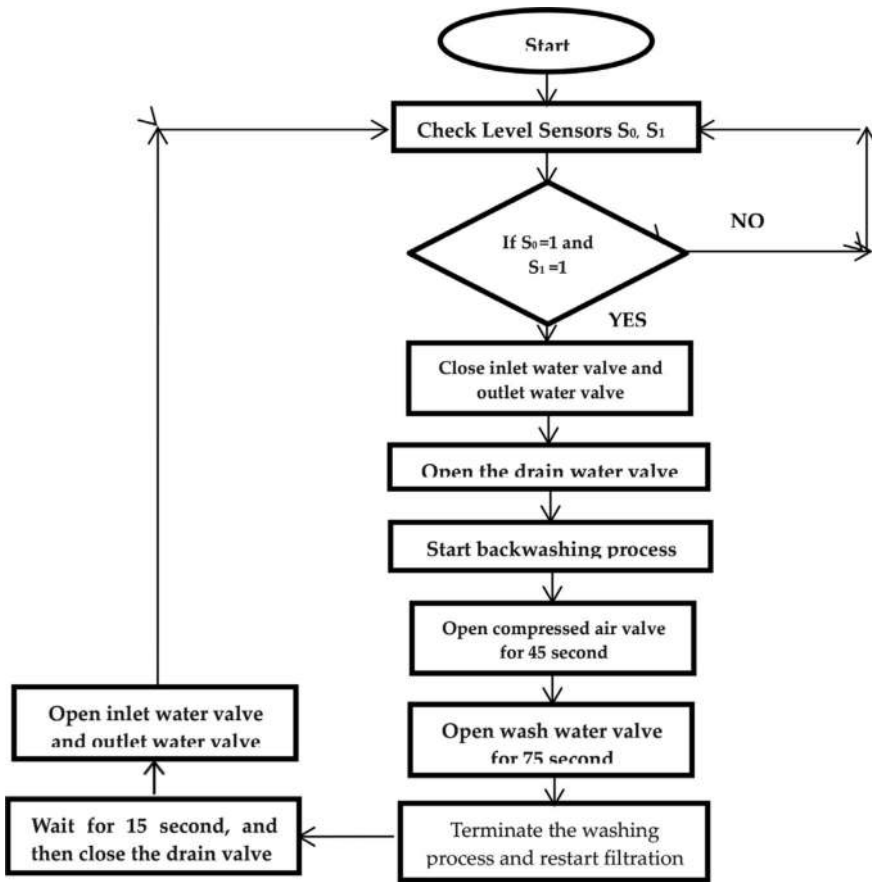
Figure 14. Backwashing control system flowchart.

Step	Valve	PLC timers configuration		Operation
		Timer	Time (s)	
1	I.W. Valve	TT1	15	Closing filter inlet water valve
2	O.W. Valve	TT2	15	Closing of outlet clarified water valve
3	D.W Valve	TT3	15	Opening of drain water valve
4	A. Valve	TT4	45	Opening of air valve
5	C.W Valve	TT5	75	Opening of clean wash water valve
6	Aux Timer	TTC	15	To closing the washing valve
7	Reset Timer	TTG	30	To terminate the washing process

Table 2. A complete time cycle of the filter washing process.

Program diagram

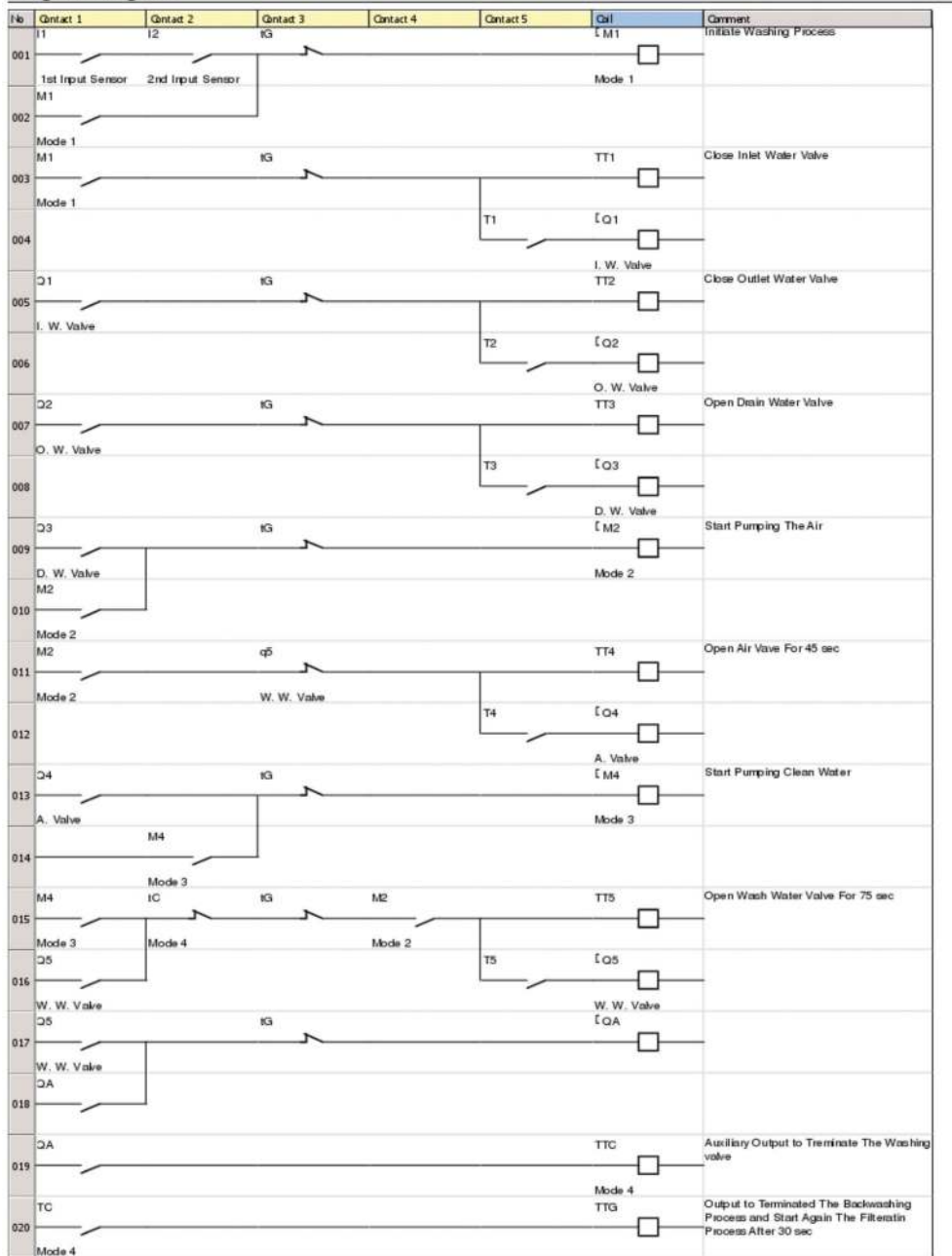| No	Contact 1	Contact 2	Contact 3	Contact 4	Contact 5	Coil	Comment
001	I1 1st Input Sensor	I2 2nd Input Sensor	tG			[M1 Mode 1	Initiate Washing Process
002	M1 Mode 1						
003	M1 Mode 1		tG			TT1	Close Inlet Water Valve
004				T1		[Q1 I. W. Valve	
005	Q1 I. W. Valve		tG			TT2	Close Outlet Water Valve
006				T2		[Q2 O. W. Valve	
007	Q2 O. W. Valve		tG			TT3	Open Drain Water Valve
008				T3		[Q3 D. W. Valve	
009	Q3 D. W. Valve		tG			[M2 Mode 2	Start Pumping The Air
010	M2 Mode 2						
011	M2 Mode 2		q5 W. W. Valve			TT4	Open Air Vave For 45 sec
012				T4		[Q4 A. Valve	
013	Q4 A. Valve		tG			[M4 Mode 3	Start Pumping Clean Water
014		M4 Mode 3					
015	M4 Mode 3	tC Mode 4	tG	M2 Mode 2		TT5	Open Wash Water Valve For 75 sec
016	Q5 W. W. Valve			T5		[Q5 W. W. Valve	
017	Q5 W. W. Valve		tG			[QA	
018	QA						
019	QA					TTC Mode 4	Auxiliary Output to Treminate The Washing valve
020	TC Mode 4					TTG	Output to Terminated The Backwashing Process and Start Again The Filteratin Process After 30 sec

Figure 15. Ladder logic inputs and outputs for filter backwashing process control.

4.3. Control on filter backwashing process

The control runs as it follows: when the PLC receives a signal coming from the sensors, it determines the start of the washing process, then accomplishes the following steps: first, closes the filter inlet and outlet water valves. Second, opens drain valve and then opens the backwash compressed air valve for 30 s. Then closes air valve and opens the backwash clean water valve for 60 s, Third, closes the wash valve and the system waits for 15 s until the dirty water passes before terminates the backwashing process. Finally, reverses the state of inlet, outlet and drain water valves to restart the filtration process again. The operations time of valves collected from plant and it was arranged to be used in the program. The control steps which have been implemented by PLCs is illustrated by the following flowchart, **Figure 14**.

In this simulation seven timers as shown in **Table 2** are set within the PLC program to control the time for each step of the filter washing process. Also, five indicators are connected to the outputs of the PLC to represent the valves which are involved in the filter washing process.

A Ladder Logic has been used for programming backwashing process so as to be functioned in the PLCs. The program output represented these processes shown in **Figure 15** [28].

5. Conclusions

The automatic control system has been proposed and implemented in this chapter regarding water treatment system. The water treatment system was dealt within two ways: the traditional system and the modified system after using WSN components. A controlled pump system has been fully developed on a PLCs system with sensors. An algorithm was designed to calculate the required doses from purification and disinfection chemical materials according to flow rate, pH, turbidity, and resident chlorine sensors reading, then added to water in a real-time application mode. The backwashing process for filters accomplished automatically using level sensors installed inside the filter basin, and automated valves. Therefore, the filter valves are working properly according to PLCs wireless control signals. In conclusion, the proposed control system has been successfully tested and the obtained results were significant. It was clear that the traditional system without WSN devices was poor and sometimes may have high risks especially in such system of drinkable water treatment. In contrast, the modified and improved system using WSN components has shown a high degree of dependability.

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